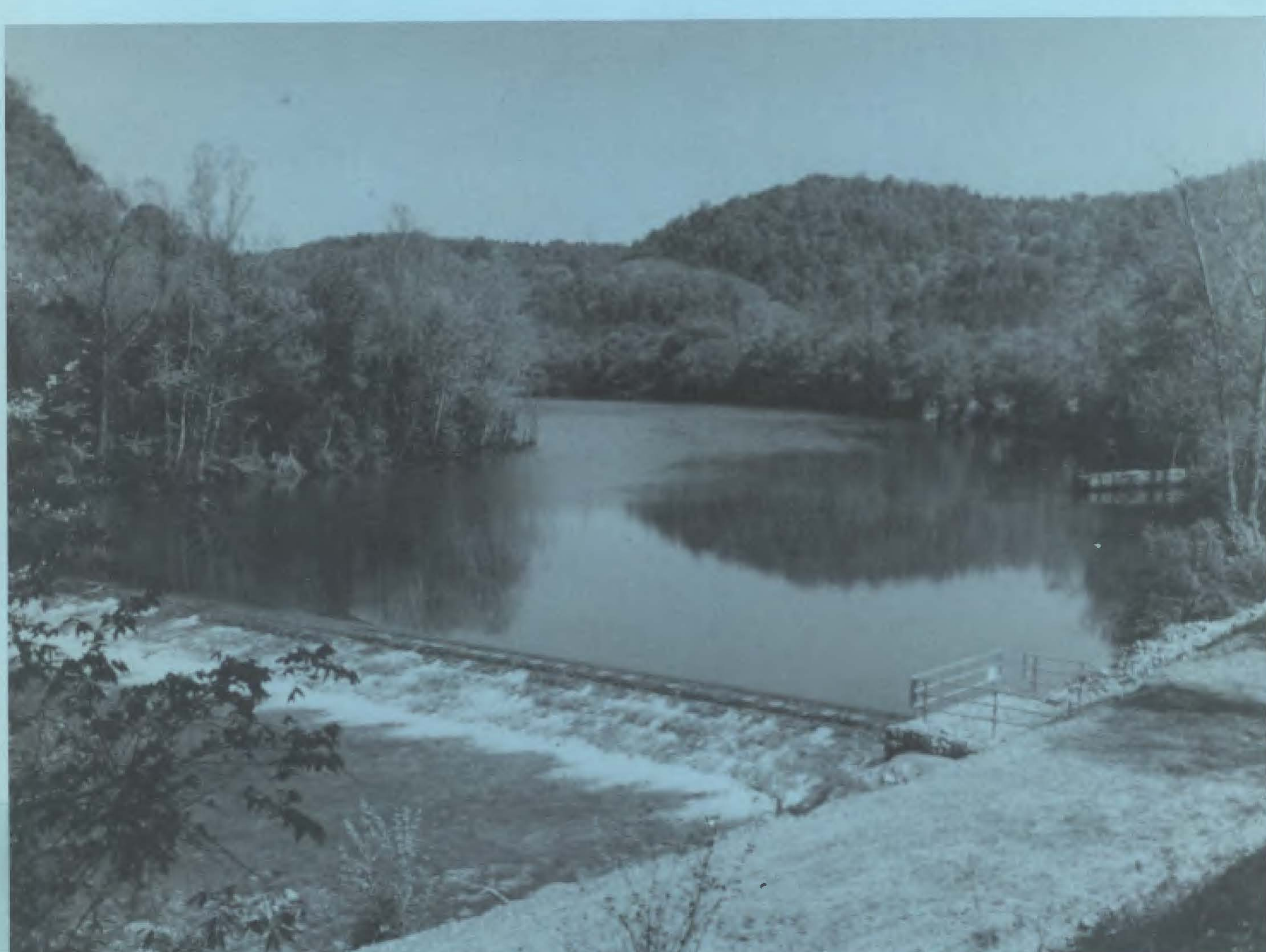
DOE/ID-10360

ENVIRONMENTAL MITIGATION AT HYDROELECTRIC PROJECTS

Volume 1. Current Practices for Instream Flow Needs, Dissolved Oxygen, and Fish Passage



U.S. DEPARTMENT OF ENERGY

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Cover Photo: Flow regulation weir constructed by the Tennessee Valley Authority (TVA) below Norris Dam on the Clinch River, Tennessee. The weir is designed to stabilize hydropower peaking releases, improve physical habitat conditions, and mitigate adverse effects on the coldwater fishery in the Norris Dam tailwater. Photograph provided by staff of the TVA Engineering Laboratory in Norris, Tennessee.

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DOE/ID-10360
Distribution Category: UC-225

ENVIRONMENTAL MITIGATION AT HYDROELECTRIC PROJECTS

Volume 1. Current Practices for Instream Flow Needs, Dissolved Oxygen, and Fish Passage

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Published December 1991

Prepared for the
U.S. Department of Energy
Assistant Secretary for Conservation and Renewable Energy
Under DOE Idaho Field Office

ABSTRACT

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

EXECUTIVE SUMMARY

The purpose of environmental mitigation requirements at hydroelectric projects is to avoid or minimize the adverse effects of development and operation. Hydropower mitigation usually involves costs, such as reduced profits to developers and reduced energy production. Much of the existing hydropower capacity in the United States will be subject to new mitigation requirements in the near future because many nonfederal projects are due for relicensing and federal projects are being reevaluated and upgraded. The relicensing process allows the revision of mitigation requirements, and new requirements could reduce existing energy capacity. To address concerns about the effects of environmental mitigation on these important energy resources, the U.S. Department of Energy (DOE) Hydropower Program has initiated a study of environmental mitigation practices at hydroelectric projects.

This first report of the Environmental Mitigation Study examines current mitigation practices for water quality [specifically, dissolved oxygen (DO)], instream flows, and upstream and downstream fish passage. This review describes information on the types and frequency of mitigation methods in use, their environmental benefits and effectiveness, and their costs. The project is conducted jointly by Oak Ridge National Laboratory (ORNL) and Idaho National Engineering Laboratory (INEL).

Information on mitigation practices was obtained directly from three sources: (a) existing records from the Federal Energy Regulatory Commission (FERC), (b) new information provided by nonfederal hydropower developers, and (c) new information obtained from the state and federal natural resource agencies involved in hydropower regulation. The hydropower projects targeted for study in this report were those projects that could be identified as having requirements for water quality, fisheries, or instream flows from a FERC compliance monitoring data base. The information provided by these projects includes the specific mitigation requirements imposed on the project, the specific objectives or purposes of mitigation, the mitigation measures chosen to meet the requirement, the kind of post-project monitoring conducted, and the costs of mitigation.

Information on specific mitigation practices was obtained from 280 projects, more than 40% of all the projects licensed during the 1980s that were identified a priori as having the mitigation requirements of interest. Of all projects receiving FERC licenses or license exemptions since 1980, instream flow requirements are the most common mitigation requirement, followed by requirements for downstream fish passage, DO protection, and upstream fish passage facilities. The proportion of projects with environmental mitigation requirements has increased significantly during the past decade.

Instream Flows

Instream flows are water that is released to the natural river channel below the project to maintain various nonpower water benefits. This study considered only instream flows designed for protection of fish resources. Hydropower operators provided information on the methods used to determine the instream flow requirements at their projects. More than one method for estimating instream flow needs was reported to have been used at many projects. Of the established and documented methods used to determine requirements for instream flows, the most frequently applied was the Instream Flow Incremental Methodology (IFIM). This method is complex and expensive to apply. Half of the project operators reported that professional judgment of resource agency staff was at least one of the methods used to set instream flows. Professional judgment was often cited in conjunction with the IFIM.

It appears that monitoring sufficient to evaluate the positive benefits of instream flow requirements to fish resources is very uncommon, a conclusion that has been

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corroborated recently by an independent study by the U.S. Fish and Wildlife Service. Information obtained for this DOE study indicates that flow monitoring (continuous, daily, or less frequently) is conducted at about 50% of the operating projects licensed with instream flow requirements. Operators of 20% of constructed projects licensed with instream flow requirements reported collection of some fish data, either by the project or by resource agencies.

Dissolved Oxygen

Water released from hydropower reservoirs can have low DO concentrations, especially during the summer and at large projects with deep reservoirs, low flushing rates, or warm climates. In response to the need to maintain adequate DO, which is necessary for respiration of aquatic organisms, methods have been developed to improve the quality of hydropower releases. These methods have been reviewed extensively in other studies, and they include tailrace aeration techniques (weirs, surface aerators, and diffusers), powerhouse aeration techniques (turbine venting and draft tube aeration), and operational techniques (adjustments to spill flows and turbine operating schedule).

Fifty-six projects provided information concerning DO for this study. About half were small (generating capacity <10 MW) projects. Most responses were from the northeastern United States. Of the DO mitigation technologies, increasing nonpower discharges (spill flows) is the most commonly used. More than 60% of all responding projects use spill flows, 9% use control of intake level to select oxygenated water for release, and nearly 30% use some form of artificial aeration of water passing through the turbine. Several projects use more than one mitigation method.

Of the projects that reported on DO mitigation, ~75% indicated that water quality (most commonly water temperature and DO concentration) is monitored, but biological monitoring is rarely conducted. Consequently, the actual biological benefits of DO mitigation are usually unknown.

Upstream Fish Passage

Blockage of upstream fish movements by dams may have serious effects on fish species whose life histories include spawning migrations or other seasonal changes in habitat requirements. Anadromous fish (e.g., salmon, American shad, blueback herring, and striped bass), eels, and some resident fish (e.g., trout, white bass, and sauger) have spawning migrations that may be constrained by hydroelectric dams. Maintaining or enhancing populations of such fish may require facilities for upstream fish passage.

Operators of 34 projects provided information on upstream fish passage facilities either in operation or under construction. Fish ladders are by far the most commonly reported means of passing fish upstream at nonfederal hydroelectric dams. Fish elevators are a less common mitigative measure, but their use may be increasing. Trapping and hauling (by trucks) of fish to upstream spawning locations is used at some older dams, but two of the projects reported that trap-and-haul operations are being replaced by fish ladders or elevators.

Preconstruction and postconstruction studies and detailed performance criteria for upstream passage facilities are frequently lacking. Forty percent of the projects had no performance monitoring requirements. Those projects that monitor the success of upstream passage generally quantify fish passage rates (e.g., fishway counts) or, less commonly, fish populations.

Downstream Fish Passage

A variety of screening devices are employed to prevent fish that are moving downstream from being drawn into turbine intakes. The simplest downstream passage technique is the use of spill flows similar to those used to increase DO concentrations or provide instream flows. Fish are naturally transported below the hydropower project in these nonpower water releases. Techniques that incorporate more sophisticated technology are under development, but are not widely used. For example, light- or sound-based guidance measures are being studied as ways to pass migrating fish downstream with a minimal loss of flow for power generation.

Information was obtained for 85 hydroelectric projects that have downstream fish passage requirements. A number of measures, some used in combination, are employed to reduce turbine entrainment of downstream-migrating fish in turbines. The most frequently reported downstream fish passage device is the angled bar rack, in which the trash rack is set at an angle to the intake flow and the bars may be closely spaced (~2 cm). This device is commonly used in the Northeast. Other frequently used fish screens range from variations of conventional trash racks (e.g., use of closely spaced bars) to more novel designs employing cylindrical, wedge-wire intake screens. Intake screens usually have a maximum approach velocity requirement and a sluiceway or some other type of bypass as well.

As with upstream fish passage measures, performance monitoring and detailed performance criteria for downstream passage facilities are relatively rare. There are no performance monitoring requirements for 82% of the projects. Post-operation studies of passage rates or mortality rates have been conducted at a few of the projects.

Mitigation Costs

Environmental mitigation costs are estimated for each mitigation type based on information provided by hydropower developers. These costs are segmented by capital, study, operation and maintenance (O&M), and annual reporting costs. All costs are presented in 1991 dollars and in terms of average cost per project, average cost per KW of capacity for capital and study costs, and average mill/kWh for O&M and annual reporting costs. Because of the large ranges for the mitigation costs, costs are also presented by capacity categories.

Costs of providing instream flows vary widely among projects. At diversion projects (where flows for power generation are diverted around a stream reach), instream flow in the diverted reach must be subtracted from that available for generation. Storage projects that generate without a diverted reach can release instream flows through their turbines. Operators of such projects frequently reported no cost associated with instream flow releases. The instream flow capital costs averaged $99,000 per plant. Environmental studies averaged $100,000 per plant. Even the requirements on instream flows below the powerhouses can cause significant costs because of forced sales of energy at base rates compared to peak rates. The average annual revenue loss for instream flow requirements amounted to $390,000 per plant.

Total mitigation costs for DO requirements are generally the lowest of the four types studied in this report. The capital costs averaged $162,000 per plant for DO mitigation equipment. The energy generation lost because of water quality environmental requirements was ~107,000 kWh per project.

The costs of upstream fish passage mitigation are relatively easy to determine. In addition to the capital costs of constructing the fishway, there are operation and maintenance costs (e.g., for clearing debris from the fish ladder or elevator and for electrical power to operate a fish elevator), lost power generation resulting from flow releases needed to operate a fish ladder or elevator (including attraction flows), and any monitoring and reporting costs. The average costs for fish ladders at the sites where they were required was $7.6 million for capital costs and they resulted in an average loss of 194,000 kWh of annual energy production. Other costs of upstream fish passages were $51,000 for environmental studies, $26,000 for annual reporting, and $80,000 per year for additional O&M for environmental requirements.

In addition to the capital costs of constructing a downstream fish passage facility, costs typically include those for cleaning closely spaced screens or maintaining traveling screens, lost power generation resulting from flow releases needed to operate sluiceways or other bypasses, and monitoring and reporting. The average costs for angled bar racks was found to be $332,000 per plant for capital costs and $3,000 per year for O&M. Studies for angled bar racks averaged $50,000 where they were performed and $1,300 per year for annual reports.

Occasionally hydropower projects are required to make some contribution to environmental projects not associated directly with the hydro plant to compensate for some environmental damage caused by the plant. Off-site compensation was reported at a few sites that averaged $136,000 per site.

Conclusions

Requirements for environmental mitigation at hydropower projects have an important and growing effect on U.S. domestic energy resources. This study has identified both technical and economic problems associated with the most common mitigation measures: the dominant role of the IFIM, in conjunction with professional judgment by agency biologists, to set instream flow requirements; reliance on spill flows for DO enhancement; use of unproven technology such as angled bar racks for downstream fish protection. All of these measures can have high costs and, with few exceptions, there is little information available on their effectiveness. Additional study needs are identified for each type of mitigation, as well as in the areas of cost estimation, valuation of benefits, and monitoring programs.

CONTENTS

ABBREVIATIONS AND ACRONYMS

ASCE	American Society of Civil Engineers
DO	dissolved oxygen
DOE	U.S. Department of Energy
ECPA	Electric Consumers Protection Act
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
FWS	U.S. Fish and Wildlife Service
ha	hectare; equal to 2.471 acres
HEP	Habitat Evaluation Procedures
HLCTS	Hydropower Licensing Compliance Tracking System (a FERC data base)
HPRA	Hydroelectric Power Resources Assessment (a FERC data base)
IFIM	Instream Flow Incremental Methodology
IFN	instream flow needs
INEL	Idaho National Engineering Laboratory
kW	kilowatt
kWh	kilowatt-hour
Mill	A money of account equal to 1/10 cent
MW	megawatt
NES	National Energy Strategy
NMFS	National Marine Fisheries Service
O&M	Operation and Maintenance
ORNL	Oak Ridge National Laboratory
PURPA	Public Utility Regulatory Policies Act
R&D	Research and Development
Target Population	For this report, nonfederal hydroelectric projects receiving FERC licenses (or exemptions from licensing) during or after 1980, and having mitigation requirements for instream flows, DO, or fish passage.
TVA	Tennessee Valley Authority
USACE	United States Army Corp of Engineers
WUA	Weighted Usable Area (a measure of fish habitat used by IFIM)

1. INTRODUCTION

This report is the first product in a series that is planned as part of the Environmental Mitigation Study being conducted by the U.S. Department of Energy (DOE) through its Hydropower Program. The mission of the Hydropower Program is to promote environmentally sound development of hydroelectric resources. This study of mitigation practices is intended to provide better understanding of environmental problems and solutions that are associated with the construction and operation of hydropower projects.

Hydropower Regulation and Mitigation

The regulatory process that controls the development of hydropower projects in the United States has become increasingly complex over the past decade. The most recent changes to hydropower regulations have come as a result of the Electric Consumers Protection Act of 1986 (ECPA), which significantly strengthened the role of fish and wildlife agencies and reinforced the "equal consideration" standard for evaluating nonpower values in hydro development. During the public hearings on the National Energy Strategy (NES), much testimony focused on the regulatory burden on hydro developers that has grown to the point where it is now a serious hinderance to development. The NES hearings also highlighted a strong divergence of opinions on the value of hydropower resources. For example, the following two extremes are typical of public comments:

> "Hydropower projects are among the most versatile, efficient, dependable (many have service lives exceeding 100 years), environmentally benign, and safest modes of energy production available."

> "Hydro dams deplete oxygen in rivers, curtail nutrient flows, interrupt or completely eliminate fish migrations, reduce the vital up- and downriver exchange of genetic material, separate terrestrial wildlife habitats from one another, alter stream side ecology and instream conditions for aquatic species, and prevent natural depositions of beaches and cobbles."

Some facts about hydropower are clear: (a) hydropower is by far the largest developed renewable energy resource in the United States (e.g., hydro provides 10 to 13% of the electricity in the country) and (b) its undeveloped resource potential is great (preliminary estimates by DOE indicate ~52,000 MW remains undeveloped). Renewable energy resources, including hydropower, will be an important part of this nation's energy future, especially as concern for acidic and greenhouse emissions increases. If hydropower's contribution to the U.S. energy portfolio is to increase, or even be maintained at its current level, hydroelectricity must be generated without unacceptable environmental effects.

Hydropower projects can have, and have had, serious adverse effects on fish populations and other natural resources.[1] The Federal Energy Regulatory Commission (FERC) is required to include mitigation of identifiable environmental impacts in the licenses it issues for nonfederal hydro projects. The President's Council on Environmental Quality (40 CFR Part 1508.20) defines mitigation to include one or more of the following:

- Avoiding an impact by not taking a proposed action
- Minimizing an impact by changing the design of a proposed action
- Rectifying an impact by repairing, rehabilitating, or restoring the affected environment
- Reducing or eliminating an impact over time by preservation/maintenance operations

- Compensating for an impact by replacing or by providing substitute resources.

Natural resource agencies generally recommend mitigation options in the priority listed above. Although there are mitigation techniques available for use at hydro projects, their costs can be very high, and their effectiveness is often poorly understood. These problems are the subject of this study.

Study Objectives

The overall goal of this study of environmental mitigation practices is to clarify some of the controversial environmental issues that surround the hydropower industry. Answers are being sought for important questions that are not well understood, such as:

- How frequently is mitigation of different types required at hydro projects?
- Are there any important trends (e.g., across regions, by project type, or over time) in the types and frequency of mitigation requirements?
- How much are mitigation requirements costing individual developers, the hydropower industry as a whole, and the nation?
- What are the measurable benefits of particular mitigation practices?
- What effects do the mitigation practices have on the operation and maintenance (O&M) of a hydropower facility?
- Are current mitigation practices effective in meeting their stated objectives, or are there any specific areas where increased research and development (R&D) could improve the current situation?

The answers to these questions can provide new guidance to hydropower developers, regulators, and natural resource managers concerning more effective mitigation practices and regulations. The study results will also help to prioritize R&D efforts by DOE, as well as other agencies and organizations.

The DOE Environmental Mitigation Study is intended to produce a series of reports on mitigation practices. The first phase of the study, of which this report is part, is limited to the examination of three specific issues that have been identified as the most problematic to hydropower development: instream flow requirements, dissolved oxygen, and fish protection. More detailed analyses of benefits and costs of these issues are planned for future volumes.

The reports following this first volume will concentrate more on case studies of specific mitigation issues. Some of the details not included in this first volume, such as regional analyses of regulations and cost patterns, are also planned for the later volumes. Subsequent studies are planned to address additional mitigation issues and expand on the findings of the first phase of the mitigation study. Additional mitigation issues that may be evaluated in later years of the study include:

- Protection of wetland/riparian ecosystems
- Recreation and aesthetics
- Terrestrial habitat evaluation procedures (HEP)
- Reservoir management
- Multiple-use water allocation
- Cumulative impact assessment.

More specific environmental studies are planned for later years to develop new assessment techniques or to generate and synthesize new information on specific issues. Studies will expand into development of improved assessment methods and mitigation procedures, where appropriate. These later mitigation studies may include consolidation of existing monitoring data with new monitoring programs for further study and guidance to industry. The issue of instream flow needs (IFN), or minimum flow requirements, has already been identified as an important area needing more research. Other environmental issues that may be addressed in the later years of this program include water quality, fish passage, and cumulative environmental impacts.

The final products of the Environmental Mitigation Study are expected to be a series of issue-specific Guidance Manuals for the selection and design of appropriate mitigation practices, targeted at a broad audience of developers, regulators, and resource managers. These manuals will be based on the best available data on the success of mitigation practices, but this information base may take several years to accumulate (see Section 6).

Scope and Organization of This Report

This first report is limited to an examination of the three environmental issues that are most often important in hydro development:

- Instream flow requirements for fish
- Water quality [specifically, dissolved oxygen (DO)]
- Fish passage upstream and downstream of dams.

The contents of this report focus on mitigation practices as they have been applied to hydropower projects over the last decade, between 1980 and 1990. The objectives are: (a) to identify, compile, and analyze information on the implementation and monitoring of specific mitigation practices; and (b) to determine the degree to which the costs, benefits, and effectiveness of these practices can be measured. The report is primarily a systematic, statistically based analysis that examines nonfederal hydropower projects that have been licensed, or exempted from licensing, by FERC. A second analysis approach using selected case studies of hydropower projects was originally considered for presentation in this volume but is now planned for later volumes in this report series.

The report is divided into 7 sections beginning with this introduction. The information sources and analysis methods used in this first volume are described in Section 2. Specific mitigation practices for IFN, DO, and fish passage, and their frequency of application, are described in Section 3. In Section 4, estimates are presented for average annual costs for each of these mitigation requirements. In Section 5, benefits of mitigation are discussed with attention to how well they can be quantified within the group of hydro projects studied. Section 6 contains the conclusions and recommendations of this initial report on environmental mitigation practices. References cited are listed in Section 7.

This research has been conducted jointly by staff from Oak Ridge National Laboratory (ORNL) and Idaho National Engineering Laboratory (INEL). ORNL staff provided project design and analyses of environmental benefits and mitigation effectiveness. INEL staff conducted the economic and engineering analyses. A number of individuals and organizations provided invaluable assistance during the course of this study in the form of advice and technical reviews, including staff from FERC's Office of Hydropower Licensing, the National Hydropower Association, the Northwest Hydropower Association, the Edison Electric Institute, the Electric Power Research Institute (EPRI), the Southwest Power Administration, the Tennessee Valley Authority (TVA), the U.S. Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service (FWS), the Michigan Department of Natural Resources, and private consultants.

Further information concerning this study can be obtained by contacting the following individuals:

- Environmental Analyses: Michael J. Sale, ORNL (615/574-7305)

- Cost Issues: Garold L. Sommers, INEL (208/526-1965)

- DOE Project Management: Peggy A. M. Brookshier, DOE Idaho Field Office (208/526-1403)

- DOE Program Management: John V. Flynn, DOE Headquarters (202/586-8171).

2. INFORMATION SOURCES AND STUDY METHODS

This section describes the sources of information and analysis methods used to select the hydropower projects described in this report. Originally, two different approaches were considered to examine mitigation practices: (a) a systematic study of all nonfederal hydropower projects that have been licensed during the past decade and (b) case studies of representative projects that have relatively more information for quantifying either benefits or costs. This report concentrates on the first approach, because it has been relatively successful and is more objective and comprehensive than selected case studies would be. Case studies are now planned for later volumes as described in the previous section. The first part of this section describes the existing and new information sources used in the systematic identification of projects with mitigation practices of interest. The second part of this section describes the characteristics of the hydro projects that were targeted in this study and how our information sources represented this population.

Throughout this report, the term *target population* is used to refer to those nonfederal hydropower projects that were licensed or exempted between January 1, 1980, and July 1, 1990, and that have mitigation requirements for one or more of the issues of interest (IFN, DO protection, and fish passage). Within the target population there are several different subsets of projects that are also of interest to the study, such as projects that have surrendered their licenses and successfully developed projects that are now generating hydroelectricity.

Information Sources

This initial report of the Environmental Mitigation Study relies on existing information as much as possible, but several new sources of information have also been developed. Available FERC licensing records were used to identify a priori those projects that were likely to have been required to mitigate environmental impacts related to IFN, DO, and either upstream or downstream fish passage. To complement the existing FERC data and confirm the existence of these requirements, additional information was obtained directly from hydropower developers and from state and federal resource agencies.

The decision to rely on existing, computerized data bases was made early in the project because the size of the target population (more than 700 projects) made it infeasible to directly examine all FERC licenses given available time and funding constraints. The limitations of existing data bases do, however, have important influences on how the results of the study can be interpreted.

Existing FERC Data. The hydropower licensing records used in this study come from two sources: (a) FERC's Hydroelectric Power Resources Assessment (HPRA) data base and (b) FERC's Hydropower Licensing Compliance Tracking System (HLCTS).

Hydroelectric Power Resources Assessment Data. The HPRA data base system is a comprehensive repository of information on developed and undeveloped hydropower resources in the United States. The data management system has been developed for FERC by a private contractor to the DOE Energy Information Administration.[2] HPRA data are the basis for FERC's biennial assessment of the nation's hydropower resources.[3] In July 1990 a partial copy of the HPRA data base was obtained from FERC describing developed and undeveloped conventional hydropower resources (only pumped storage projects and other non-conventional hydro projects were excluded). For this study, HPRA was used to obtain descriptive information on existing projects in the study's target population, including such characteristics as licensing and construction status, project location, and developer type.

Hydropower Licensing Compliance Tracking System. The HLCTS data base is used by FERC's Division of Project Compliance and Administration to track license requirements and compliance actions. HLCTS includes codes for all study and reporting requirements that are defined in each project's license, license articles, or exemption order. Although these codes do not completely describe all mitigation measures, HLCTS is the only computerized data base available that contains general information on mitigation requirements for recent FERC licenses and exemptions.

A partial copy of the HLCTS data was obtained for this study in July 1990. The HLCTS data obtained included all records, or observations, in the data base, but not all the information on each record. For example, initial license requirements (information from the HLCTS "A, B, and C Screens") were included, but information on specific compliance actions (e.g., reports submitted by the developers or compliance letters sent out from FERC) were not included. Environmental mitigation requirements specified in FERC license articles are coded into HLCTS in broad categories, so FERC project numbers with general environmental mitigation license conditions can be identified. Hydropower projects in this study's target population were identified from the HLCTS data by extracting FERC project numbers with License Article Requirement Description Codes associated with IFN, water quality, or fish passage.

Three HLCTS descriptor codes were used to identify 583 projects with potential instream flow requirements: No. 87, Minimum Flow - Interim; No. 89, Minimum Flow Requirement; and No. 90, Minimum Flow Study. HLCTS descriptor code No. 139, Water Quality, was the only one used to identify 206 projects with potential DO requirements. Two different codes were used to identify 336 projects with potential fish passage requirements: No. 64, Fisheries Resources; and No. 71, Fishway Facility Design.

Because there are not one-to-one correspondences between the HLCTS Description Codes and the three specific mitigation requirements of interest here, there are some unavoidable errors in our a priori target population definition. For example, some projects that have "Water Quality" requirements may not have DO requirements. However, after consultation with FERC staff at the beginning of the project, it was decided that this application of HLCTS data was the best way to use existing information and to identify hydro projects of interest, short of a direct examination of each license.

Information Obtained from Hydropower Developers. Information available from FERC data bases was not sufficient to evaluate site-specific mitigation practices or their costs and benefits. Therefore, a major effort was made to acquire new information directly from the developers of projects in the target population. Developers were contacted in October 1990 and asked to voluntarily provide information on their mitigation practices. Developers were asked to describe the specific mitigation measures that were required by their FERC licenses, the extent to which the requirements have been implemented, the extent to which data have been collected to determine if mitigation was successful, and the success of mitigation requirements in protecting aquatic resources. This part of the study was designed in consultation with a group of hydropower industry representatives, which met at a workshop in Atlanta in September 1990. The information provided by developers is summarized in Appendix A.

The information provided by hydro developers was voluntary in nature and not part of a survey explicitly designed to reach all subgroups of hydro projects. Therefore, the sample of information does not represent all subgroups equally well. An examination of potential bias in the developer information is presented in the next part of this section.

Information Obtained from Natural Resource Agencies. To obtain additional information on mitigation policies, effectiveness, and available data and to ensure a balanced view of current practices, state and federal agencies that have responsibilities for recommending environmental mitigation at hydro projects were also asked for information. In February 1991 two or more agencies in each of the 50 states, as well as the regional offices of the FWS, EPA, and the National Marine Fisheries Service (NMFS), were contacted and asked to provide information on instream flow, DO, and fish passage issues. Agencies were provided with a list of the hydro projects of interest in their respective state or region, asked to describe their mitigation policies and practices, and asked to identify any studies that could be used to quantify benefits and costs.

A total of 66 agencies provided information on mitigation policies and practices, covering 36 states, five of the six regions of FWS, two of the four regions of NMFS, and three of the 10 regions of EPA. Among the states that responded, 10 have written policies regarding instream flows, nine have written policies for fish passage, and 13 have written DO policies (often state water quality standards). States that have policies relating to these issues are also those that have had the greatest number of hydropower projects (e.g., Pennsylvania, Idaho, Michigan, Maine, and Washington). The specific results of the agency information request are discussed in Sections 3, 4, and 5, and summarized in Appendix B.

Target Population of Hydro Projects

The first step in studying mitigation practices was to define the population of hydropower projects that have been required to mitigate for IFN, DO, or fish passage.

Projects Developed In the 1980s. Benefits to small hydropower developers, such as those derived from the Public Utility Regulatory Policies Act (PURPA) (Pub. L. 95-617) and other incentives for energy development, led to an extraordinary increase in applications for hydropower development during the early 1980s.[4] Much of this proposed development was speculative, and many of the applications for new projects have either been abandoned during the FERC licensing process or have expired prior to development. More than half of the project applications received since 1978 are now inactive, and a disproportionate share of these abandoned projects (~75%) were proposed by private nonutility developers.[4]

According to FERC data, there currently are ~1700 nonfederal hydroelectric projects that hold active FERC licenses or active license exemptions. Approximately 650 of these active projects are small projects with exemptions, and many of both the licensed and the exempted projects have not been developed to the point that they are generating hydroelectricity. The HLCTS data set used for this project contains information on ~3300 projects with licensing status ranging from preliminary permits to surrendered licenses. Projects that have surrendered their licenses during the past decade are considered to be potentially of interest in evaluating mitigation practices, since those projects were subjected to environmental assessment, design, and cost assessment. However, preliminary permits are not of interest because their mitigation requirements have not been determined. Eliminating preliminary permits and projects developed before 1980, the total population of hydro projects considered to be of interest to this study is 1638. This total population number includes projects that are no longer active because they have surrendered their licenses. Of these licensed or exempted projects of interest to this study, HLCTS records indicate that 256 projects have officially surrendered their licenses or license exemptions (Figure 2-1).

Projects with Mitigation of Interest. Initially, 707 projects were identified from HLCTS as being in the study's target population because of indications they had mitigation requirements for IFN, DO, and/or fish passage. An attempt was made to contact the developers of all of these projects. However, information could not be obtained from some of these projects, because their addresses and phone numbers listed in HLCTS were incorrect. The number of projects that were not contacted

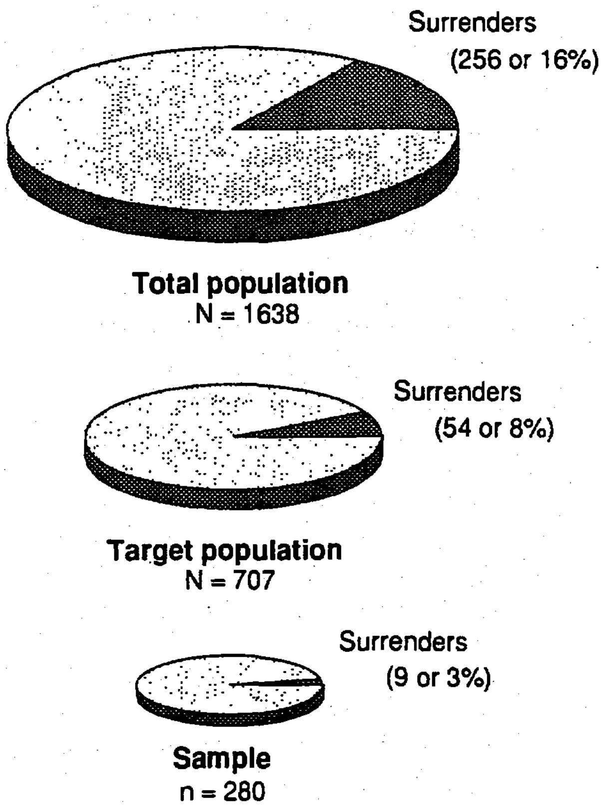

Figure 2-1. Proportion of inactive, or surrendered, projects in the total and target populations and in the sample of projects obtained from hydro developer information (the shaded portion of the pies and the numbers in parentheses represent surrendered projects).

is estimated to be in the range of 25-50 (3 to 6%). A total of 280 of the targeted projects eventually provided information for this study. This response rate of more than 40% represents a high degree of cooperation from the hydropower community.

The active projects in the target population that were considered a priori to have mitigation of interest are 47% of all active projects that have received licenses or exemptions since 1980. However, experience from this study indicates that there are some inaccuracies in our a priori identification of the target population of projects. For example, a significant number of projects that were originally identified from HLCTS data as not having instream flow requirements subsequently provided information to the contrary. Overall, 17, 13, 8, and 31 projects that were initially identified as not having instream flow, DO, upstream fish passage, and downstream fish passage requirements, respectively, reported that they do in fact have these requirements. There are several explanations for these apparent errors: e.g., missing HLCTS codes (i.e., incomplete data), the incorporation of mitigation requirements into standard articles ("L-form" articles) that are not coded in HLCTS, and situations in which mitigation was requested and implemented after licensing by resource agencies. The implication of these problems is that our estimates of the frequency of mitigation requirements are likely to be an *underestimate* of the actual frequency of mitigation practices. Our best estimate is that the number of projects with mitigation requirements has been under-reported by our study by at least 6% for instream flows, 4% for DO, 3% for upstream fish passage, and 10% for downstream fish passage. No further steps have been taken to account for these relatively minor errors in the statistical analyses.

The sample of the target population underrepresents the frequency of license surrenders relative to active projects (Figure 2-1). For example, only 3% of the projects providing developer information were surrendered projects, whereas 8% and 16% of the target and total populations, respectively, are surrendered licenses or license exemptions. However, if only active projects are considered, the sample data does accurately represent the licensing status distribution (i.e., full licenses versus license exemptions) and regional distribution of projects in the target population.

The sample also appears to be biased in terms of developer type, because private utility developers are overrepresented and private, nonutility developers are underrepresented (Figure 2-2). Therefore, our sample of developer information must be used cautiously in extrapolating to the target population of hydropower projects. It seems reasonable to use the sample data to describe active projects

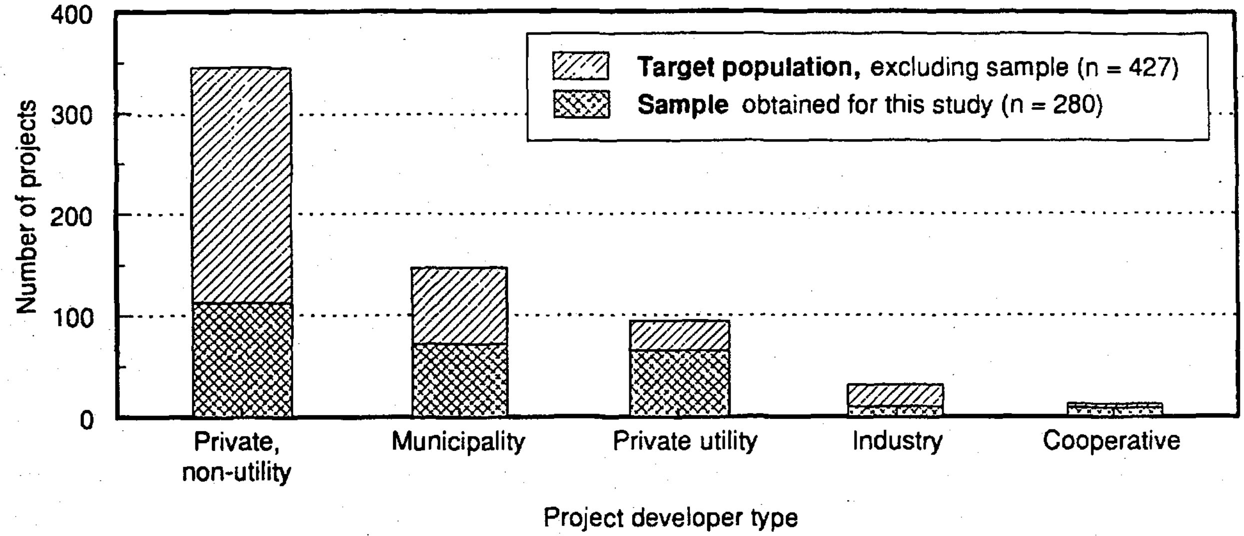

Figure 2-2. Proportion of various types of hydro project developers, in the target populations and in the sample of projects obtained from hydro developer information.

but not to describe inactive projects. The results of these extrapolations may be biased slightly toward the experiences of utility developers.

Statistical Extrapolations. Inferences about the frequency of occurrence of specific practices within the target population of projects require that assumptions be made of the sample characteristics, including (a) the assumption that the original population definition included all projects with the mitigation of interest and (b) the assumption that the sample was unbiased and random. Because of the voluntary nature of the information request to hydropower developers, there were violations in at least the first of these assumptions. Nevertheless, the statistics presented in Section 3 do assume that the a priori population definition was complete and that the sample was random.

Estimates of the percentage of projects with particular mitigation requirements are calculated as the ratio of affirmative responses to total responses for the specific question asked. Percentages within the target population are assumed to be the same as those within the sample. Extrapolations from the target to the total population of projects can be made by multiplying the target population percentages by the ratio of the number of targeted projects to total projects. The implication of violations of the statistical assumptions described in this section are believed to result in an overall tendency to underestimate mitigation frequencies, rather than overestimate them, and are not large enough to affect the overall conclusions of this report. Further analysis of these data is planned for future volumes of the Environmental Mitigation Study.

3. CURRENT MITIGATION PRACTICES

This section describes the types and frequencies of application of mitigation practices that have been required at FERC-licensed hydropower projects over the past decade. Background information is presented for each mitigation issue to define terminology and concepts and to review other relevant studies. Unless indicated otherwise, the description of current practices in this section is based solely on the new information provided by hydropower developers and agencies for this study (see previous section for details).

Instream flows are the most common mitigation requirement at nonfederal hydropower projects. From data provded by hydropower developers, it is estimated that 56% of the target population of projects licensed between 1980 and 1990 had instream flow requirements. DO mitigation are estimated to have been required at 20% of the projects, upstream fish passage at 11% of the projects, and downstream fish passage at 28% of the projects. Although there is no significant regional bias in the sample of projects providing information for this study, the frequency of occurrence of the different mitigation requirements does differ by region (Figure 3-1). Generally, instream flow requirements are more common in the west and northeast, whereas DO requirements are morecommon in the east. Downstream fish passage requirements are more common than upstream passage requirements, and all fish passage requirements are more common in the western regions than in the east. There is a distinct temporal pattern in the frequency of mitigation requirements (Figure 3-2). Over the 10 years, instream flow requirements have increased in frequency among the target population of projects from 54 to 65%. DO requirements have increased from 19 to 28% in the same period. Upstream fish passage requirements have not shown a significant increase, but downstream fish passage requirements have increased from 22 to 35% in the target population.

Instream Flow Requirements for Fish Resources

An instream flow requirement is a form of environmental mitigation that limits the amount of natural stream flows that can be used for hydropower generation. Instream flow requirements usually focus on lower flow limits (e.g., minimum flow requirements that ensure aquatic habitat will not be degraded), but they may also include limits on the maximum flow or on the rate of change of flows to downstream areas. This study focused on instream flows that are required primarily for fisheries resources (including fish populations and sport and commercial fish harvests). Instream flows intended to improve temperatures or water quality, with subsequent benefits to fish, were not the primary focus of the instream flow mitigation discussed here.

Environmental mitigation at federally-owned and operated hydroelectric projects is not regulated by FERC or by states. Providing instream flows for protection of fisheries has not historically been an authorized purpose of federal projects, but this trend is changing. At many federal projects instream flow releases are now provided by the agency operating the dam, usually in coordination with state and federal fish and wildlife agencies. However, an examination of instream flow requirements at federal dams was not within the scope of this report.

Background on Instream Flow Issues. The environmental benefits and costs of instream flow releases depend on the type of hydropower project, the resource to be protected, and the instream flow rate itself. The flow rate is a function of the methods used to determine IFN, so the selection of a method of determining the instream flow rate is an important mitigation decision. The following information is provided as background for understanding the effects of instream flow practices.

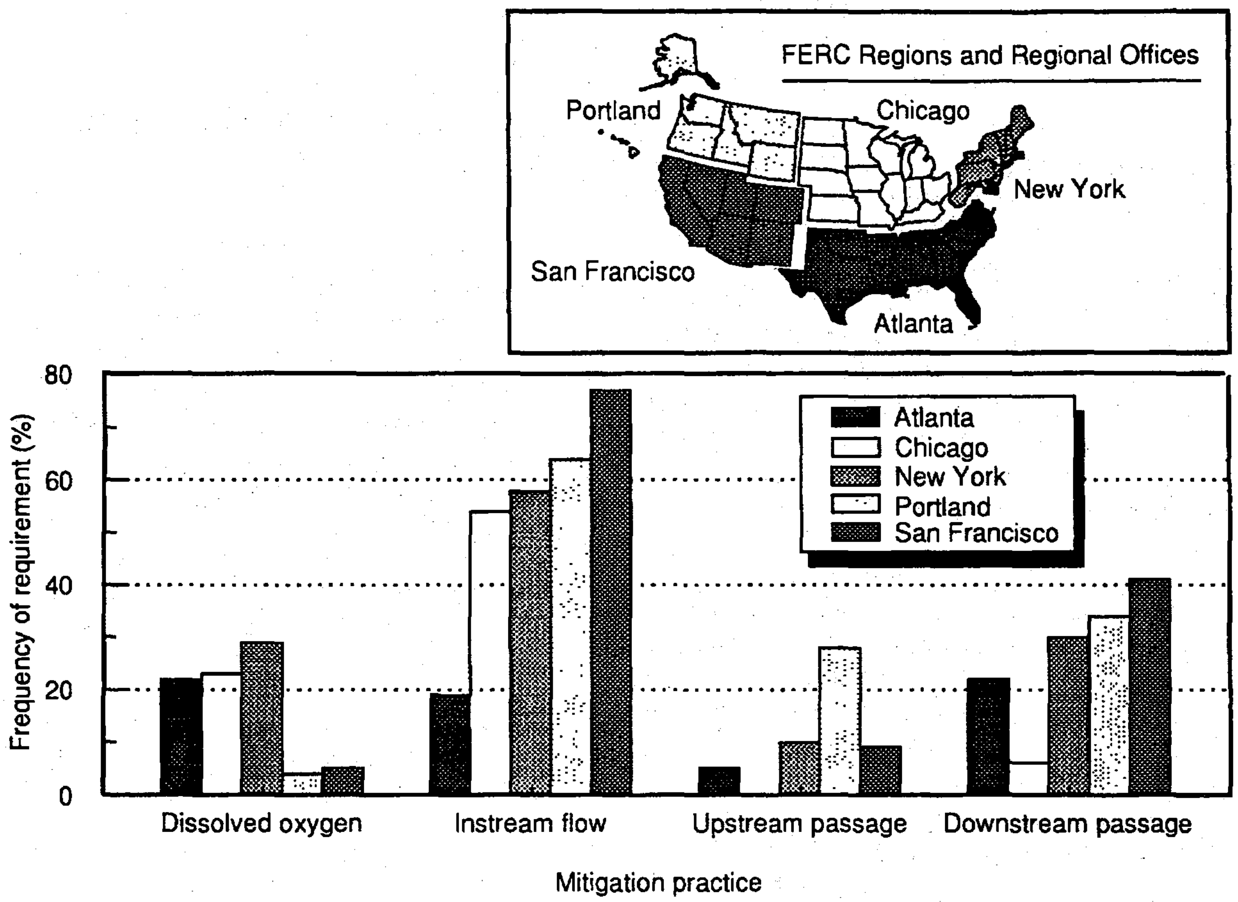

Figure 3-1. Regional distribution of different types of mitigation requirements in the target population of hydropower projects.

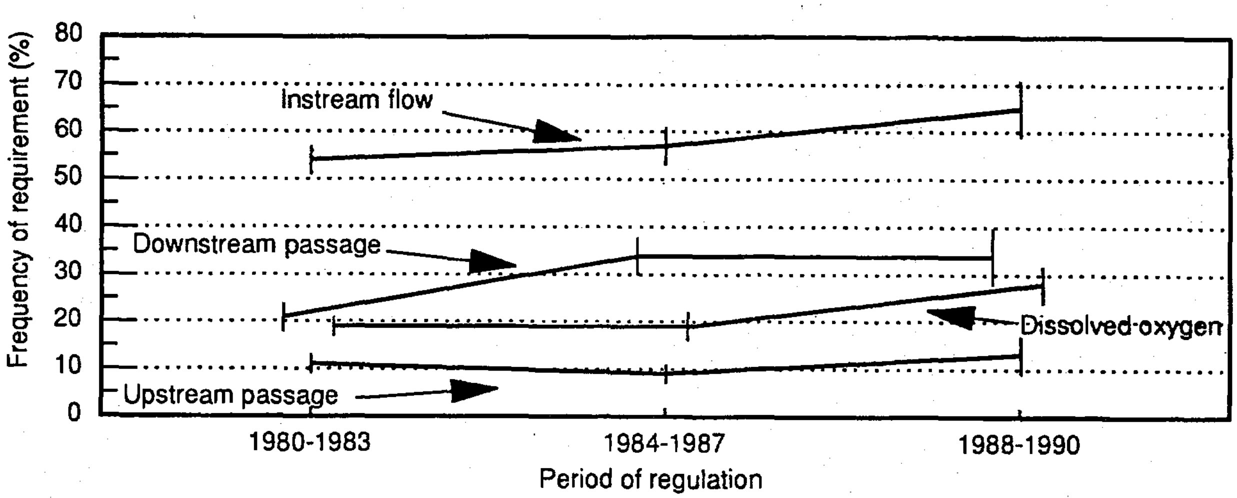

Figure 3-2. Temporal trends of mitigation requirements in the target population of hydropower projects (symbols are plotted at mean and whiskers represent ±1 S.E. of estimate).

Types of Instream Flow Releases. Instream flow requirements are implemented in many different ways, depending largely on the design and mode of operation of hydro projects. Diversion projects, storage reservoirs, and low head dams involve different instream flow requirements and costs.

Diversion projects transfer water out of natural stream channels into conduits and penstocks leading to a powerhouse. When diversion projects are operated in run-of-river mode (i.e., by releasing flows equal to inflow rates), natural flows are reduced only in the bypass reach between the upstream diversion dam and the powerhouse, where flow from the project reenters the stream channel. Many small diversion projects do not have storage capacity at the diversion dam and are required to operate in run-of-river mode. Other diversion projects have a large enough dam and reservoir to store water and release it over seasonal or daily cycles, which alters the flow downstream of the powerhouse as well as in the bypass reach (see the following discussion of storage projects). Instream flow requirements in the bypass reach are enforced below the diversion dam in the bypass reach and are therefore unavailable for power generation. Except when stream flows exceed the sum of the maximum power plant flow capacity plus the instream flow requirement, instream flow requirements for diversion projects reduce power generation. Instream flow requirements at diversion projects are usually minimum flows to provide a lower threshold of habitat condition, but they may also include flushing flow requirements that are short-term, high flows designed to provide sediment transport capability.

Storage projects are defined for this report as projects without bypass reaches, where generation occurs as water is released from the dam, and where flows can be stored in a reservoir and released later. Storage projects do not alter the overall volume of water passing any point in the stream (except for evaporation from the reservoir that is usually minor), but do alter the timing of releases over seasonal and daily time scales. Storage projects typically store water during high runoff seasons and augment power-producing flows by releasing it during low runoff seasons. Daily releases from storage projects can be made in three modes: (a) baseflow mode, in which flows are relatively constant throughout the day; (b) peaking mode, in which power production (and flow releases) follow the power demand rates throughout the day, with higher releases during the hours when power demand is greatest; and (c) pulsing mode, in which flow varies with power demand but the degree of variation is limited by a limited water storage capacity. Instream flows are required to protect fisheries during periods when the project would otherwise release little or no flow. Instream flow releases can be made through the existing turbines or, if flow requirements are small compared with turbine capacities, through sluice gates or special small turbines designed specifically for the instream flow release. At some storage projects these flow releases can be used to generate power and do not result in a loss of net power production. However, instream flow requirements can result in lost power production when they are enforced during times when power demand, and therefore the economic value of the power, is lower than during the peak demand periods.

Low head projects without storage capacity have been and are being developed at many sites, such as existing navigation dams on larger river systems. These projects are also sometimes referred to as run-of-river projects, but they are distinct from diversion projects. At these low-head projects, there is no bypass reach and no storage of water to alter instream flows. However, water flows may become more concentrated into a portion of the river channel in the turbine tailrace as the result of development of this type of project. A form of instream flow requirement common at low-head projects is the requirement to maintain a portion of the original spill flows over the dam or through gates, instead of through turbines, to maintain downstream water quality (by providing aeration) or to provide turbulent, high velocity fish habitat downstream of the dam. Such spill flows may be considered instream flow requirements because they are partially designed to provide fish habitat. (Spill flows for DO mitigation are discussed in the following section on DO Mitigation Methods and in Table 3-2.) Spill flow requirements reduce the flow available for power production (except when streamflow is greater than the sum of the power plant flow capacity plus the spill flow requirement).

Determination of Flow Requirements. A number of different assessment methods are used by resource agencies and FERC in determining what instream flow releases should be made to protect fisheries. These methods have been compiled and compared several times over the last decade.[5,6,7] Methods vary in complexity from recommendations based on fixed standards to analyses using complex hydraulic and habitat simulation models.

Instream flow requirements at some sites are based on the judgment of fisheries biologists without the use of formal methods. Such decisions may take into account experience with other similar projects and streams, observations of fisheries under past low-flow conditions, historic flow distributions, and other information that is not incorporated in a formal method.

The Aquatic Baseflow method is a typical simple "desktop" instream flow method (i.e., not requiring field studies) that is commonly used in the Northeast.[7] This method is based on the assumption that a specific flow rate per unit of watershed area will provide an adequate minimum flow. Instream flow requirements are determined simply by multiplying the watershed area of the stream at the project site by a parameter that is constant for a state or region. The method is not specific to individual fish species or lifestages.

The IFIM appears to be the most widely used formal instream flow method, although there are many others. The IFIM is used in 38 states and is required for instream flow studies in California, Oregon, and Washington.[7] The IFIM typically involves the use of a hydraulic simulation model and physical habitat models to predict the availability of physical habitat (as defined by area, depth, velocity, substrate type, and sometimes cover and temperature) as it varies with flow.[8,9] Extensive site-specific field studies are required. Judgment of the biologist applying the IFIM is required in conducting the modeling and in interpreting the results. Determination of an instream flow requirement from the relationship between physical habitat availability and flow may be either a matter of agency policy or judgment or the product of negotiation among agencies and project proponents.

Frequency and Type of Instream Flow Requirements. This section presents data on mitigation practices for IFN at FERC-licensed projects. Information was obtained from a sample of 185 target population projects that have instream flow requirements (i.e., 185 individual power plants, some of which are grouped under the same FERC license number; 170 different FERC license numbers are included). These projects are among the ~580 identified as potentially having instream flow requirements in their FERC license; the regional distribution of both the instream flow target population and the sample of these projects described here are shown in Figure 3-3.

The projects that provided information have a wide distribution of required instream flow rates, ranging from 0.25 to 4,000 cfs. The distribution of flow requirements is shown in Figure 3-4; the values used in the figure are time-weighted averages for projects at which instream flow requirements vary seasonally or daily. Other information describes the objectives of the instream flow requirements, the methods used to determine instream flows, and the kind of monitoring conducted. The responses of operators of hydropower projects with instream flow requirements to specific questions about these issues are summarized in Appendix A. The statistical analysis of this information indicates that instream flow mitigation is required at 56% of projects licensed since 1980 (see previous section).

Of the 185 projects with instream flows, 29% had flow requirements that vary seasonally or daily. Restrictions on the rate of change in

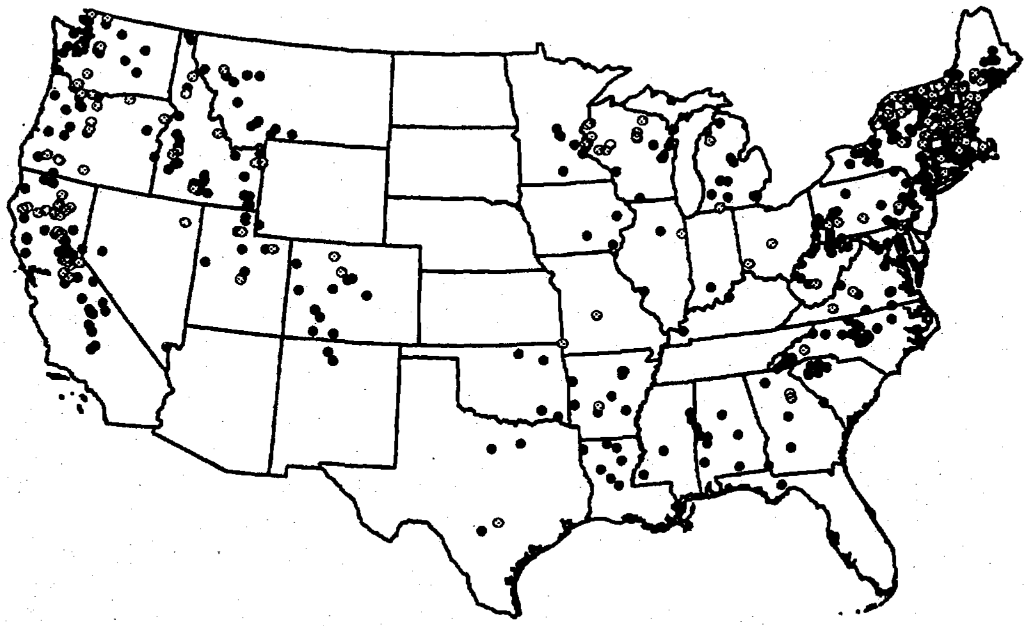

Figure 3-3. Distribution of sample of target population projects with minimum flow requirements. Light-shaded points are members of sample, block-shaded points are all other projects in target population.

flows (ramping rates) were reported at 11% of projects. The projects with instream flow requirements were categorized as (a) diversion projects, including diversions with storage (b) storage projects with the powerhouse at the dam; and (c) others, which include run-of-river projects at navigation dams with spill flow requirements (Figure 3-5).

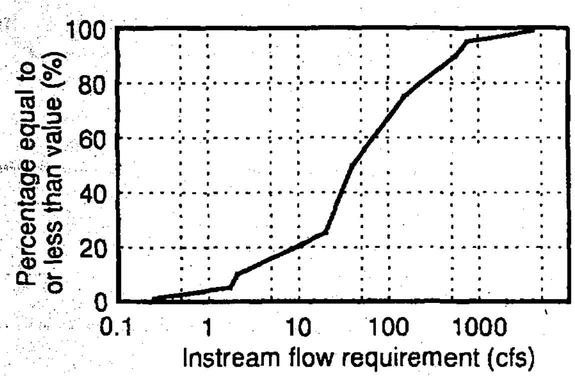

Figure 3-4. Distribution of instream flow requirements. The y axis is the percent of projects that reported instream flow requirements that have an annual average instream flow less than or equal to the value on the x axis (e.g., 50% of projects had instream flow requirements of 40 cfs or less).

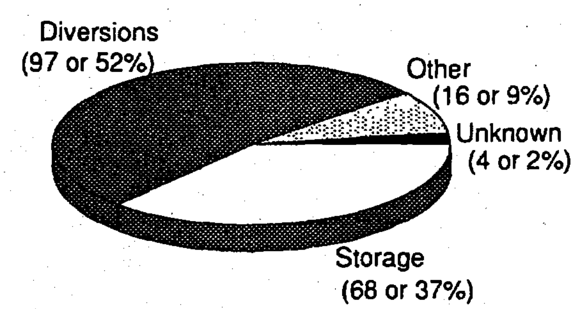

Figure 3-5. Kinds of projects with instream flow requirements, based on information provided by developers. Values in parentheses represent numbers and percentages of projects in each category.

Only projects with specific instream flow requirements for protection of fisheries were included in these results, although some projects may have had instream flow requirements designed for other purposes as well as for fish (e.g., recreation). Most of the projects (55%) reported that instream flows were intended to protect all life stages of sport or commercial fish (e.g., resident or spawning populations), whereas only 4% reported that instream flows were intended to protect only adult sport or commercial fish (e.g., at a stocked put-and-take fishery). Instream flows to protect nongame species were reported at 26% of the projects, and threatened or endangered species were reported as a concern at only 7%.

Objectives other than those directly aimed at fish, such as temperature and water quality requirements for aquatic biota, were commonly cited as being involved in instream flow requirements (Figure 3-6). These other objectives also include recreation, such as boating, protecting riparian vegetation, preventing harmful accumulation of sediments, and other objectives that frequently included aesthetics. It is apparent from these results that temperature, water quality, and sediment types are fish habitat parameters recognized as important at a number of sites, and that these issues may be regulated in conjunction with instream flows for the benefit of fish resources.

It is also apparent that riparian vegetation and recreation are important benefits of instream flows at a significant number of sites. Because instream flow assessment methods for several of these secondary objectives are less developed than those available to assess fish habitat, they are an important subject for future instream flow research. Instream flow requirements are obviously complex, with requirements for fish often inseparable from other resources.

Many different methods have been used to determine IFN (Figure 3-7). Project operators apparently believe that the professional judgment of agency staff ("Judgment" in Figure 3-7) is a common part of instream flow decisions. This result is not surprising, considering that other methods (especially the IFIM) require judgment in their implementation. Also, project operators who were unaware of or have forgotten what methods were used by agencies to set flow requirements (the participating projects were licensed as many as 10 years ago) are likely to have chosen professional judgment as the method used. Of the 89 projects reporting judgment as a method, 45% reported other more formal methods as also being used (e.g., 50% of operators reporting use of the IFIM also reported judgment as a method). However, 26% of all the projects with instream flow requirements reported that agency judgment was the only method used to determine the requirements.

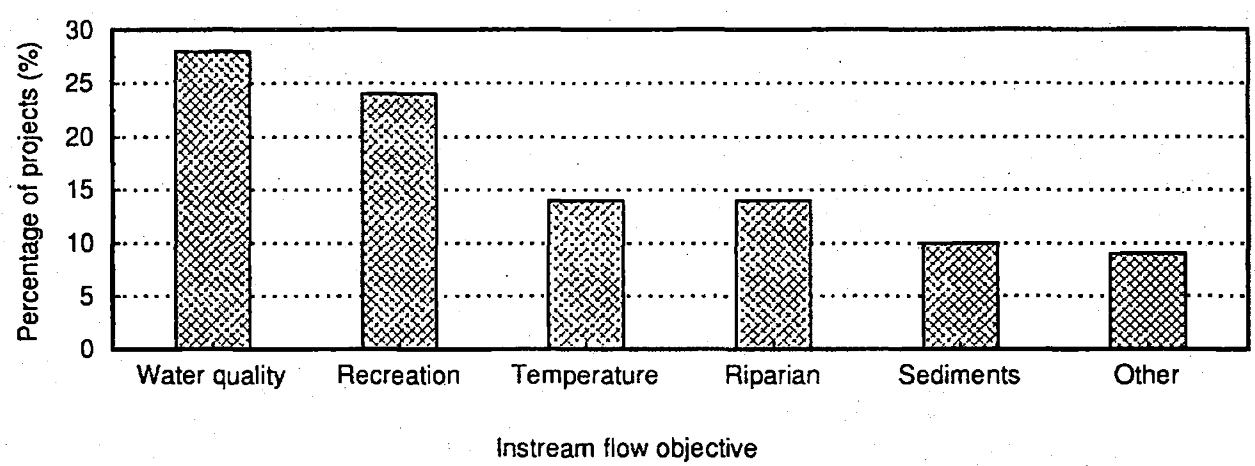

Figure 3-6. Additional objectives of instream flow for fisheries, based on information provided by developers.

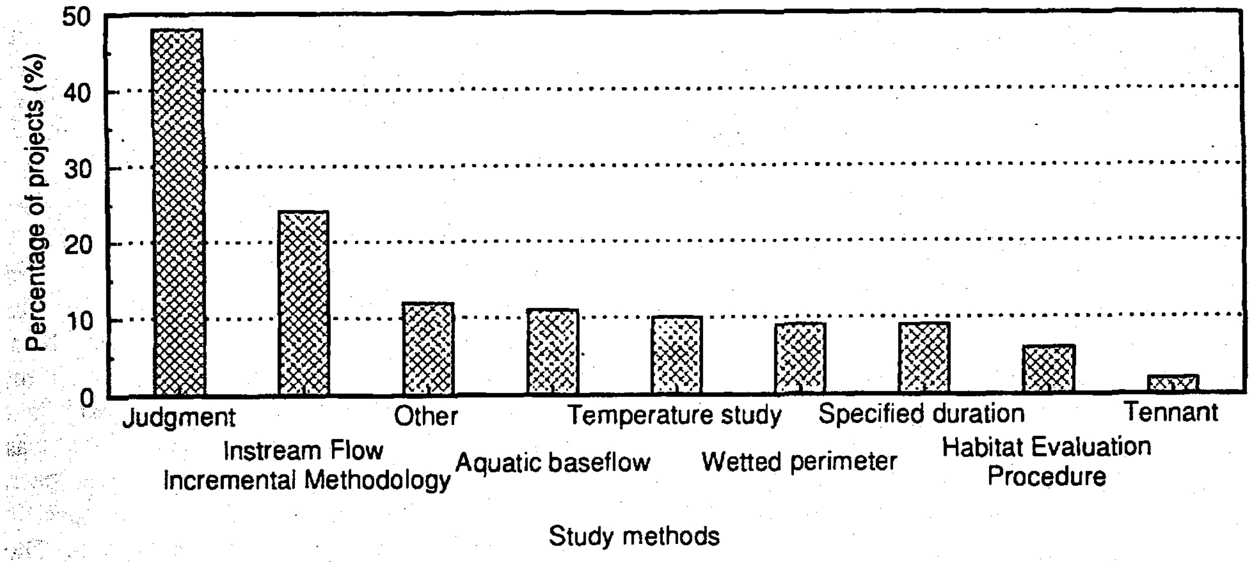

Figure 3-7. Methods used to determine instream flow requirements, based on information provided by developers.

The reliance on a relatively high degree of professional judgment in determining instream flow requirements may be unavoidable, but it is troublesome. When practiced by a professional with a high degree of training and experience, judgment is invaluable and often cost-effective. However, when it is a substitute for well-defined standard practices, such as exist widely in other engineering disciplines, an excessive reliance on professional judgment can contribute directly to the uncertainty and controversy in the regulatory process faced by hydropower developers. Unfortunately, it can also be argued that the blind application of simplified, or canned, methods by inexperienced personnel is worse than reliance on professional judgment. However, the worst situation is probably the application of professional judgment by inexperienced personnel, and this is too often the case today. A very real example of this problem is the selection of target fish species and appropriate habitat suitability functions for IFIM studies. Furthermore, once habitat response functions (an index of habitat conditions at various flow rates) are produced by an IFIM study, professional judgment is unavoidable in selecting a limiting habitat value, and consequently the minimum flow. Despite more than 15 years of IFIM studies, every application is site-specific and relatively subjective.

An additional problem with excessive reliance of professional judgment in setting instream needs is that it may result in inflexible recommendations that do not include the supporting evidence, rationale, or incremental tradeoffs that are needed by FERC in its licensing decisions. Ultimately, it is not possible to determine for the available data or the analyses in this report whether specific instream flow requirements are defensible or not; to do that would require much more detailed examination of the environmental assessments for each of the projects included in the sample. However, this level of analysis is planned on a case-study basis for future volumes of the overall Environmental Mitigation Study.

These results concerning instream flow requirements indicate that more research is needed to improve assessment methods by making them more predictive and objective. This conclusion is supported by other recent evaluations by the American Fisheries Society[7] and by the FWS.[10] It is apparent that project developers understand the IFIM well enough to acknowledge the role of professional judgment in its application. It can also be concluded that many projects have instream flow requirements set without the benefit of an established, documented assessment method. The value to developers and to aquatic resources of conducting more sophisticated instream flow studies at such projects appears to be an important research subject.

Agency Positions on Instream Flow Mitigation. Information provided by natural resource agencies on instream flow practices is summarized in Table 3-1 and Appendix B. Less than half of the states responding reported that they did not have had any written policy on instream flow requirements, and of the states that do have written policies, most are general statements of intent rather than specific requirements that clearly define assessment methods or requirements. The IFIM was by far the most frequently identified assessment methodology by state agencies. This finding is consistent with asimilar survey of state policies conducted in 1988 by the American Fisheries Society.[7] Every state providing information stated that they develop instream flow recommendations or requirements based on non-fishery as well as fishery values.

The FWS is the most active federal agency in determining instream flow requirements. All 6 of the FWS regional offices responded to this study's request for information. The general FWS policy with regard to instream flow requirements is contained in two position statements: the Mitigation Policy of 1981[11] and their unpublished Hydropower Policy [12] that was originally issued in 1988 and has never been finalized. Neither of these policies are specific on any aspects of instream flow mitigation. The FWS Northeast region (FWS Region 5) does have a very specific instream flow policy, called the New England Flow Policy, which relies on the median August historical flow as an instream flow standard (referred to as the Aquatic Baseflow method above). While all FWS regions cited the IFIM as the most common, and usually preferred method used to determine IFN, all regions listed more than one assessment

Table 3-1. Summary of state resource agency responses to agency information request regarding instream flow mitigation (see Appendix B for additional information).

	Yes	No	No response
Does the state have a written policy regarding instream flow requirements?	13	21	14
Does the state accept compensation for fish losses through off-site mitigation?	16	13	17
Does the state have instream flow requirements for FERC-licensed projects?	23	4	19
Does the state utilize more than one assessment methodology to develop instream flow recommendations or requirements?	15	7	22
Is operational monitoring for effects of instream flows on habitat or fish populations conducted?	10	13	21
Are instream flow recommendations or requirements based on non-fishery values?	22	0	22

method as being used. The Northeast Region placed less emphasis on the IFIM and more on its simpler Aquatic Baseflow standard. "No net loss" in habitat potential was cited often as the objective of instream flow requirements by the FWS regions. A large number of different ecological considerations were also cited as being important factors in determining IFN, including endangered species, migration and spawning needs of anadromous fish, and integrity of warmwater fish communities. A large number of non-fishery issues were also cited as important (e.g., recreation, riparian vegetation, invertebrate communities, wetlands, and aesthetics).

A recent evaluation of IFIM applications by the FWS[10] documented 616 applications since the IFIM was developed in approximately 1976. More than 80% of these applications were in the western states, and most applications were by non-FWS personnel. Two major problems were associated with IFIM applications: (1) it is technically too simplistic, and (2) it is too complex to apply. This apparent contradiction illustrates the uncertain nature of determining instream flow requirements and the fact that more research is needed in this area.

The NMFS and EPA were also contacted for information on instream flow requirements. EPA generally differs to FWS for instream flow recommendations. The most active NMFS region in terms of setting instream flow policies is in the Pacific Northwest, where anadromous salmon and trout populations are declining due to hydropower and other impacts. The only written NMFS policy on mitigation practices is contained in an unpublished report entitle "Policies and Roles in Reviewing Small Hydroelectric Developments in the Pacific Northwest", which is available from the NMFS regional office in Portland.

Dissolved Oxygen Requirements

Background on Dissolved Oxygen Issues. Impacts of hydropower operations on DO below dams have not been as common a mitigation issue as either instream flow or fish passage in the last ten years (Figure 3-2). DO impacts have, however, become more frequently regulated and will continue to increase in importance to hydropower developers as large reservoirs come up for relicensing. FERC therefore considers DO mitigation as the third most important environmental mitigation issue to face the hydropower industry today.[13] A brief description of processes affecting DO in hydropower releases and a review of available DO mitigation techniques are presented in the first parts of this section. Current practices, as determined by a systematic examination of a sample of the target population of hydropower projects, are presented in the second part. State and federal resource agencies' positions regarding DO impacts and mitigation are presented in the last part.

Environmental Issues. Man-made impoundments, and the hydroelectric projects that may be developed at them, can have adverse effects on downstream DO concentrations through two primary modes of impact: (1) the release of water with reduced DO, and (2) reduction in the large air-water oxygen transfer that occurs at dam spillways. Awareness of this potential problem has caused mitigation of DO problems to become a relatively common requirement in hydropower development licenses. Hydropower operation can also significantly affect tailwater temperature regimes and other physical and chemical tailwater characteristics. Comprehensive discussions of these other effects, not considered in this report, are available.[14,15]

Effects of Hydropower Development on Dissolved Oxygen and Tailwater Ecosystems. The effects of a hydroelectric installation on the DO of a river can be quite variable, depending on the mode of operation of the project (e.g., daily pattern of generation, minimum flow policies), and the physical characteristics of the project and tailwater (e.g., natural river flow rates, nutrient inputs to the reservoir, depth at which flow is released from reservoir, climate, topography).[15]

The effects of larger impoundments on tailwater DO have been well documented, perhaps because changes in downstream quality are more pronounced at deep reservoirs with long retention times.[16] Deep storage reservoirs tend to thermally stratify during the summer, and thermal stratification promotes chemical changes in reservoir outflow.[14] Isolated hypolimnetic zones tend to become oxygen-depleted or anoxic during the summer as a result of benthic oxygen demand, flow patterns, and the oxygen demand associated with decay of algae that have settled to the hypolimnion. DO in releases will depend on reservoir retention time, outlet depth, and metalimnetic and hypolimnetic DO; factors influencing reservoir DO include organic loading from inflows and sediment oxygen demand.[17]

Several recent studies have also documented negative effects on DO concentrations resulting from hydropower projects that eliminate well-aerated spill flows at smaller projects.[18]

DO is necessary for the metabolism of aquatic animals, so low DO releases from hydropower projects can have detrimental effects ranging from reduced feeding and growth rates to mortality and the elimination of some or all species. The effects of DO concentrations on aquatic biota have been summarized and quantified.[19]

According to FERC records, of the 1638 projects licensed or exempted from licensing since 1980, about 200, or 13%, have a license article for mitigation of water quality impacts, most of which are for mitigation of dissolved oxygen impacts. Water quality license articles included in new licenses began to appear with increasing frequency in the mid-1980s (Figure 3-2). Although this study focuses on nonfederal hydropower in the United States, some insight about the extent of DO problems can be gained by considering the experience of federal agencies. For example, out of 52 dams operated by TVA, releases from about 20 fall below state DO standards (a problem being addressed by the TVA through its Lake Improvement and Reservoir Releases programs).[20]

Mitigation Methods. There have been several aeration and DO mitigation research programs conducted in the past two decades, and a considerable volume of literature on the subject is available. The major sources of information are research and literature reviews published by the hydropower industry and industry consortia, such as EPRI,[21] by the federal agencies that manage much of the hydropower in the United States such as United States Army Corp of Engineers (USACE),[22,23] and the American Society of Civil Engineers' (ASCE) biennial waterpower engineering conference. The most recent, comprehensive guide to DO mitigation technologies includes descriptions of each method, working examples, engineering costs, design principles, and industry examples.[21] Much of the information in Table 3-2 was extracted from this guide.

At least a dozen wholly distinct DO mitigation methods exist and have been applied at hydroelectric installations in the United States and other countries. Some of these techniques are similar in principle or mechanism, such as the use of oxygen diffusers in the tailrace and in the reservoir hypolimnion; but because they differ in point of application and immediate objectives, they are considered in this report to be distinct. Figure 3-8 illustrates a generic hydroelectric reservoir, dam, and tailwater, and indicates the locations where 12 of these well-known mitigation technologies are commonly applied. Table 3-2 presents descriptions, advantages, and disadvantages of these technologies. All systems have been tested to varying degrees, although some methods have been tested only in pilot studies or have been applied primarily in wastewater treatment or other nonhydroelectric generating situations. Some methods, such as spill flows and turbine aeration, appear to have become popular among hydro license holders (following paragraphs).

Frequency and Type of Requirements. The analysis of DO mitigation requirements presented in this section is based on a systematic study of the target population of hydropower projects licensed during the 1980s and identified

Table 3-2. Dissolved oxygen (DO) mitigation technologies.

Technology	General advantages	General disadvantages
(1) Tailrace weirs: structure built zig zag across a tailwater, typically resulting in headloss of 2–5 ft and plunge pool of 4–10 ft, where air is entrained as water is exposed an mass transfer occurs when the nappe impinges on the tailwater and bubbles are submerged for some residence time.[21,24]	Can produce large (5+) mg/L increases in DO,[21] be relatively maintenance free, and require no direct energy expenditure. Can be used especially beneficially when there is "free head" available,[24] and to achieve both minimum flow and aeration objectives.[25]	Capital cost can be high and efficiency low (depending on height of weir). Power and head loss can be induced, and performance may be difficult to predict.[21] Safety problems in the plunge pool must be considered in design. Weirs are non–navigable and can require excessive crest height for high flow applications.[25]
(2) Submerged tailrace diffuser: an air–supplied diffuser array anchored in the tailrace, supplied by compressed air from the stream bank.[21]	Diffusers have been widely accepted as aeration devices and may have some stream applicability. High diffuser efficiencies (17–35%) have been reported.[21,24]	Low transfer efficiencies can occur because of shallow tailwater depths. Diffuser systems can have high initial costs and possible maintenance problems,[24] and can require large tailwater areas.[21]
(3) Surface tailrace aerators: these supply air by negative head produced by the rotor — oxygen is transferred by surface renewal and interchange .[24] *Aspirating* surface aerators are mounted at an angle to the surface and direct a strong mixing current of air and water downward.[21]	Considered highly applicable to stream reaeration except where they may pose recreational or aesthetic hazards,[24] and may especially be suitable for smaller flow volumes, or for large flows with small oxygen deficits. Performance of such aerators is fairly predictable.[21]	Initial equipment cost can be high .[24] Sites with shallow tailwater depths (<10 ft), flows lower than 2000 cfs, or oxygen deficits greater than 3 mg/L may require considerable surface areas for efficient operation.[21]
(4) Reservoir epilimnion pumps for intake aeration or local destratification: a floating platform fixed to the dam or shore with a motor connected to a submerged impeller, capable of moving large volumes of warm, oxygen–rich epilimnetic water at low velocities into the withdrawal zone.[21]	Field applications of localized mixing in reservoirs, near hydroturbines, demonstrates that it can be simple and cost–effective.[26] The working principles are well–documented and tests have been favorable.[21]	This technology can be difficult and costly to install. Reservoir sediments can be disturbed and coldwater releases that may support downstream fisheries can be eliminated.[21] This technology can be constrained when reservoir depths are less than 150 ft or during low surface DO episodes (e.g. caused by high respiration and low photosynthesis).[17]
(5) Air or oxygen injection in forebay (intake aeration): fine bubble diffuser systems located within the withdrawal zone of the intake, supplied with pure oxygen, which takes advantage of high pressures in the forebay to increase oxygen transfer and of local currents to aerate only water that passes through the turbine.[21]	Well-suited for high-head, high hydraulic capacity (>3,000 cfs) with large DO deficits (>4 mg/L) where energy revenue is important. Oxygen transfer efficiency can approach 100% with sufficient depth. Only water which passes through turbines need be aerated.[21]	Improper location of the system can lead to problems associated with incomplete adsorption of oxygen (e.g. corrosion in the turbine systems and unoxidized hydrogen sulfide).[21,17] These systems must be sized for the project's maximum hydraulic capacity at highest DO deficit.[21] Oxygen, not air, must be used in deep reservoirs due to N-supersaturation possibility.[27]

Table 3-2. (continued).

Technology	General advantages	General disadvantages
(6) Turbine draft tube venting: injection ports in draft tube immediately downstream of turbine are used to introduce air into the flow, taking advantage of high turbulence.[21]	This method uses existing (or modified) structures and is therefore advantageous.[21,24,28] Draft tube venting is sometimes already used to effectively control cavitation and swinging in high-head installations.	Oxygen uptake potential is limited. Generator output will be reduced by 1-5%, and installation of apparatus can be difficult and expensive.[21] Performance is difficult to predict accurately.[17]
(7) Turbine venting through vacuum breaker system: air passage through the turbine head cover with exit ports on the turbine hub. Hub baffles over the ports can be used to increase suction.[21]	Similar to draft tube aeration.	Disadvantages are similar to those for draft tube venting. Also, this type of venting has been associated with increased cavitation damage on older turbine runners and increased wear on turbine bearings.[21]
(8) Selective withdrawal: the withdrawal of water from selected reservoir depths where DO (and temperature) may be desirable. Structures used to accomplish selective withdrawal include wet wells and submerged weirs.[21]	Can be well suited for small (<15 MW) projects; applications at large projects (>500 MW) also exist. Makes use of stratification in reservoirs with high epilimnetic DO, and can be low-cost.[21,29,30]	Most prior uses of selective withdrawal have been at non-hydro sites. Release temperatures may rise and interfere with tailwater fisheries objectives. Retrofit for selective withdrawal is difficult and costly, and this method is inappropriate for sites with large reservoir level fluctuations or for some navigation projects.[21]
(9) Reservoir destratification: this method involves the input of mixing energy (mechanical pumping or compressed air systems) at the deepest point in the reservoir to break down the thermal and chemical stratification that contributes to hypolimnetic DO depletion.[21]	Destratification can be inexpensive and performance can be closely predicted especially in small reservoirs. It can be effective especially when used to prevent initial stratification, and can also prevent related water quality problems[21,31] or control undesired effects of cold hydropower releases on tailwaters.[24]	Application can be difficult at large, high-flow projects,[17] can affect reservoir fisheries by changing habitat characteristics, can disturb sediments, and may be incapable of achieving DO standard.[21] Energy requirements for this technology can be prohibitive.[24]
(10) Hypolimnion aeration: the hypolimnion of a reservoir is aerated or oxygenated through systems of diffusers submerged and anchored in the reservoir.[21]	This technology is considered suitable for large storage / peaking impoundments (volume >3,000 ac-ft) with cold tailwater fisheries. Pure oxygen use is efficient and avoids nitrogen supersaturation problems. Use of the hypolmnion as storage for aerated water may reduce the required capacity of the system. Reservoir water quality can benefit (e.g. through oxidation of hydrogen sulfide and dissolved iron).[21,17]	Hypolimnion aeration is not considered suitable for large run-of-river projects where the system would have to be sized for maximum hydraulic capacity of plant. It is crucial to closely estimate hypolimnetic oxygen demand and rates of oxidation. The highest cost item is pure oxygen.[21,17]

Table 3-2. (continued).

Technology	General advantages	General disadvantages
(11) Spill flows and other turbine bypass flow aeration techniques: spill flows involve the non-power release of water over spillways, via bypass valves, through gated conduits, or other hydraulic structures.[21]	The performance of spill flows can be accurately predicted.[21] Spill flows can be suitable at small projects (<15 MW) where costs of artificial aeration are high and the extent of DO problems is limited or uncertain. Existing structures can often be readily modified for aerating capability.[18,32,33]	Lost power revenue can make this technology economically undesirable. Spill flows can increase wear on bypass structures, and the costs of adding bypass structures can be.[21]
(12) U-tube aeration and other sidestream injection methods: U-tubes divert a portion of water flow downward in a deep entering channel and upward into an exit channel; air is introduced at the top of the downward channel.[21,24]	Sidestream injection techniques are considered to hold much promise, particularly for run-of-river applications, for saturating a flow with oxygen at reasonable costs.[21,17]	No applications of these technologies are available at a scale comparable to hydro tailwaters; these methods are considered experimental or developing.[21,17]
(13) Reservoir water quality management: the reduction of point and nonpoint sources in watershed and inflows of organic material and nutrients that lead toward eutrophication and anoxia in reservoirs.	No documentation available.	Additional treatment of point sources, beyond levels achievable by modern secondary treatment and effluent standards, is costly, and such additional treatment may not lead to measurable improvements in DO in hydropower releases.[34]
(14) Operational considerations for hydropower turbines: measures to control tailwater DO, such as strategic choice of which and how many turbines to operate.[17]	Measures such as these lack capital or maintenance expenses and can contribute at a substantially reduced cost the balance of tailwater aeration needed to achieve a fixed numerical standard.[17]	Operational considerations alone may not be sufficient to meet a specified numerical DO standard.[17]

a priori to have water quality requirements. Results and conclusions are applicable industry-wide to the extent that the sample reflects the characteristics of the target population.

In total, our sample contains information on 56 projects that operate DO mitigation (Figure 3-9). Mitigation information was obtained from 43 projects in the target population. In addition, thirteen projects from the target population that, according to FERC records, do not have a water quality requirement (but had a fish passage or minimum flow requirement) also reported on their DO mitigation.

Of the 56 projects providing information, most have a capacity below 50 MW. Thirteen projects are less than 1 MW, 17 are between 1 and 10 MW, 21 are between 10 and 50 MW, 2 are between 50 to 100 MW, and 3 are greater than 100 MW. The distribution of these projects into project generating capacity classes and into geographic regions matches broad patterns in the target population. In terms of project size, our sample well reflects the target population bias away from extremely small (<1 MW) projects

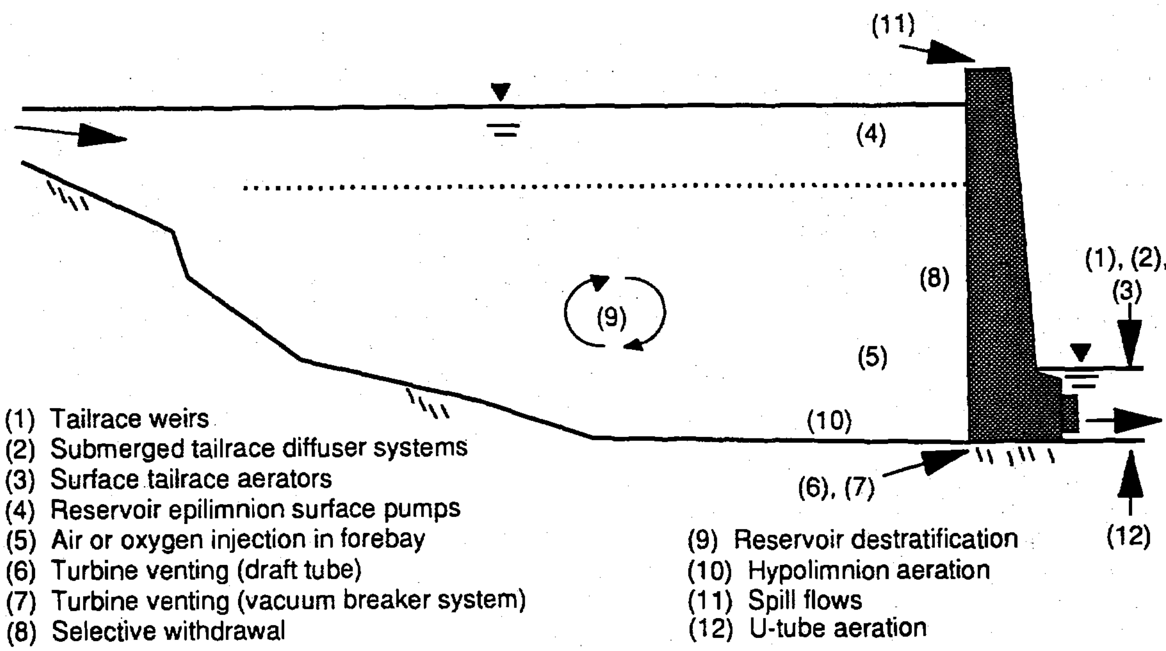

Figure 3-8. Dissolved oxygen mitigation technologies and their points of application, shown on a schematic hydropower reservoir, dam, and tailrace.

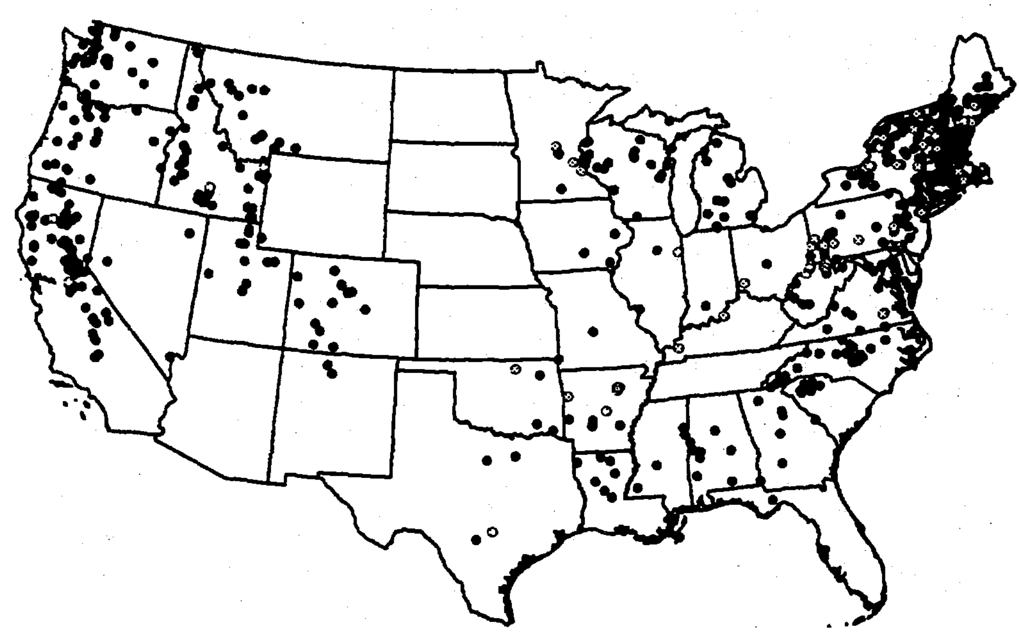

Figure 3-9. Distribution of sample of target population projects with dissolved oxygen requirements. Light-shaded points are members of sample, black-shaded points are all other projects in target population.

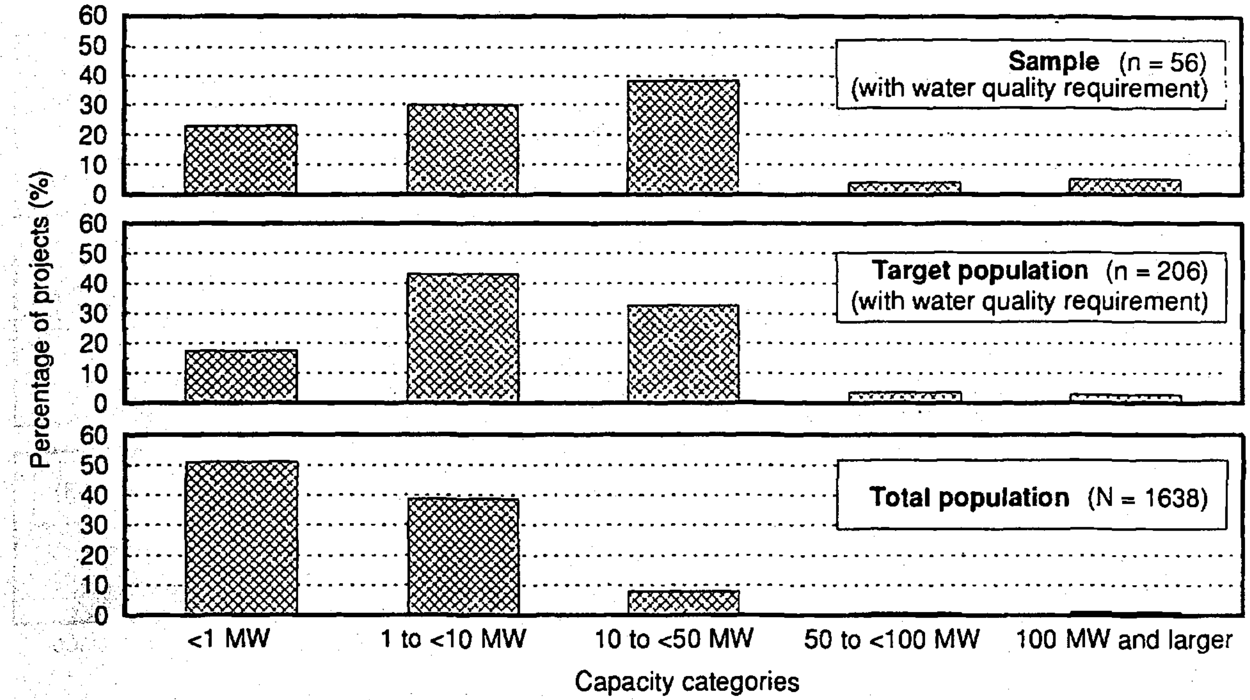

Figure 3-10. Distribution of total population, target population (with water quality requirements), and sample (with water quality requirements) projects, in megawatt capacity classes. Based on data from Federal Energy Regulatory Commission data sets (described in Section 2) and on information provided by developers.

and toward small to medium hydro (1 to 50 MW). However, our sample overrepresents the 10 to 50 MW group, while underrepresenting the 1 to 10 MW projects (Figure 3-10). In terms of project regions, our sample in a broad sense reproduces the pattern of bias in the New York and Atlanta regions. However, our sample has a far higher proportion of observations from the New York region than the proportion for this region in the target population, and a lower proportion of observations in the Atlanta and San Francisco regions (Figure 3-11). The most significant point to be kept in mind in the following discussions is that projects from the New York region are substantially overrepresented.

Frequency of Mitigation Method. Spill flows and turbine aeration are the most common mitigation methods among the sample of projects with DO mitigation (Figure 3-12). Of the 53 projects providing information on mitigation methods, 66% indicated that spill flows had been selected as the sole mitigation measure or as one of several measures. Six percent indicated spray devices had been selected, 9% indicated intake level controls, 6% indicated reservoir water quality improvements, 28% indicated turbine aeration, 9% indicated tailrace aeration, and 11% indicated some other method. "Other" methods include the use of tailrace aeration weirs, intake aeration, reservoir destratification, and operational constraints. No developers indicated that reservoir aeration had been selected as a mitigation technology. A combination or a set of alternative mitigation technologies had been selected at 25% of the projects.

Figure 3-13 displays the distribution of mitigation types in project capacity classes (<1 MW, 1 to <10 MW, 10 to <50 MW, 50 to <100 MW, and >100 MW). For all projects under 50 MW, spill flows are much more frequently selected than other methods. Turbine

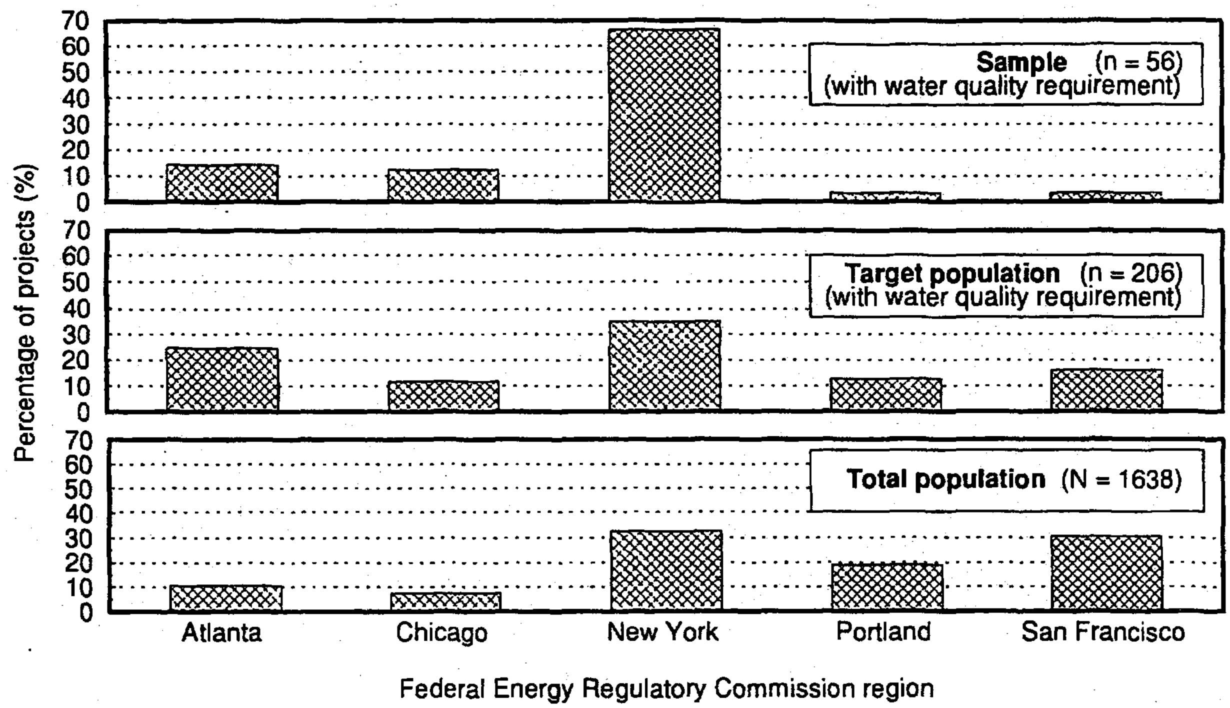

Figure 3-11. Distribution of total population, target population (with water quality requirements), and sample (with water quality requirements) projects, in Federal Energy Regulatory Commission (FERC) regions. Based on data from FERC data sets (described in Section 2) and on information provided by developers.

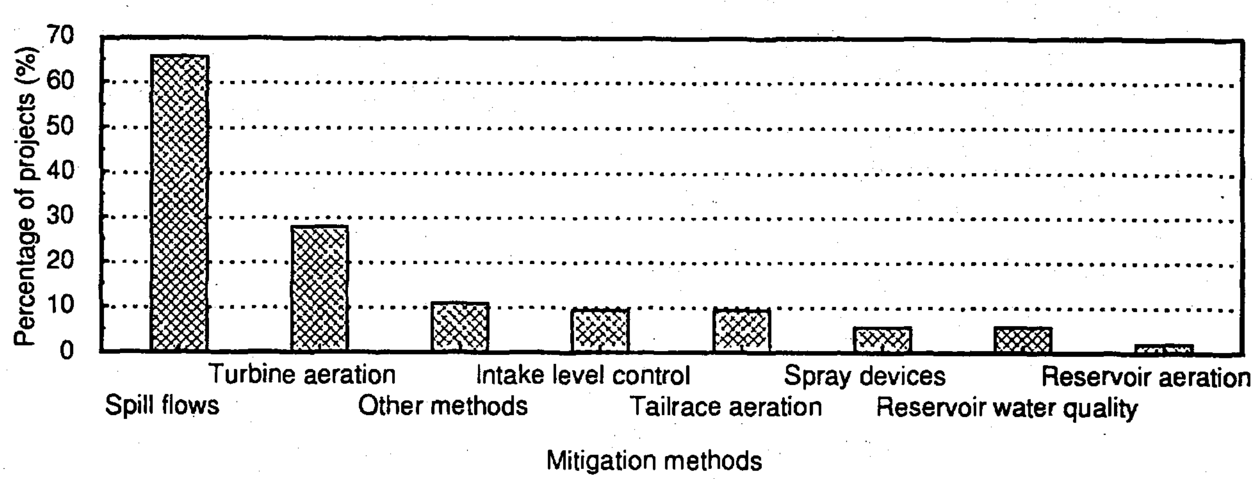

Figure 3-12. Frequency of dissolved oxygen mitigation methods, based on information provided by developers.

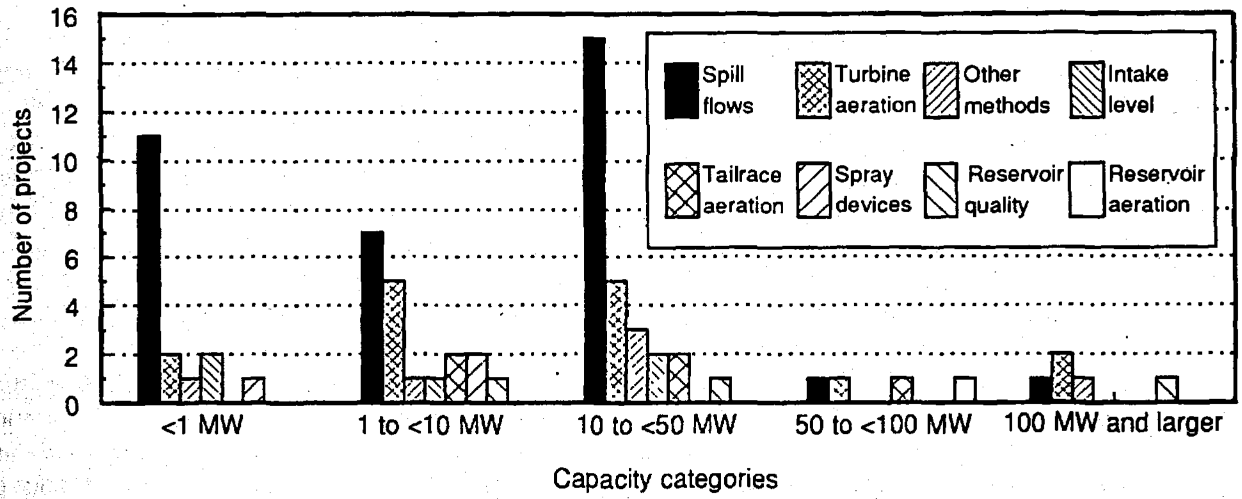

Figure 3-13. Frequency of dissolved oxygen mitigation methods, by project capacity category, based on information provided by developers.

aeration is selected frequently among developers of projects between 1—50 MW. Other aeration techniques, such as intake level control (selective withdrawal), reservoir aeration, or improvements to reservoir water quality, were infrequently selected by developers of all sizes of projects.

The overwhelming preference toward spill flows as a mitigation measure deserves discussion, since the costs of spill flows in foregone power generation can by far exceed total costs of virtually all other mitigation options. Developers providing information for this report indicate that spillage for aerating tailwaters can cause losses of more than 30% of total annual power production (see Section 4).[21] Although other mitigation technologies may have greater capital costs, they typically do not involve substantial losses of power production potential.

This pattern may be attributed to several factors. First, projects from the FERC New York region in this sample almost invariably use spill flows as one mitigation method; projects from the New York region account for 81% of projects in this sample using spill flows. Thus the prevalent use of spill flows may be explained in part by a regional bias in the sample and by the very high frequency of spill flow use in the overrepresented region.

Second, FERC commonly requires continuous spill flows to mitigate DO problems at low-head projects.[35] As Figure 3-10 illustrates, most of the projects considered in this study were small (over half with capacity <10 MW). FERC policy may explain much of the preference toward spill flows.

Spill flows, moreover, may be attractive to small hydro developers because other technologies require prohibitive capital investment. Such capital investments appear especially inappropriate when the frequency and severity of sub-standard DO periods are uncertain or low[18,36]; and developers may only rarely have to implement mitigative spill flows. In addition, the oxygen transfer efficiency of spill flows is highly predictable and reliable, compared with that of other mitigation methods like reservoir destratification.

It is also possible that developers and their contractors are unaware of the variety and effectiveness of alternative mitigation strategies, or are hesitant to invest in technologies that are not as well tested (see Table 3-2). Selective withdrawal, for example, has been identified as an economically feasible option for small developers where facilities exist and where lake stratification occurs,[18] but only 9% of developers indicated that intake level modifications were used to mitigate DO problems. Reservoir destratification has also been highly regarded as an economical and efficient mitigation method, but was rarely identified by developers.

Another reason that spill flows are used so frequently may be that spill flows and other bypass flows can be used to provide instream flows for fisheries and other purposes. This expectation can be explored by examining information provided by hydro developers for this study. Of the 53 projects providing information on DO mitigation methods used, 23 have a concurrent instream flow requirement. Of this group with a concurrent instream flow requirement, 78% use spill flows. This is in contrast with the 66% of all projects with DO mitigation that use spill flows (Figure 3-12). Clearly, the frequency with which spill flows are selected as the DO mitigation method is higher for projects with a concurrent instream flow requirement. This result suggests that the observed general preference for spill flows as a DO mitigation method may be explained in part by the usefulness of spill flows for IFN.

However, of the 30 projects that perform DO mitigation and do not have a concurrent instream flow requirement, a clear majority (57%) still use spill flows (the next most popular method is turbine aeration, employed at 27% of the projects in this group). This result suggests that spill flows' usefulness for IFN does not entirely explain the popularity of spill flows as a DO mitigation method among hydro developers.

Mode of Operation. Of the 53 developers reporting on mitigation technology, 45 provided information on when the mitigation is used (Figure 3-14). Of these 45, 40% report that mitigation is used at all times, 38% report that mitigation is implemented only when necessary (e.g., when DO monitors indicate that DO levels in releases or upstream of the intakes has fallen below a critical level), and 9% indicate that mitigation is used only during a specified season. Mitigation methods are reported to be used seasonally, only when necessary, at 13% of these projects. Significant differences in power losses and operating costs can be involved when, for example, a spill flow is maintained only during episodes of sub-standard tailwater DO, or if it is maintained continuously throughout the summer. It appears that a large fraction of projects with DO mitigation are required, or choose, to mitigate only when a DO problem occurs; but an

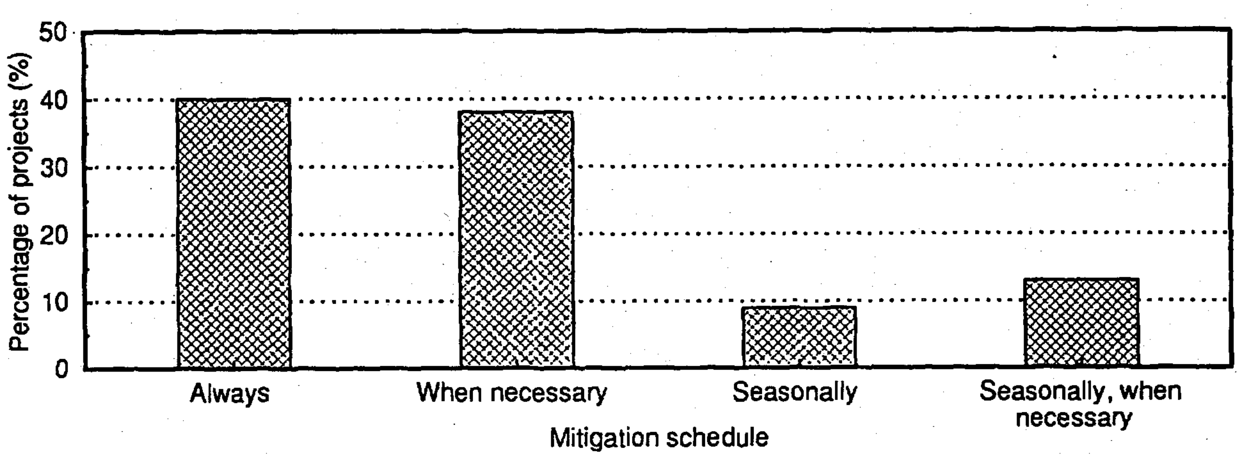

Figure 3-14. Times when dissolved oxygen mitigation must be implemented, based on information provided by developers.

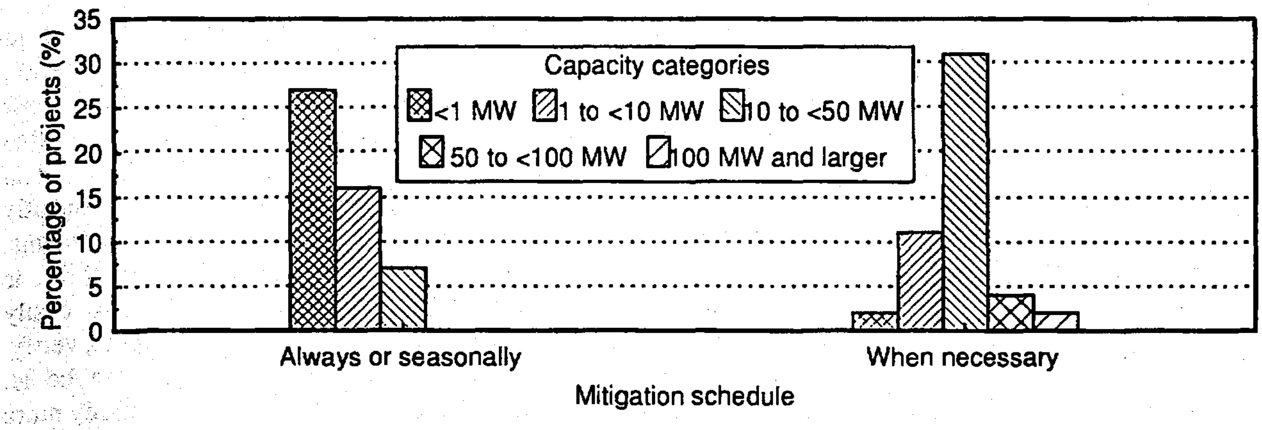

Figure 3-15. Times when dissolved oxygen mitigation must be implemented, by project capacity category, based on information provided by developers.

almost equally large group are required, or choose, to mitigate even at times when it may not be needed. It appears that smaller capacity hydropower projects have more stringent DO mitigation requirements (Figure 3-15); of all projects required to mitigate at all times or over a season, the majority are <10 MW. Of the projects required to mitigate only when necessary, the majority are >10 MW.

Policies and Objectives. Fifty-four developers provided information on the objective of the mitigation (Figure 3-16). Multiple mitigation objectives were reported at 41% of these projects. Developers at 76% of the projects indicated that maintenance of state water quality standards were a mitigation objective, 9% indicated state antidegredation objectives (i.e., compliance with requirements, usually applied to selected waterbodies, that no degradation of water quality be allowed), 9% indicated state site-specific standards, and 39% indicated fish and wildlife agency management objectives. Eleven percent indicated that FERC determined

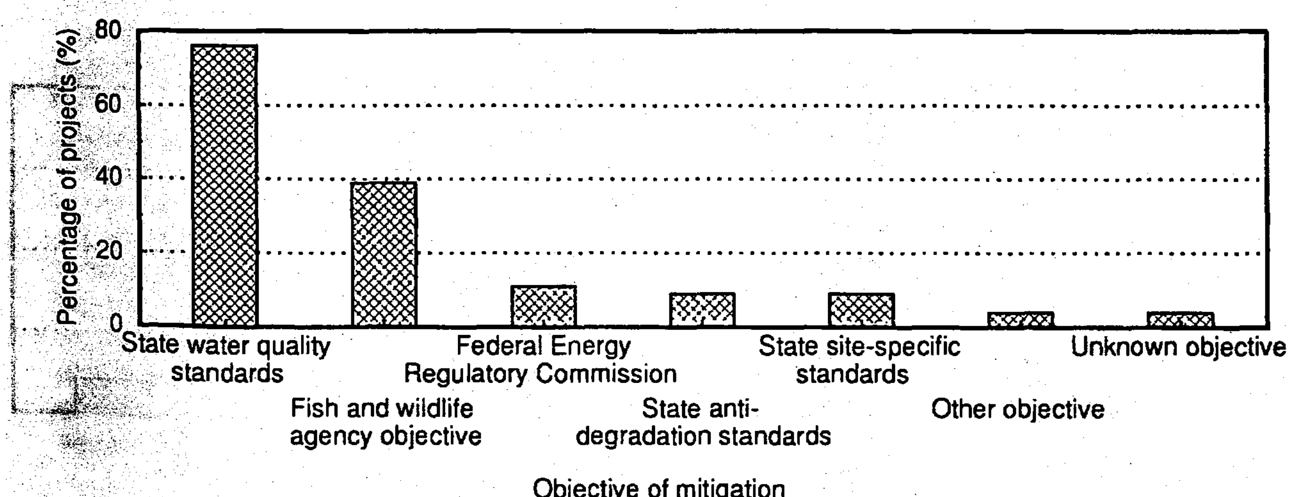

Figure 3-16. Objectives of dissolved oxygen mitigation requirement, based on information provided by developers.

the DO objectives, 4% indicated other objectives, and 4% indicated that water quality objectives were not clarified during the licensing process. It is apparent that compliance with state water quality standards is the most common purpose of DO mitigation. It is also interesting to note that antidegradation requirements have rarely been applied to hydropower projects, but many projects report having DO mitigation at least partially as a result of fisheries agency concerns.

Forty-eight of the 56 respondents provided information on specific DO requirements. Eighty percent indicated a specific chemical DO requirement; these range from 4 mg/L to 7 mg/L (Figure 3-17). In some cases, the chemical DO requirement or objective was stated as a percent saturation or as an unspecified state DO standard. The variety in DO criteria reflects, among other things, differences among state DO standards.

Method Used to Determine Mitigation Requirement. Fifty-four developers provided information on the method of study used to determine license requirements (Figure 3-18). Forty-six percent of those projects providing information indicate that pre-startup or early water quality monitoring was the only basis for the DO requirement. A modeling study was the only basis for determining the need for DO mitigation at 15% of the projects. As many as 13% of the projects indicated that both monitoring and modeling work were used to determine the license requirement. At 13%, professional judgment was the basis for determining the need for DO mitigation. Nine percent indicated no studies were used. It is noteworthy that monitoring is most frequently used to determine DO mitigation requirements, because it has been suggested that monitoring is expensive. DO modeling, while also costly because monitoring is needed to calibrate, verify, and provide input for the model, can be an appropriate, less expensive, and potentially more useful method for determining the nature and extent of a DO problem and the need for DO mitigation.[18]

The cost of inappropriate mitigation can far exceed the costs of conducting effective studies. Moreover, pre- and post-operational reservoir and tailwater quality monitoring and modeling can be very useful in identifying optimum strategies. For example, one developer reported that a 150 cubic feet per second (cfs) spill flow was assigned, based on professional judgment, to a 1 MW project in New York. This spill flow represents a large portion of flow available for power generation. However, a subsequent water quality monitoring study demonstrated that although turbine releases cause some DO reduction, DO stays well above the minimum standard even in the absence of spill flows.

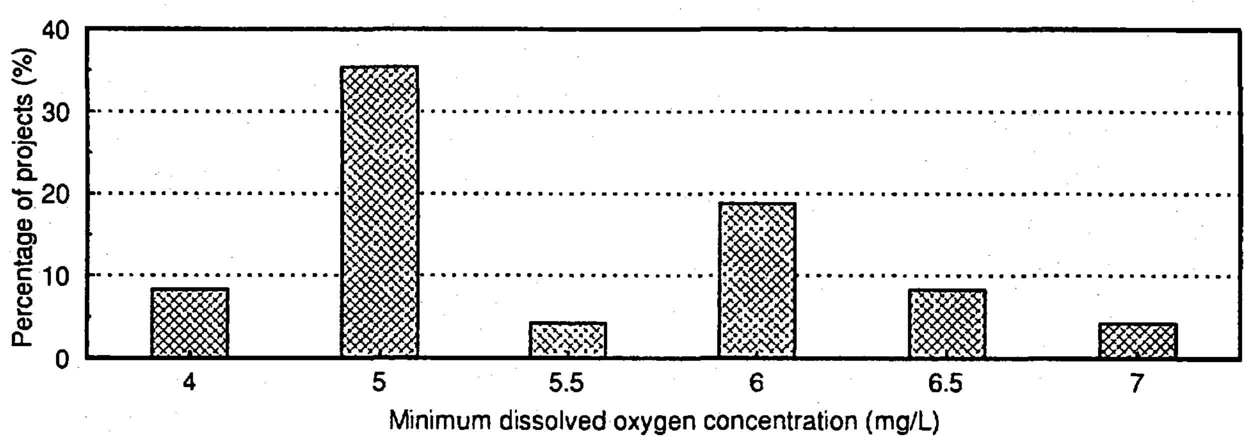

Figure 3-17. Dissolved oxygen standards for reservoir releases, based on information provided by developers.

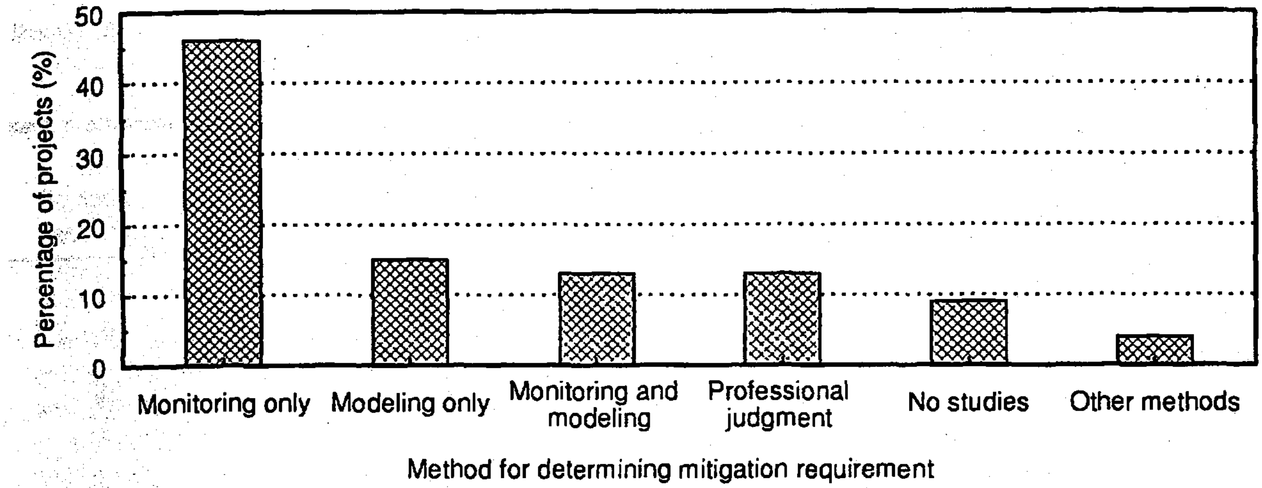

Figure 3-18. Method of study used to develop dissolved oxygen mitigation requirements, based on information provided by developers.

Agency Positions on Dissolved Oxygen Mitigation. The positions of state and federal resource agencies on DO mitigation at hydropower developments was solicited with the Agency Information Requests, described in Section 2 of this report. State agency responses on DO mitigation policies are summarized in Table 3-3 and are presented in greater detail in Appendix B. Responses from federal agencies are also discussed below, with data presented in Appendix B.

Of 36 states for which policy information was received, about 40% (14 states) have a written policy (Table 3-3) applicable to DO mitigation at hydropower developments. Nearly 60% of states responding to the question indicated that state water quality standards were the objective of mitigation; about 30% cited antidegradation objectives, and only 16% cited other fish and wildlife objectives of mitigation (Table 3-3). However, when state standards were indicated, the response was often worded similarly to "the objective of mitigation is to maintain state water quality standards which protect fish and other aquatic life."

Of the 28 states that provided information on method(s) used to determine a need for DO mitigation, 43% cited water quality monitoring as one of the methods, 29% cited modeling as one method, and 14% cited professional judgment as one method. As from the information obtained from developers, it appears that water quality monitoring to determine the need for mitigation is the most common method; however, the information from the agencies suggests that modeling is more frequently employed than the information from the developers indicates (Figure 3-18).

Federal resource agency (EPA, FWS, NMFS) positions on hydropower mitigation were also examined in this study. Information obtained suggests that while federal agencies can and do play a vigorous role in setting DO mitigation objectives, they do not do so consistently.

The FWS is directly involved in studies to determine the need for DO mitigation at hydro projects, performing onsite direct measurements and monitoring in addition to reviewing historical water quality data and existing information in at least one region. Although this level of involvement is probably exceeded in other regions,[37] responses from other FWS regions indicate that this is not always true (Table B-4). In general, the responses from many offices of federal resource agencies indicate that the agency is not directly involved

Table 3-3. Numbers and percentages of state resource agency responses to agency information request regarding dissolved oxygen (DO) mitigation (see Appendix B for additional information).

	Percent responding "yes"	Number of responses
Written DO mitigation policy	39	36
DO requirements for FERC-licensed projects	57	30
Professional judgment used as a method to determine the need for DO mitigation at a project	14	28
Water quality modeling used as a method to determine the need for DO mitigation at a project	29	28
Water quality monitoring used as a method to determine the need for DO mitigation at a project	43	28
States citing state water quality standards as the objective of DO mitigation	58	31
Antidegradation standards are the objective of DO mitigation	32	31
Other fish and wildlife objectives are the objective of DO mitigation	16	31
Spill flows suggested as a mitigation method or one of several methods	41	27
Turbine aeration suggested as a mitigation method or one of several methods	22	27
Improvements to reservoir water quality suggested as a mitigation method or as one of several methods	15	27
Intake level control suggested as a mitigation method or as one of several methods	26	27
Studies of DO mitigation effectiveness with respect to water quality	17	30
Studies of DO mitigation effectiveness with respect to biological endpoints	13	30
Studies of DO mitigation effectiveness, with endpoint unspecified	17	30
Total number of states with studies of DO mitigation effectiveness[a]	40	30

[a]Some states reported both biological and water quality effectiveness studies.

at hydropower sites, but primarily reviews information provided by other resource agencies and by the developer (Table B–4).

None of the federal agencies cited policies specific to dissolved oxygen problems at hydropower projects; no written policies at all regarding mitigation at hydropower projects were cited by responses from EPA respondents. In contrast, FWS involvement in hydropower mitigation issues is governed by two policies: a Mitigation Policy published in 1981, and a more recent Hydropower Policy drafted in 1988 and as yet in review.[12] The goals of the FWS' Mitigation Policy are to clarify the agency's objectives and approaches to protecting and conserving important fish and wildlife resources while facilitating balanced development of the nation's natural resources.[11]

The underlying goal of the FWS Hydropower Policy is to "ensure that hydropower projects are planned and implemented with full and equal consideration for the protection, mitigation, and enhancement of fish and wildlife resources. The intended effect of this policy is to protect and conserve the most important and valuable fish and wildlife resources while meeting the Nation's energy demands."

Protection of fish and wildlife resources, rather than the protection of water quality criteria, are the driving objectives of the agency. The distinction between fish and wildlife objectives and state water quality objectives is important. Pursuit of fish and wildlife objectives can be much more complex, requiring greater agency involvement, data, and analysis, than pursuit of a simple numerical dissolved oxygen standard (e.g., 5 mg/L).

However, state water quality objectives only were identified as the mitigation objective by the EPA and by several of the FWS offices. Descriptions of respondents' objectives behind involvement in hydro DO mitigation issues read similarly to, in a number of cases, "maintain state ambient water quality standards". In some cases, the issue of water quality problems at hydropower plants is deferred to state water authorities. Variability in the stated policy and objectives of agency involvement in mitigation probably leads to variability in the degree to which agency offices are involved in the determination of mitigation requirements.

Fish Passage Requirements

Hydropower projects can affect fish by blocking their movements in both upstream and downstream directions. These movements are most important to anadromous and catadromous fish, which spend part of their life cycles in rivers and part in oceans or other large waterbodies such as the Great Lakes. Other fish species can migrate long distances within a river. For fish trying to move upstream, a dam can pose an impassable barrier unless mitigation is provided. Fish moving downstream are likely to be entrained in the turbine intake and may be killed by the turbine if downstream passage mitigation is not provided.

Mitigation practices that are intended to facilitate upstream and downstream movement of fish are described in this section, including background information on fish passage mitigation, current fish passage practices (as determined from the information requested from project developers), and agency positions on fish passage mitigation.

Background on Upstream Fish Passage. The blockage of upstream fish movements by hydroelectric dams may have serious impacts to species whose life history includes spawning migrations. Anadromous fish (e.g., salmon, American shad, blueback herring, striped bass), catadromous fish (e.g., eels), and some resident fish (e.g., trout, white bass, sauger) could all have spawning migrations constrained by such barriers as hydroelectric dams. Maintenance or enhancement of these species may require the construction of facilities to allow for upstream fish passage.[1] Descriptions of the basic types of upstream fish passage measures are provided in earlier reviews.[38-42] Upstream passage measures can be placed into three general categories: trapping and hauling, fishways, and fish lifts.

Trapping and hauling is a labor-intensive mitigation measure that can be used when fish need to be transported long distances upstream or around a large number of obstacles. Upstream-moving fish may be collected at a single location (e.g., the farthest downstream dam) and transported by tank truck to upstream stocking locations. The techniques and factors important to the survival of transported fish are relatively well understood[38] based on experience with hatchery fish, where collection of fish in the raceways is relatively easy. It is less efficient as a method for moving wild fish past a dam because collection is more difficult and target fish may be present in the vicinity of the dam in large numbers for only short periods of time.

Fishways (or fish ladders) are widely used to transport fish above single obstacles such as dams and may also be used to collect fish for hauling to upstream stocking locations. The term *fishway* describes any flow passage that fish negotiate by swimming or leaping; it can be a high-velocity chute, a cascade or vertical waterfall, or an artificial structure such as a culvert, a series of low walls across a channel (weir-and-pool fishway), or merely a chute up which the fish swim.[41] Hydroelectric plants have commonly employed such general types as pool-and-weir, vertical slot, Denil, and Alaska steep pass fishways. The key difference between fishways and the other two categories of upstream fish passage measures is that fishways rely more on the swimming ability of fish to negotiate an obstruction.

The wide variety of fishway designs have been reviewed periodically[38,40,41]. As with the hauling of fish, substantial experience in design and operation of fishways, dating back to early in the last century, has led to the development of standard design criteria.[38,39] There are four general elements that are important to the design of efficient fishways: (a) speed and success of fish passage must be optimized to minimize delay, stress, damage, and fallback of fish; (b) water use should be minimized in order to maximize water for such other uses as power production; (c) the range of stream flows under which the fishway is operable should be maximized; and (d) construction, operation, and maintenance costs should be minimized.[41] Optimizing the first element may be relatively difficult if the goal is to pass a variety of fish species that have different behaviors, sizes, and swimming abilities. For this reason, the most successful (and cost-effective) fishways are often those that can be designed to transport a specific run of anadromous fish that have a uniform size and predictable behavior. Some species (e.g., striped bass, smelt, sturgeon, and blueback herring) are reluctant to pass through fishways.[40] There are, however, numerous examples of nontarget fish species using fish ladders to surmount obstacles.[43-46]

Fish lifts (elevators) and fish locks rely less on active movement of the fish than do fishways. In these devices, fish are attracted to a water-filled chamber or hopper in the tailrace and then are transported passively to the top of the dam. The primary disadvantages of fish lifts or locks are that they have an intermittent mode of operation that can delay upstream-moving fish at the base of the dam and are more susceptible to mechanical problems than fishways. Because of the potential for failure of mechanical parts, automated operation is difficult and, unlike fishways, personnel must be present during operation.[40] A major biological advantage of fish locks and lifts is that they can pass practically all species of fish, including small or weakly swimming fishes. For this reason, locks and lifts may be favored for restoration of such weak swimmers as American shad and blueback herring.[47] Although fish locks have been installed in Europe[39] and South America,[48] they are uncommon in North America.[38,42] Compared to fishways, the capital costs of fish lifts/locks are in the same order of magnitude, O&M costs are higher, water requirements are lower, and the ranges of species that can be transported are broader.[1]

The effectiveness of fish lifts for transporting American shad has been studied at the Holyoke Dam on the Connecticut River.[47] An average passage efficiency of 50% was observed among radio-tagged fish, which was consistent with independent shad passage estimates ranging from 40% to 60% of the total run from 1976 to 1983. Adverse conditions can drastically reduce passage efficiency, however; extended high flows in 1978 reduced passage at the Holyoke fish lifts to 18% of the shad run.[47]

Background on Downstream Fish Passage. A variety of downstream fish passage screening devices have been employed to prevent fish from becoming entrained in the turbine intake flows. The simplest, spill flows, can transport fish over the hydropower dam rather than through the turbines. At the other end of the scale, sophisticated physical screening and light- or sound-based guidance measures are being studied to bypass downstream migrating fish with a minimal loss of water that could otherwise be used for power generation. Extensive reviews of downstream fish passage mitigation measures are available.[38,49,50]. There is presently no single fish protection system or device which is biologically effective, practical to install and operate, and widely acceptable to regulatory agencies.

Increased spillage may be used to flush fish over a dam or through a bypass; this measure may be especially cost-effective when the downstream migration period of a target species is short, when migration occurs during high river flows when water would be spilled anyway, or when spill flows are needed for other reasons, (e.g., to increase DO concentrations or maintain minimum instream flows in a diverted reach). Although the costs of construction and labor are low for this mitigative measure, additional costs are incurred because spilled water is not available for power production.[1] As with any fish passage device, care should be taken to ensure that mortality associated with spillway passage does not exceed turbine passage mortality.

Sluiceways or bypasses are used to transport fish to below the dam, either alone or, more commonly, in conjunction with some other mitigative measure such as screens. If fish tend to be concentrated in the upper portion of the water column, they may use orifices or overflow areas leading to ice and trash sluiceways to bypass the turbine intakes.[50] Designing an effective bypass for low-head dams can be relatively easy, given proper consideration of scale. However, at high dams or where the amount of debris or ice in the water is high, fish may suffer injury or mortality in the bypass channel or pipeline. Criteria for designing effective bypass systems have been described.[51]

A simple and common means of reducing turbine passage of fish is to modify the trash racks that power plants use to prevent large debris from entering the intake. One common modification is the angled bar rack, where the trash rack is set at an acute angle to the flow direction (rather than perpendicular to flow), and individual bars may also be set at an angle to the flow. Water entering the turbine must abruptly change direction as it passes through the angled bar rack. The belief is that fish can sense and avoid this change in direction of the bulk flow and will be guided downstream along the angled rack to a bypass. Frequently, the bars within an angled bar rack are spaced more closely than in a conventional trash rack; spacing between the bars may be reduced from typical values of 8 to 20 cm (3 to 8 in.) to no more than 2.5 to 5 cm (1 to 2 in.). Closely spaced bars will prevent large fish from becoming entrained in the intake flow even if the behavioral guidance aspect of the device fails. Although this measure is commonly employed in the Northeast, many of the installations are relatively recent. There appears to be only one study of the effectiveness of angled bar racks, at the Wadhams hydroelectric project.[52] Only small numbers of Atlanta salmon smolts were tested, but diversion efficiency was good. The effectiveness of angled bar racks at other installations is as yet unknown.

Traveling screens are also used to prevent fish from passing through the turbines. Vertical traveling screens are commonly used at steam electric power plant intakes and rotary drum screens are often used at irrigation diversions; these designs have been modified for hydropower intakes. The most frequently studied traveling screens for hydropower applications are the gatewell screens installed at several dams in the Columbia River basin. These screens are installed in the upper portion of the turbine intake gatewell. Because some downstream migrating salmonids are surface oriented, they encounter the screen and are forced upward into gatewells, where they pass into a flume and are routed either to a collection point (for truck or barge transportation downstream) or are discharged into the tailrace to continue their downstream migration. Five of the USACE dams on the Columbia and Snake rivers now include submersible traveling screens and fingerling bypass systems; plans are in progress to provide similar systems at other dams in the basin.[53] Recent research indicates that there is considerable site-to-site, year-to-year, and species-to species variability in the efficiency of gatewell screens[53]; the high guiding efficiencies of gatewell screens in early applications have been followed by disappointing results at other dams. For example, juvenile chinook salmon bypassed with gatewell screens at the Bonneville Dam second powerhouse had significantly lower survival rates than those which passed through the turbines[54]; it is speculated that predation by squawfish in the tailrace may be a cause of this observation.

A variety of other fish screens have been suggested for hydropower applications, but some are recent developments and few have received the extensive biological testing at hydropower plants that is needed to determine their general effectiveness. Inclined plane screens, vertical punched plate screens, Coanda screens, submersible traveling screens (described above), and cylindrical wedgewire screens have been recommended.[55] One version of an inclined plane screen (known as the passive pressure or Eicher screen) has been installed in a penstock at the Elwha Dam in Washington. In this design, downstream-migrating fish can be diverted out of the penstock and into a bypass. Studies of the diversion and survival of coho and chinook salmon smolts and steelhead yearling smolts have been encouraging.[56-58] A cylindrical screen fabricated of wedgewire has recently been installed at the Arbuckle Mountain Hydroelectric Plant in California.[59] Although there are no bypasses associated with this installation, the narrow openings of 2.4 mm (0.094 in.) between the wires would prevent entrainment of even small resident fish such as juvenile trout. Static angled wedge-wire screens were installed at the Leaburg Dam in Oregon. Biological testing of the screens began in 1984 and is continuing. Initial studies indicate that salmonids >60 mm (2.4 in.) in length are protected by the screen, but large numbers of smaller fry (which are too large to pass through the screen slots) are impinged on the screen and killed.[60]

Barrier nets have been tested at both steam electric and hydroelectric power plants[50] but have not gained wide acceptance. Deployment and maintenance can be very labor intensive. A mesh size sufficiently small to exclude a variety of fish species and sizes will also collect water-borne debris, thereby requiring cleaning and protection from wave action. The usefulness of barrier nets for preventing fish entrainment is being studied at two hydroelectric projects in the Midwest, the Pine Hydroelectric Plant in Wisconsin[61] and the Ludington Pumped Storage Plant in Michigan.[62]

Other mitigative measures depend on fish behavior rather than physical screens to exclude fish from turbine intakes. Behavioral barriers that have been studied include electric screens, bubble and chain curtains, chemical repellents, underwater lights, and sounds. Although the results of studies of these measures have been equivocal,[1] some refinements of behavioral barriers continue to be examined at hydropower plants. For example, studies of the utility of strobe and mercury vapor lights to draw downstream-migrating American shad away from turbine intakes are being conducted at the York Haven plant on the Susquehanna River.[63,64] Strobe lights will be used to repel downstream-migratory salmon at the Mattaceunk Project in Maine; installation of the lights is scheduled to be completed by November 1992, and performance monitoring would begin soon after. In contrast to the nonspecific, high-energy underwater sounds previously found to be ineffective, investigators have begun studied traveling screens for hydropower applications are the gatewell screens installed at several dams in the Columbia River basin. These screens are installed in the upper portion of the turbine intake gatewell. Because some downstream migrating salmonids are surface oriented, they encounter the screen and are forced upward into gatewells, where they pass into a flume and are routed either to a collection point (for truck or barge transportation downstream) or are discharged into the tailrace to continue their downstream migration. Five of the USACE dams on the Columbia and Snake rivers now include submersible traveling screens and fingerling bypass systems; plans are in progress to provide similar systems at other dams in the basin.[53] Recent research indicates that there is considerable site-to-site, year-to-year, and species-to species variability in the efficiency of gatewell screens[53]; the high guiding efficiencies of gatewell screens in early applications have been followed by disappointing results at other dams. For example, juvenile chinook salmon bypassed with gatewell screens at the Bonneville Dam second powerhouse had significantly lower survival rates than those which passed through the turbines[54]; it is speculated that predation by squawfish in the tailrace may be a cause of this observation.

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The choice of mitigative measures is dependent on the species and behavior of fish in need of protection. If the intent of the mitigation is simply to prevent resident fish from becoming entrained in the turbine intake flow, then a physical exclusion device (e.g., angled bar rack, cylindrical wedge-wire screen, barrier net) without bypass facilities may suffice. If there is a need to transport downstream-migrating fish below the dam, then the mitigative measure must also incorporate some means of safely conducting the fish (e.g., through bypasses, trash sluices, collection and hauling). In such cases, not only the intake exclusion device but also the subsequent downstream transport measure must be evaluated for effectiveness.

Frequency and Type of Requirements. This section describes current mitigation practices for fish passage at nonfederal projects. Costs of these mitigation practices are also summarized. The methods used for these analyses are described in Section 2.

Analysis of FERC's HLCTS data base indicated that there are 79 projects where fish passage facilities have been specifically mentioned in the license. These projects are mapped in Figure 3-19. In addition, however, information on fish passage mitigation was requested from 295 other projects where HLCTS indicated that some kind of fishery resource requirements were in the license.

Upstream Fish Passage. Information for 34 projects with upstream fish passage facilities was obtained from hydropower developers. More than 90% of these facilities were either in operation or completed. Figure 3-20 shows the general types of upstream fish passage measures that are employed and their relative frequencies.

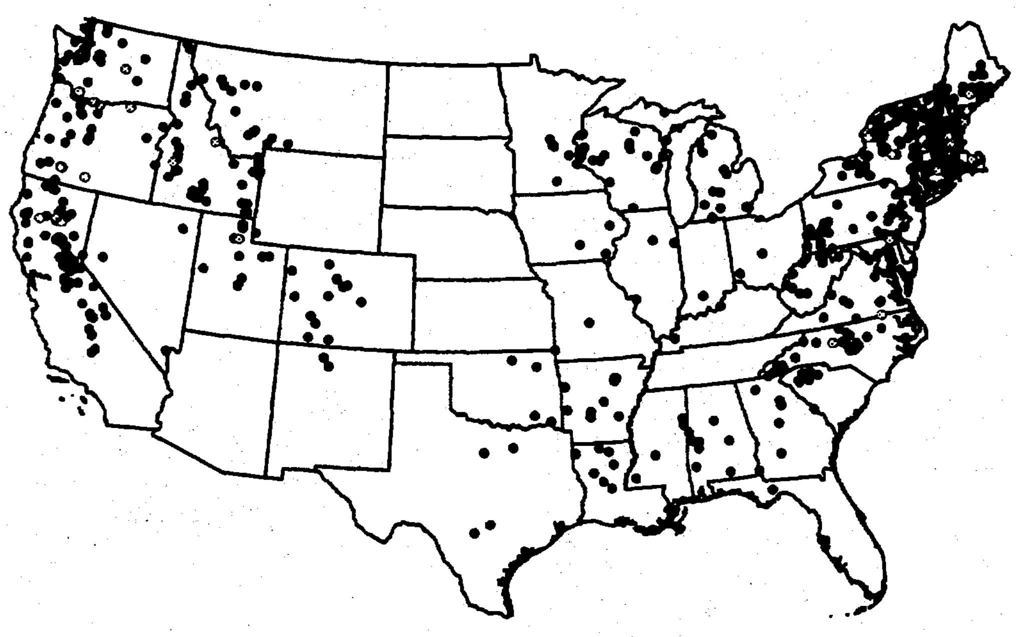

Figure 3-19. Distribution of sample of target population projects with fish passage requirements. Light-shaded points are members of sample, black-shaded points are all other projects in target population.

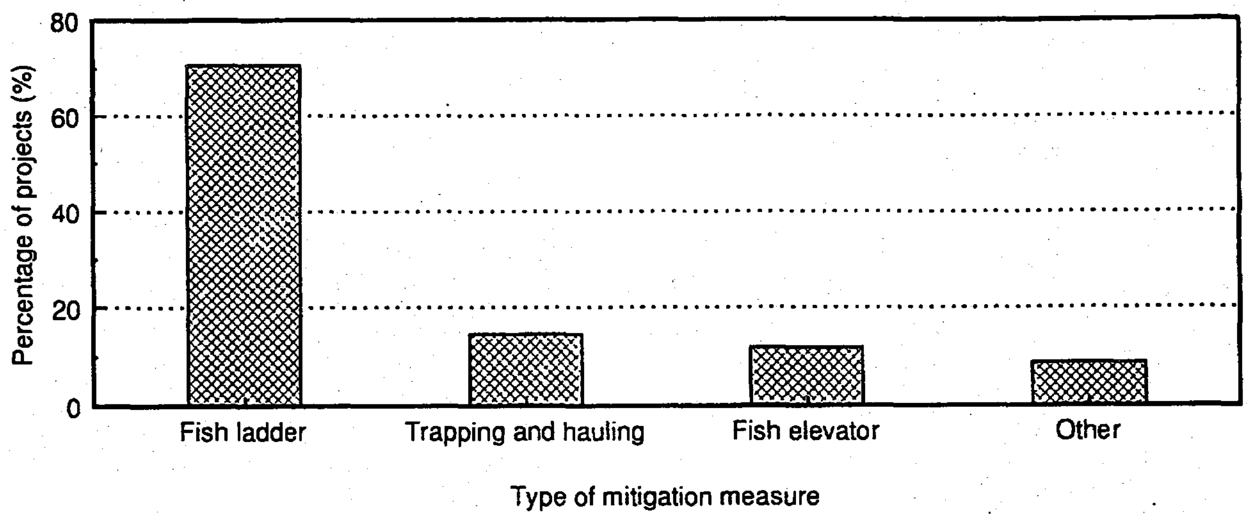

Figure 3-20. Relative frequency of upstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers.

Fish ladders, more than 70% of the upstream passage devices reported, were by far the most common. Fish ladders are employed throughout the United States. Some of the ladders are quite old, dating back to the turn of the century. Fish elevators are a less common (12%) but relatively recent mitigative measure. Trapping and hauling of fish (by trucks) to upstream spawning locations are used at some older dams (15% of the projects with upstream passage facilities) but in two of the projects fish ladders or elevators are replacing this labor-intensive mitigative measure. The "Other" category in Figure 3-20 includes an assortment of upstream passage measures that are used at very few sites, such as berms (to encourage upstream migrating fish to avoid a powerhouse discharge) and the use of navigation locks.

Projects with upstream fish passage requirements were categorized as (1) diversion projects, in which the powerhouse is on a different stream than the diversion dam; (2) run-of-the-river projects, in which the dam is ≤10 feet high and with minimal storage capacity; or (3) storage projects, in which the dam is >10 feet high. Based on information provided by the developers, diversion, run-of-the-river, and storage projects accounted for 17, 75, and 8 percent respectively of the nonfederal, FERC-licensed hydropower facilities with upstream fish passage requirements. Among the 29 upstream fish passage facilities that are in operation, 41% reported that the facilities are in operation at all times (Figure 3-21). Another 35% of the projects reported that the mitigative measure is operated only during specified seasons, whereas 14% are required to operate only during certain hours (e.g., nighttime) during specified seasons.

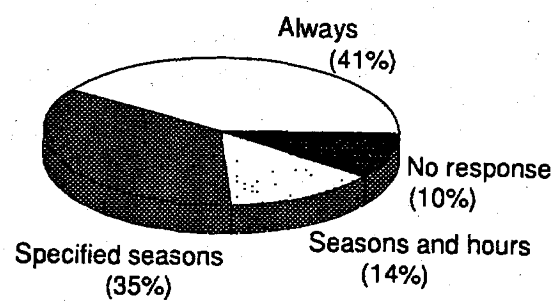

Figure 3-21. Frequency of operation of upstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers. Values in parentheses represent percentages of projects in each category.

Anadromous fish are protected at 68% of projects with upstream passage mitigation (Figure 3-22); 35% of the projects are required to protect only anadromous fish. On the other hand, some hydroelectric projects are required to maintain upstream movements of resident (nonanadromous) fish as well. Thirty-eight percent of the projects reported resident fish passage requirements, and 12% reported only resident fish passage requirements. Not all of these facilities presently transport the fish they were designed to protect. Some upstream passage facilities were installed on the expectation that future fish restoration efforts will result in the need for passage.

In the view of the developers that provided information to the study, professional judgment by the agencies was the most common basis for the incorporation of an upstream fish passage requirement; 50% reported that professional judgment contributed to the requirement, and 35% reported that this was the sole basis for the requirement. Licensee-conducted and agency-conducted studies contributed to the development of the fish passage requirement in 21% and 18% of the projects, respectively. Twenty-four percent of the project operators were not aware of any studies conducted to determine a need for upstream fish passage at their sites. Regarding the role of professional judgment in setting fish passage requirements, it should be noted that in many cases the agency position may reflect knowledge or studies unknown to the developer. For example, the need to pass anadromous fish upstream of an existing dam may have been identified long before submission of a FERC license application. Existing information about the fish community and the effectiveness of fish passage measures at other, similar sites may save the developer both time and financial resources needed to carry out new studies.

Performance objectives are an important part of assessing the benefits of a fish passage facility. Performance objectives can be defined as the measurable benefits provided by a mitigation facility. Benefits may be expressed, for example, as the ability of a measure to extend the upstream range of an anadromous fish species or the ability to pass without mortality a particular number or percentage of fish moving either upstream or downstream. Information was obtained from 30 projects on whether performance objectives were specified for the upstream fish passage measure by the fisheries agencies (Figure 3-23). The majority (57%) indicated that "no obvious barriers to upstream movement" was one of the criteria used to judge effectiveness; 50% reported that this was the sole

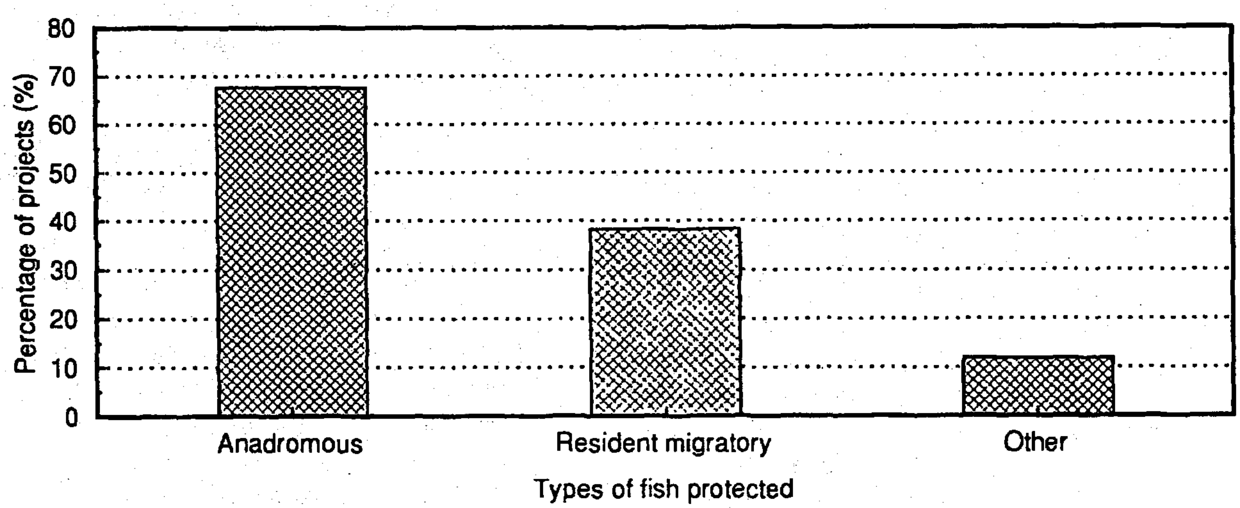

Figure 3-22. Types of fish that are transported by upstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers.

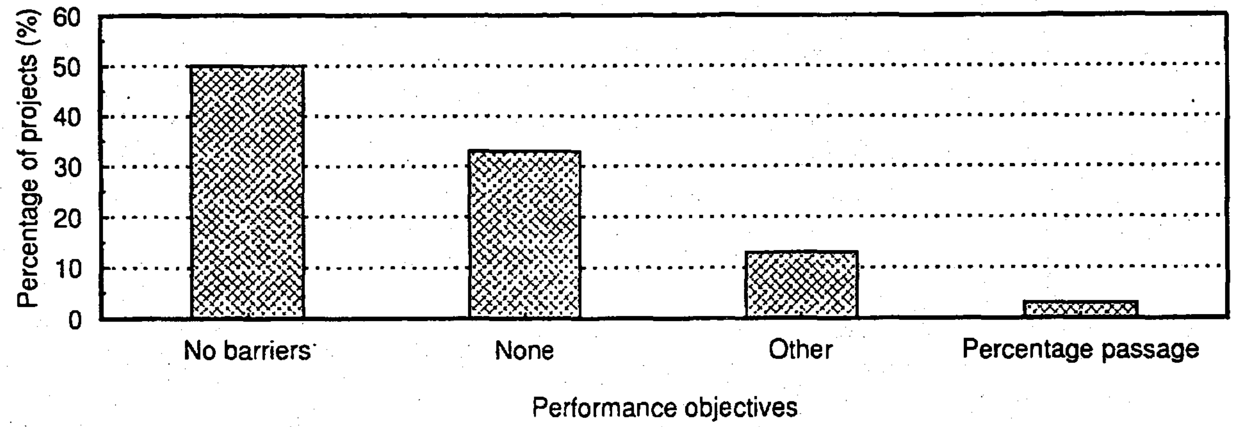

Figure 3-23. Performance objectives for upstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers.

criterion. One facility (3%) was required to pass a specified percentage, and one facility a specified number, of migratory adults. Thirteen percent had some other performance criterion, which generally was consistent with goals of a larger fishery restoration program. Operators of ten of the projects (33%) were unaware of any performance objective for the upstream fish passage measure at their sites.

Downstream Fish Passage. Information was obtained from 85 hydroelectric projects that have downstream fish passage requirements. The fish passage measure is in operation at 68% of these projects. A wide range of measures is employed to reduce turbine entrainment of downstream-migrating fish, some of which are used in combination with others (Figure 3-24). The single most frequently required downstream fish passage device is the angled bar rack. This mitigative measure, in which the trash rack is set at an angle to the intake flow and the bars may be closely spaced (ca. 2 cm), is commonly required in the Northeast. Angled bar racks are used by 38% of the projects with downstream passage facilities. Other types of fixed fish screens (34% of the projects) range from variations of conventional trash racks (e.g., use of closely spaced bars) to more novel designs employing cylindrical, wedge-wire intake screens. Traveling screens are used at three of the projects (4%); these screens are commonly installed in the gatewells of large hydroelectric projects.

Intake screens of all kinds may have a maximum approach velocity requirement and a sluiceway or some other type of bypass (Figure 3-24). The maximum approach velocity is designed to enable fish to avoid being drawn into the turbine intake area; the requirement should reflect the swimming abilities of the fish that are protected. Bypasses or sluiceways may be required because projects on streams with migratory fish must provide a means not only to prevent turbine entrainment (e.g., by screens) but also to transport the fish below the dam. In some cases a properly designed trash sluiceway may serve to transport screened fish safely downstream. Twenty-four percent of the projects have a velocity limit on the intake flows and 22% have a sluiceway or some other form of bypass. Only three of the projects (4%) have a maximum approach velocity requirement as the sole measure to reduce turbine entrainment. Eight of the projects (9%) have a sluiceway or bypass as the only mitigative measure to enhance downstream fish passage.

The other types of downstream fish passage measures reported are barrier nets, blockage of the top portion of the trash rack to guide surface-oriented fish to a sluiceway, modification of the sequence of operation of multiple-unit projects,

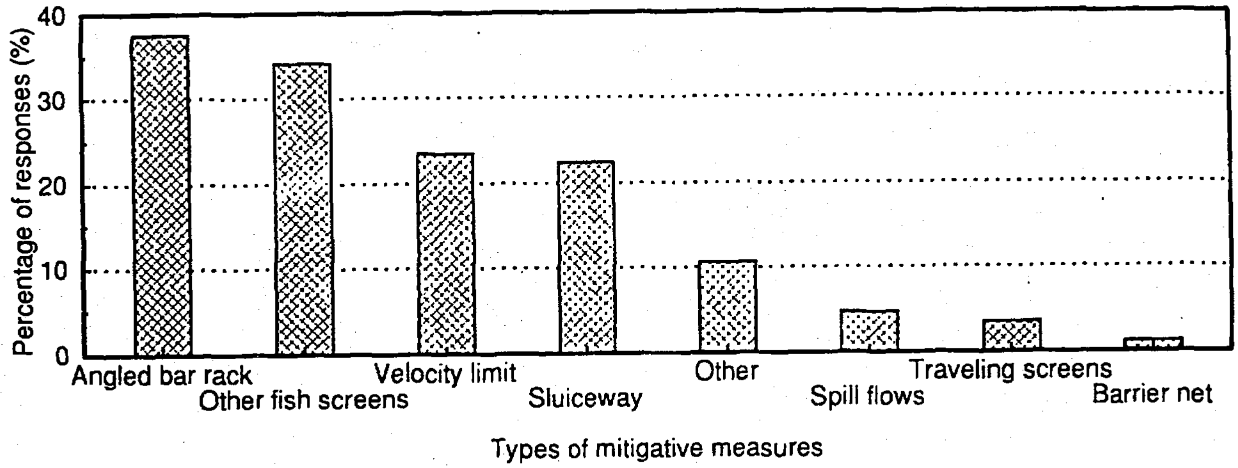

Figure 3-24. Relative frequency of downstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers.

and the experimental use of strobe lights or underwater sound to drive fish away from the turbine intake area.

Projects with downstream fish passage requirements were categorized as (1) diversion projects, in which the powerhouse is on a different stream than the diversion dam; (2) run-of-the-river projects, in which the dam is ≤10 feet high and with minimal storage capacity; or (3) storage projects, in which the dam is >10 feet high. Based on information provided by the developers, diversion, run-of-the-river, and storage projects accounted for 8, 87, and 5 percent respectively of the nonfederal, FERC-licensed hydropower facilities with downstream fish passage requirements. As with upstream fish passage facilities, a large percentage (57%) of the downstream fish passage measures are in operation at all times (Figure 3-25). Twenty-one percent of the projects operate the mitigative measure only during specified seasons, whereas 4% are operated only during certain hours of specified seasons. Seventeen percent of projects did not report when the downstream fish passage measures are used, perhaps because many are still under construction and specific requirements have not been determined.

Downstream fish passage facilities were most frequently designed to protect adult resident fish (55% of projects with such facilities; Figure 3-26). Juvenile resident fish (41%) and juvenile anadromous fish (25%) were also important targets for these mitigative measures. Downstream fish passage facilities are intended to protect fish eggs and larvae at only 8% of the projects.

In the view of the developers providing information to this study, professional judgment by the agencies was the most common basis for the incorporation of a downstream fish passage requirement; 51% of the 85 projects reported that professional judgment contributed to the requirement, and 38% reported that this was the

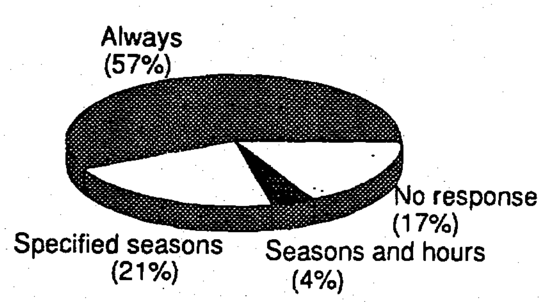

Figure 3-25. Frequency of operation of downstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers.

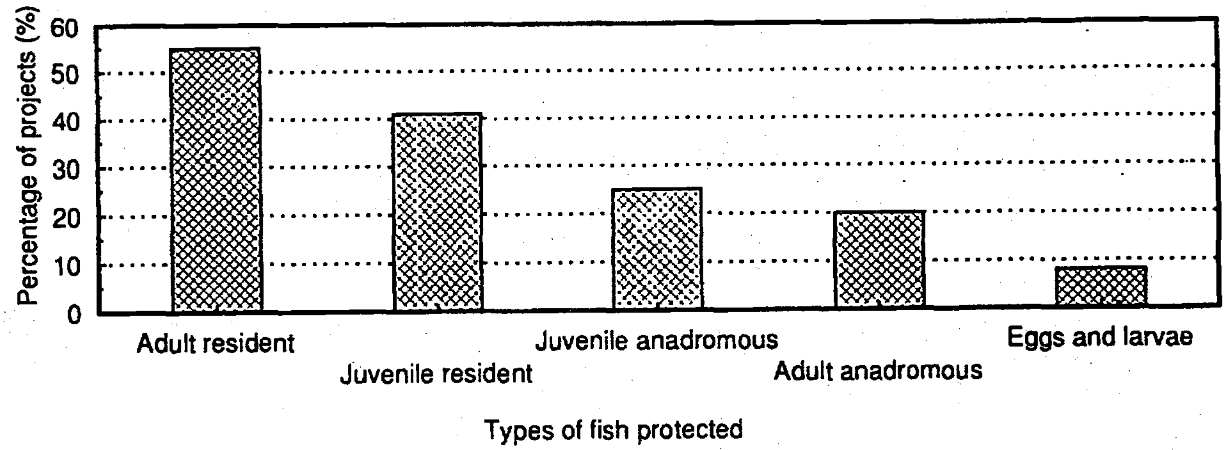

Figure 3-26. Types of fish that are protected by downstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers.

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

Information was provided on performance objectives for the downstream fish passage measure that were specified by the fisheries agencies (Figure 3-27). Most (70%) of the 71 projects providing this information reported that no performance objectives had been specified. Four facilities (6%) were required to exclude a specified percentage of fish from entrainment, and three facilities (4%) were required to limit mortality of downstream migratory fish to a

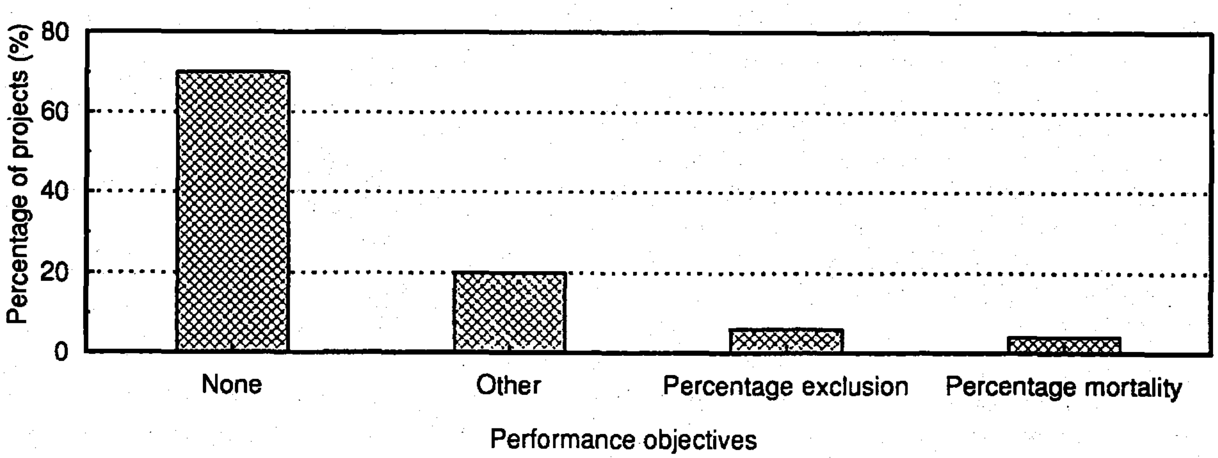

Figure 3-27. Performance objectives for downstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers.

specified level. Twenty percent had some other performance objective, usually a qualitative goal such as "effective operation."

Agency Positions on Fish Passage Mitigation. As described in Section 2, information on the role of state and federal resource agencies in fish passage mitigation was solicited by means of the Agency Information Request. State agency responses to the Agency Information Request regarding fish passage issues are summarized in Table 3-4 and described in greater detail in Appendix B.

Relatively few responding states have required mitigation of fish passage impacts associated with nonfederal hydroelectric projects, and these have been most often associated with runs of anadromous fish. Nine of the state agencies providing information to this study have a written policy regarding mitigation of fish passage impacts of hydropower (Table 3-4). These policies range in stringency from advisory recommendations to requirements by state law that every dam or other obstruction across a stream be provided with fish passage measures (Appendix B). Twelve of the agencies responding indicated that they would accept compensation for losses of fish through off-site mitigation, but often only as a last resort. Five agencies reported setting quantifiable performance objectives for fish passage mitigation measures (e.g., a defined number or percent passage), and an equal number are aware of or participate in operational performance monitoring (Table 3-4). None of the federal resource and regulatory agencies contacted for this study has a specific written policy regarding

Table 3-4. Summary of state resource agency responses to agency information request regarding upstream and downstream fish passage mitigation (see Appendix B for additional information).

	Number of responses	Upstream fish passage	Downstream fish passage
Number of states with a written policy re fish passage mitigation	34	9	9
Number of states that accept compensation for fish losses through off-site mitigation	28	12	12
Number of states that have required fish passage facilities at FERC-licensed projects	22	8	11
Number of states which require fish passage facilities for anadromous fish only	22	7	7
Number of states which require fish passage facilities for resident fish only	19	3	7
Number of states which require fish passage facilities for both anadromous fish and resident fish	22	1	4
Number of states in which performance monitoring of fish passage measures is conducted	19	6	5
Number of states with quantifiable performance objectives for the mitigative measure	19	5	5

mitigation of fish passage impacts at hydroelectric projects (Appendix B). The FWS has two policies related to the hydropower licensing/exemption process. The first, published in 1981, covers impacts of all types of development projects, including hydropower. This policy does not specifically address instream flows, DO, or fish passage requirements, but rather identifies a procedure which the FWS uses to determine all types of mitigation. The FWS also has a Hydropower Policy, issued in 1988. Although the Hydropower Policy is in effect, public comments on the need, scope, and content have been requested,[68] and the policy is currently under review. Neither the National Marine Fisheries Service nor the EPA regions that responded to this information request have written hydropower mitigation policies.

4. MITIGATION COST ESTIMATES

The cost estimates presented in this section are based on a subset of the hydropower projects described in Section 3. The information available for mitigation costs was less extensive than that for the more general mitigation requirements, because only 141 of the 280 projects that provided information included sufficient cost data. This volume's scope was to only provide information as it was reported. Future volumes of the Environmental Mitigation Study report series are planned to include more detailed cost information and refined analyses.

The cost data are presented in figures, tables and narrative. The figures provide a general view of the cost data. The tables provide the average cost for each capacity category, type of cost and mitigation method. The number of projects reporting the respective data is also listed in each table. The narratives provide details explaining some of the practices and the associated costs. Providing the cost data by figures, tables and narratives allows the reader to view the cost information at various levels of detail.

Capital and study costs are presented in the same tables as they are both generally one-time expenditures. The capital and study costs are also presented as dollar costs per kilowatt of capacity, again because of their single expenditure nature. The O&M and annual reporting costs are also presented together because they are both annually occurring costs. The O&M and annual reporting costs are also presented as annual mills per kilowatt-hour of energy to reflect their recurring nature. Each type of cost is presented by mitigation method with a brief overview. The data handling assumptions that were used to arrive at these cost estimates are described in the data assumptions section at the end of this section. All of the costs presented in this report, regardless of when they occurred, have been converted to 1991 dollars. The index used to convert the costs to 1991 dollars is also discussed at the end of this section. A cost conclusions and recommendations section is included in the final section of this report (Section 6).

Estimates of generation loss are presented for each mitigation method. However, the generation loss data was difficult to interpret. It is difficult to determine from available data whether an entire water source represents potential energy or if only a partial quantity of a water resource is available for generation. Some regulatory agencies, for example, may not view that part of a river that is reserved for minimum flows as a resource that is available for generation. The developer may hold a dissimilar view. For reasons such as this, the generation losses will be subject to future analysis in latter volumes and are simply presented in this volume as they were provided by project developers.

Introduction

The analyses conducted for this volume indicated that, within each mitigation method, costs were quite variable. Upstream fish passage mitigation methods, for example, include fish ladders and trapping and hauling. Fish ladders are very capital intensive whereas the trapping and hauling procedures generally have high O&M costs. Future analysis will break down the individual upstream fish passage methods, as well as the other three mitigation methods, into specific practices for closer examination. Future analysis are also planned to attempt to identify associations such as DO and instream flow costs as a function of stream flows. It must be noted that these cost data do not represent an unbiased sample of all FERC-licensed projects.

Literature Search. An initial literature search was conducted to identify previous cost studies of the issues of DO, instream flow, and fish passage that included subelements of costs (actual costs only, no estimated or modeled costs) and engineering. The following resources were used in this literature search: HCI Publications, Bureau of Reclamation, EPRI, USACE, and the INEL library. The results are from the 5,162 references that were obtained for the period 1985 to August 1991. There were 1,881 abstracts of papers/reports chosen for review. From this group, 133 papers/reports were chosen for further review, with only one report[69] showing any potential information that could be useful in future cost analysis. It appears that there has been a lot of work done in the issue areas, but very little actual cost or engineering information is included in the published reports. The lack of information indicates that a substantial level of effort will be required to obtain and develop factual cost and engineering analysis to support the environmental mitigation study.

Sample Characteristics. The cost estimates presented in this section are based on a sample of 141 hydropower projects that provided mitigation cost information. The 141 projects is a subset of the 280 projects that provided information for this study. Sample sizes for each mitigation issue are shown in tables throughout this section. Figure 4-1 provides a breakdown by capacity categories of the number of projects providing mitigation cost data. Several projects (Figure 4-2) provided cost data for more than one mitigation requirement, in a variety of combinations. The cost data is dominated by projects with major licenses and run-of-river operation (Table 4-1). Average project characteristics are shown in Table 4-2. Of the 141 projects used for cost analysis, none of the projects provided data for all of the attributes and costs requested. This was because either the projects did not have all of the mitigation requirements or did not have access to the various data requested.

Analysis Approach. Unless otherwise noted, all of the costs in the tables are averages for the projects in each capacity category and mitigation method. The capacity categories are (a) projects <1 MW; (b) projects 1 MW to <10 MW; (c) projects 10 MW to <50 MW; (d) projects 50 MW to <100 MW; and, (e) projects 100 MW and larger. Additionally, some of the tables contain a column titled "Summary." This is a weighted average of all of the aforementioned capacity categories. Under each cost, within several of the tables, is the number of projects that provided data for the respective costs. The lower the number of projects reporting costs, per category, the increased likelihood that the average project cost may be skewed by one or

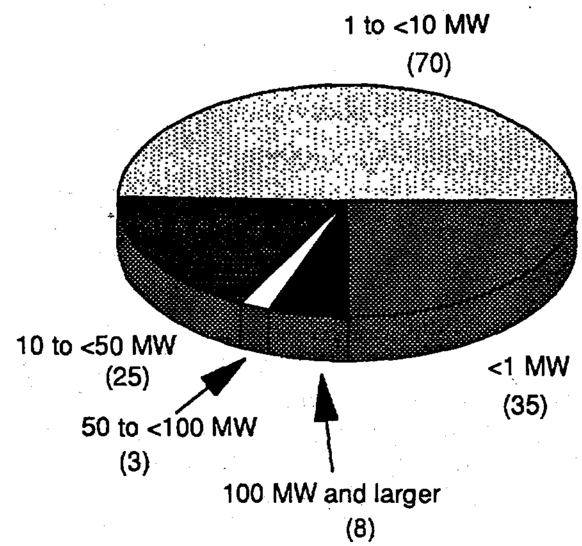

Figure 4-1. Number of projects providing cost information, by project capacity category. Numbers in parentheses are the actual numbers of projects in that category.

Table 4-1. The type of licenses and operation modes of the 141 projects used for cost analysis.

Type of Licenses		
Major	Minor	Exempt
81	36	20
Operation mode		
Run of river	Store & release	Other
97	30	9

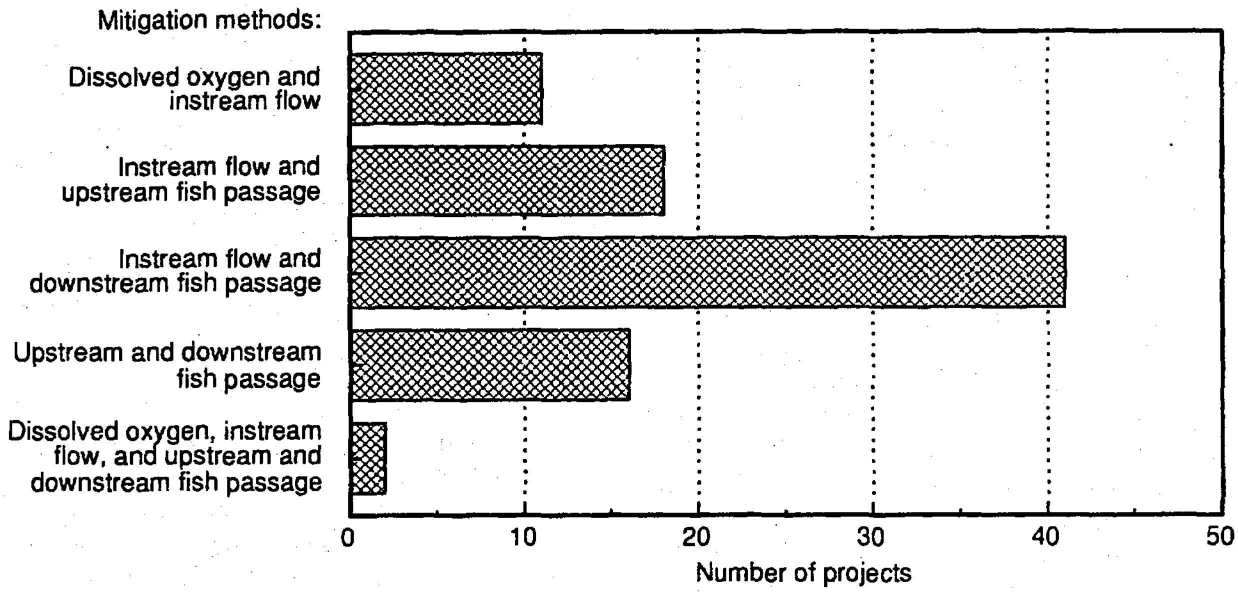

Figure 4-2. Number of projects providing cost information for various combinations of mitigation requirements. Other combinations are possible. A total of 141 projects provided cost information.

more projects. For instance, the average capital cost for the 15 projects reporting DO capital costs is $162,000. However, one of these 15 projects reports a DO capital cost of $2,049,000. Temporarily eliminating this project from the data set results in an average DO capital cost of $27,000, which is ~$135,000 lower than the original average. For reasons such as this the costs are broken down into capacity categories to best reflect the costs that similarly sized projects would encounter.

The intent of providing cost breakdowns by capacity sizes is so that a developer of a new project or of an operating project facing relicensing, can study the past mitigation costs encountered by similarly sized projects. It would be imprudent to compare the costs of a 300 KW project with the average costs of the entire database with its average capacity size of 29,000 kW. Instead, by using the capacity size categories, a developer can study the costs associated with projects in the <1 MW capacity category if the project was of the aforementioned 300 KW size.

Table 4-2. Average capacity, annual energy and design head of the 141 projects used for cost analysis.

Total capacity	4,117 MW
Average capacity	29 MW
Average design head	166 ft
Total annual energy	18,719,000 MWh
Average annual energy	137,000 MWh
Average turbine flow	3,900 ft^3/s

When the cost tables are viewed it should be noted that N/A in a table indicates that there were not any projects providing costs for a type of mitigation within a capacity class. Associated with the N/A will be a zero in the "Number of projects" row, indicating that there are not any projects providing cost information for this mitigation method and capacity category. When a zero is provided in the cost row, it indicates that the costs for a mitigation issue are zero. It may be argued that if the cost was zero, than there is not any cost. True, but the costs associated with mitigation issues are being measured, and this cost may sometimes be zero. Perhaps an example would clarify this. The instream flow capital costs reported by two projects in the 100 MW and Larger capacity category is $0. Both of these projects satisfy their instream flow requirements by releases through the turbines with no additional capital cost to implement instream flow requirements. So a zero value in a cost row does not indicate an unknown value; rather, a zero value indicates that no additional cost was incurred to meet a mitigation requirement. The significance of this is that the average costs are lowered when including zero costs.

The various mitigation methods each contain a wide range of costs that appear to be dependant on a project's size. Simply viewing the average cost for each type of mitigation requirement provides too broad of an examination. Analysis suggests that the breakdown of costs by capacity categories may provide the best illustration of costs. The reader can best anticipate the mitigation costs associated with individual issues for select project sizes by reviewing the costs based on capacity categories. For instance, the downstream fish passage capital costs are vastly different when viewed as averages for all projects ($958,596 or $17.39/KW), averages for projects in the capacity category 10 to <50 megawatts ($650,025 or $35.45/KW), and average for projects <1 MW capacity ($25,911 or $80.02/KW).

Generally, the following data show that the smaller the project, the smaller the average per project capital cost expenditure to satisfy downstream fish passage mitigation requirements. The dollar per kilowatt of capacity method also indicates that there is a variation of costs based on capacity size. The low average cost of the downstream fish passage capital costs for All projects (141) ($17.39/KW of capacity) is a reflection of the low capital cost ($14.05/KW of capacity) exhibited by two large projects. These two projects represent 1,836 MW of capacity, or 90% of the total capacity of all projects that provided downstream fish passage capital costs. It is recommended that the reader be aware that analyzing the cost data can provide a variety of results. It is best to view the data by capacity categories.

The quality of the data presented is based on the ability of the project owners to accurately provide the cost information. The data presented has been filtered for errors and inaccuracies. Although the authors acknowledge that some of the data may not be explicit and exact costs, the results presented here should be useful to accurately reflect the costs of mitigation issues hydropower developers have encountered.

Each project presents a unique set of circumstances, and it should be acknowledged that a developer's specific site may differ from the characteristics of the projects presented here (Table 4-3). All of the costs presented here should be used as a guideline, not a guarantee, of the types and magnitudes of expenses that may be encountered in conjunction with the various mitigation methods.

Mitigation Costs Overview

This section provides an overview of the average costs reported. None of the 141 projects in the cost database provided information for every question. Only 15 projects, for example, contain DO capital costs. Although it might be assumed that this reflects that only 15 of the 141 projects have DO requirements and associated capital costs, the reality is that only 15 projects reported DO capital costs. Twenty-two projects indicated that they actually had some type of DO requirements. It is presently unknown whether the 7 projects not indicating any DO capital costs did not have any DO capital cost, did not know the DO capital cost, were simply unable to obtain a breakdown of the DO capital cost for their project, or did not want to furnish their DO capital costs.

Table 4-3. Breakdown by capacity category of the physical characteristics of the 141 projects in the database. Because not all of the 141 projects in the database provided information for every question, the number of projects reporting data in the table will often be less than 141. The various unit values are stated in the left hand columns.

	Capacity categories				
	<1 MW	1 to <10 MW	10 to <50 MW	50 to <100 MW	100 MW and larger
Total number of projects	35	70	25	3	8
Average capacity (KW)	375	3,787	19,804	75,607	389,619
Number of projects	35	70	25	3	8
Average annual energy (MWh)	1,670	18,763	89,813	293,000	1,785,108
Number of projects	34	67	25	3	8
Average design head (feet)	94	177	209	402	153
Number of projects	30	58	22	3	7
Average turbine flow (cfs)	165	707	3,673	497	41,840
Number of projects	29	58	23	1	8

Capital Costs and Study Costs. The capital and study costs are provided as average costs per project (Figure 4-3a) and as average costs per kilowatt of capacity (Figure 4-3b). Upstream fish passage mitigation is the most capital intensive mitigation method. This is due to the high cost of structures such as fish ladders and fish elevators. Instream flow and DO mitigation methods have the lowest capital costs. Instream flows and DO projects report that their capital costs are often low as they meet mitigation requirements by flow releases through turbines or spillways with no mitigation required capital structures. Downstream fish passage mitigation has the highest average study cost. This may reflect the difficulty of determining the safest methods to protect fish from the turbines.

The upstream fish passage average capital costs are influenced by three large projects, averaging 783 MW capacity each. Removal of these projects and their $74 million of upstream fish passage capital costs lowers the average upstream fish passage capital cost to $421,000. This again suggests that costs should be examined on the basis of relative plant capacity size. One project constituted more than half of the total DO study dollars. Removal of this 512 MW capacity, $307,000 study provides an average DO study cost of $25,000.

A review of the instream flow study costs indicates that a single project has a significant influence on the amplitude of the average cost of a study. Removal of this $1,083,000 study results in an average instream flow study cost of ~$67,000.

The downstream fish passage study costs are greatly influenced by two projects, having combined study costs of almost $12 million. The removal of these two projects results in the remaining 19 projects reporting an average downstream fish passage study cost of $90,000.

Operation and Maintenance, and Annual Reporting Costs. The O&M and annual reporting costs are provided as average annual costs per project (Figure 4-4a) and as average mills per kilowatt-hour of energy (Figure 4-4b)

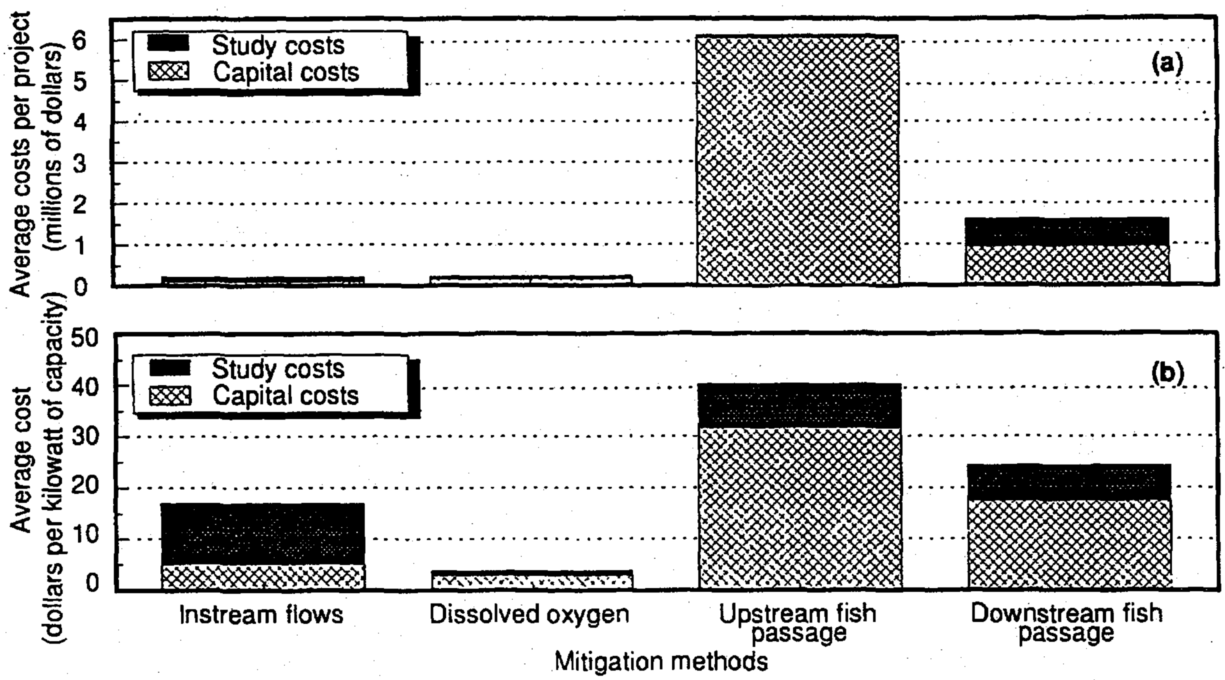

Figure 4-3. Capital and study costs as (a) average cost per project and (b) average cost per kilowatt of capacity. Costs are provided for each of the four types of mitigation.

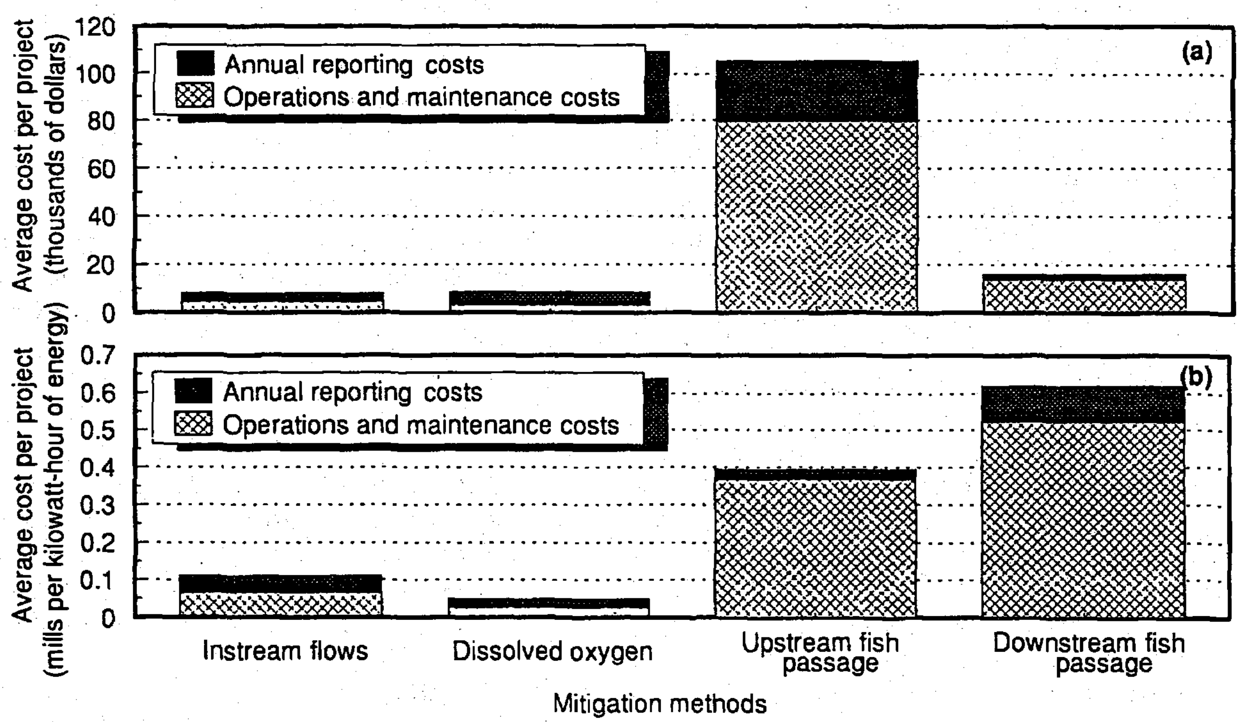

Figure 4-4. Annual reporting costs and operation and maintenance (O&M) costs as (a) average cost per project and (b) average mills per kilowatt-hour of energy per project for each of the four types of mitigation.

for each project. Upstream and downstream fish passage mitigation requirements have the highest annual reporting and O&M costs.

Upstream fish passage O&M costs contain a single project representing 90% of the total reported upstream fish passage O&M costs. Removal of this single $717,000 project results in an average upstream fish passage O&M cost of $9,300. This figure is considerably closer to the other O&M averages. Upstream fish passage annual reporting costs are considerably larger than the reporting costs of all of the other mitigation methods. In fact, the upstream fish passage costs for annual reporting are almost 13 times more expensive than the downstream fish passage costs.

Removal of the two projects with the highest costs produced an average upstream fish passage annual reporting cost of $7,280. This is still the highest average annual reporting cost but significantly closer to the demonstrated averages for the other mitigation issues. The two projects with the highest costs have an average annual reporting cost of $108,000. Both of these projects are in the Pacific Northwest and involve anadromous fish.

Lost Generation. The concept of lost generation due to mitigation is controversial. In some cases, spills required for mitigation may be a resource that is not available for hydropower use. There has not been any attempt here to support either viewpoint of this potential controversy. The loss generation data is merely presented as it has been obtained from the hydropower developers.

Two of the downstream fish passage projects have combined generation losses of 129,171,000 kWh per year. Removal of these two projects results in an average downstream fish passage generation loss of 295,000 kWh per year. These two projects both use spill flows for downstream fish passage. They have average flows of 122,500 cfs. Assuming an average generation loss of 64,585,500 kWh per year and an average value of $0.05 per kWh, this generation loss equates to a $3.2 million yearly loss for each of these two projects as a result of downstream fish passage mitigation practices. Average generation loss varies by mitigation requirement (Table 4-4). The generation losses also vary by project capacity (Table 4-5).

Instream Flow Costs

This section contains a breakdown of the costs associated with instream flow requirements. It must be recognized that the capital and study costs may not be for the same projects. Respondents, for example, may have provided capital costs for instream flow mitigation only or study costs for instream flow mitigation only or

Table 4-4. Average generation losses by mitigation issue.

	Total kWh yearly loss	Number of projects	Average project kWh loss	Average project loss @ $0.05/kWh
Instream flow	119,480,910	48	2,489,186	$124,500
Dissolved oxygen	1,177,520	11	107,047	$5,350
Upstream fish passage	4,488,480	4	1,122,120	$56,100
Downstream fish passage	135,066,000	22	6,139,364	$307,000
Total	260,212,910	85	3,061,328	$153,100

Table 4-5. Breakdown by capacity category and mitigation issue of the average annual generation lost per project for the 141 projects. Because not all of the 141 projects in the database provided information for every question, the number of projects reporting data in the table will often be less than 141.

	Capacity categories				
	<1 MW	1 to <10 MW	10 to <50 MW	50 to <100 MW	100 MW and larger
Instream flow (kWh/year)	160,938	1,719,600	11,471,000	4,464,260	0
Number of projects	10	30	5	2	1
Dissolved oxygen (kWh/year)	46,260	12,500	345,000	N/A	0
Number of projects	2	4	3	0	2
Upstream fish passage (kWh/year)	88,480	300,000	100,000	N/A	4,000,000
Number of projects	1	1	1	0	1
Downstream fish passage (kWh/year)	87,500	464,444	338,333	N/A	64,585,500
Number of projects	8	9	3	0	2

both capital and study costs for instream flow mitigation. Four projects have provided capital costs for instream flow mitigation in the 1 to <10 MW capacity category, but only two projects provided study costs for instream flow mitigation in the same capacity category. Similarly, the O&M costs, and the annual reporting costs may be for different projects, but they are also summed. Capital and study costs for instream flow mitigation are summarized by project capacity categories in Table 4-6. O&M and annual reporting costs are summarized in Table 4-7.

Capital Costs for Instream Flow Requirements. A graphical summary (Figure 4-5a) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for instream flow capital costs.

<1 MW. These projects reported required release rates from <1 cfs to 230 cfs. Eight of the projects reported that the release requirements are required in a diverted reach. Two projects have release requirements through the turbines. One project reports release requirements both through the turbine and a diverted reach. Three of the projects either provided unclear or insufficient data on release requirement locations. Three projects reported that they did not experience any additional capital expenses because of instream flow release requirements. The largest capital cost, $340,000, was for a multilevel outlet tower. One project reported spending $124,000 for a minimum flow turbine. One project spent $100,000 on a bypass structure and monitoring equipment, the proportion of which is unknown. Several projects monitor flows on an hourly basis with monitoring equipment whereas other projects perform weekly visual checks. Of the 11 projects reporting if the instream flows are for objectives other than fisheries, 4 reported they are for vegetation, 1 reported they are for recreation and 1 reported instream flows are only for the benefit of fisheries. Four projects reported releases are for a combination of factors, including vegetation, recreation, flushing sediments, and water quality and temperature. The eleventh project indicated that the instream releases are for the flushing of sediments. Three projects reported that they do not have a capital cost associated with instream flows. One of

Table 4-6. Average capital and study costs for instream flow mitigation, provided by capacity categories. Because not all of the 141 projects in the database provided complete information, the number of projects reporting data in the table will often be less than 141.

	Capacity category					
	<1 MW	1 to <10 MW	10 to <50 MW	50 to <100 MW	100 MW and larger	Summary
Capital costs:						
Average per project	$48,008	$38,731	$183,689	$1,255,378	$0	$99,083
Average per KW capacity	$119.53	$9.78	$10.24	$17.14	$0	$5.24
Number of projects	14	33	7	2	2	58
Study costs:						
Average per project	$14,279	$46,636	$231,452	$1,083,530	N/A	$99,756
Average per KW capacity	$24.69	$11.67	$10.89	$12.04	N/A	$11.66
Number of projects	4	22	4	1	0	31
Totals:						
Average per project	$62,287	$85,368	$415,141	$2,338,908	N/A	$198,839
Average per KW capacity	$144.22	$21.44	$21.14	$29.18	N/A	$16.90

these three capital cost-absent projects releases minimum flows through the turbine, one releases minimum flows through a diverted reach, and the third project's minimum flow requirement of 5 cfs from June to March is met by leakage past the flood gate and its minimum flow of 50 cfs during April and May is met by overtopping. If the most expansive capital cost project, $340,000, is removed from the data set, the average instream flow capital cost drops from $48,000 to $26,000 for the <1 MW category. The average release requirement for projects reporting release requirements in this category is 14 cfs. **Cost Range: $0 to $339,396.**

1 to <10 MW. Five projects in this group of 33 projects indicated that they did not have any capital costs resulting from instream flow release requirements. Of the projects reporting capital costs greater than zero, the range was $324 to $226,264. Known capital costs include $174,000 for fish habitat improvement structures and a flow measurement gate at one project, and $25,000 for equipment to constantly record the water releases at another project. Of the 33 projects in this category, 23 projects released through the project and 1 project had release requirements both via the project and a diverted reach. Twenty-nine projects indicated if the instream flow releases were for objectives other than fisheries. Of these 29, 17 indicated fish protection is the only objective, 3 indicated water quality is a significant objective, 5 indicated recreation is a significant objective, and 2 indicated that visual objectives are significant. Two projects listed a combination of objectives. Significant objectives means what objectives are present other than fisheries and instream flow releases meant to enhance or support these significant, secondary objectives. Several projects indicated that even when fish protection is the overriding primary objective for instream flow releases, other objectives such as water quality and temperature, recreation, and vegetation are usually secondary considerations to some degree that they influence the operation

Table 4-7. Average operation and maintenance, and annual reporting costs for instream flow mitigation, provided by capacity categories. Because not all of the 141 projects in the database provided complete information, the number of projects reporting data in the table will often be less than 141.

	Capacity category					
	<1 MW	1 to <10 MW	10 to <50 MW	50 to <100 MW	100 MW and larger	Summary
Operation & maintenance:						
Average per project	$1,833	$5,436	$8,956	$5,122	$0	$4,768
Number of projects	13	27	7	1	2	50
Average mills per KW capacity	1.28	0.28	0.11	0.04	0	0.07
Number of projects	12	26	7	1	2	48
Annual reporting:						
Average per project	$1,305	$2,121	$11,600	$0	$0	$3,381
Number of projects	11	26	8	1	2	48
Average mills per KW capacity	1.13	0.11	0.14	0.00	0.00	0.46
Number of projects	10	25	8	1	2	46
Totals:						
Average per project	$3,138	$7,557	$20,556	$5,122	$0	$8,149
Average mills per KW capacity	2.41	0.38	0.25	0.04	0	0.11

of the hydroelectric site. The average reported release requirement for this category of projects is 111 cfs. **Cost Range: $0 to $226,264.**

10 to <50 MW. Of the seven projects in this group, one project reported that it did not have an associated capital cost. The reported capital costs range from $0 to $915,000. The median value is $40,000, considerably lower than the average of $184,000. Removal of the single largest capital cost for instream flow lowers the average project capital cost to $62,000. Five projects release instream flows via a diverted reach, one releases 2,200 cfs through the turbines, and the seventh project releases instream flows by both methods. Six of the 7 projects indicate they have release requirements in addition to fisheries considerations. The seventh project does not answer this question. Of the instream release requirements in addition to fisheries considerations, water quality or water temperature are the other objectives, listed four times, and recreation is the other objective, mentioned twice. One project reported that an objective of instream flow releases is that wildlife and raptores feed on fish, and this is supported by the releases. The average reported release rate is 444 cfs for projects in this category. **Cost Range: $0 to $915,450.**

50 to <100 MW. Only two projects reported having instream flow capital costs in this capacity range. The two costs are $745,000 and $1,766,000. The $1,766,000 cost is for a minimum flow unit. The lower cost project reported instream flow releases only for fisheries, whereas the more expensive project listed all aquatic resources as its instream flow release objective. Both required releases are via a diverted reach, with an average release

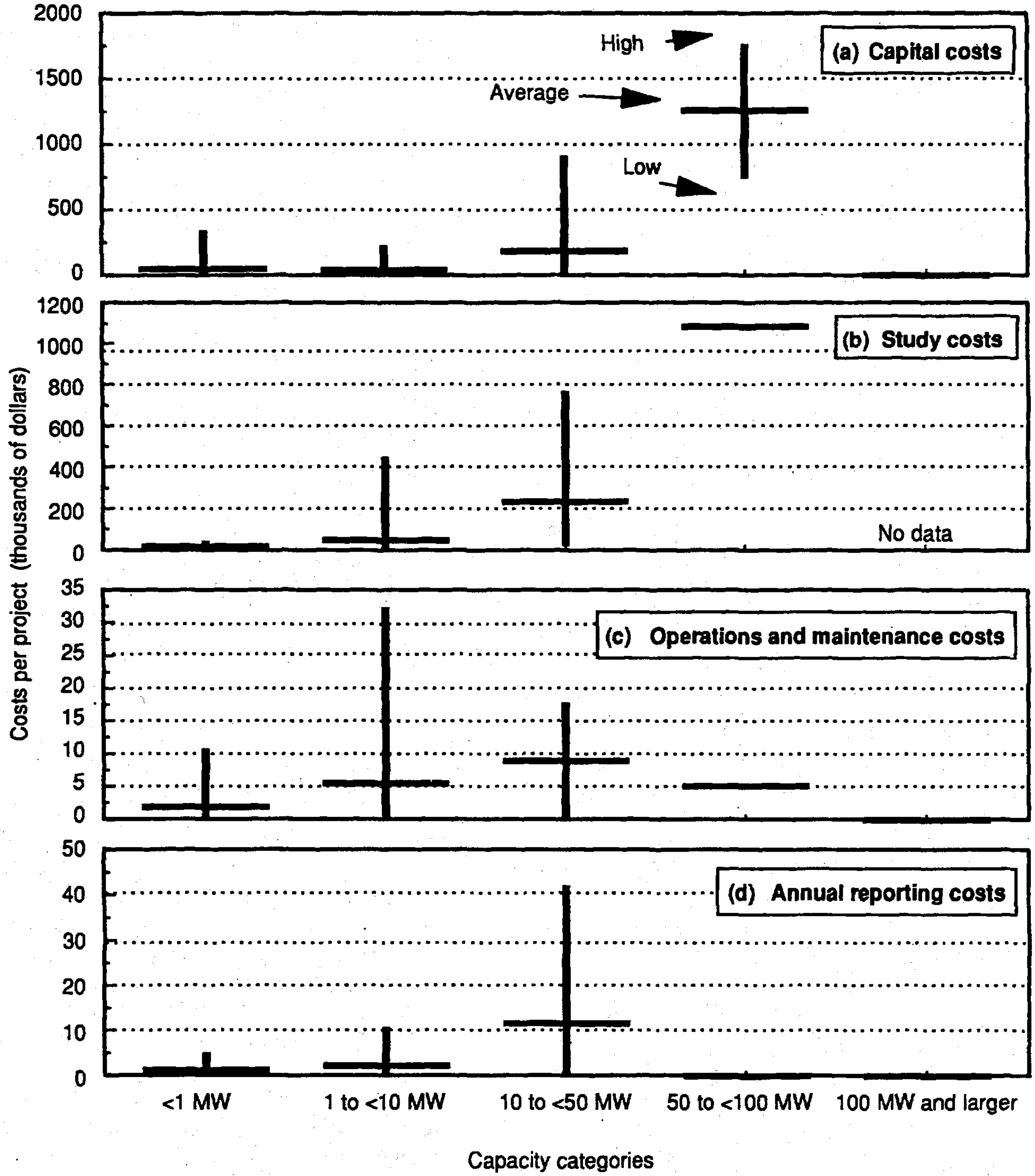

Figure 4-5. Range and average costs per project for instream flow mitigation, by project capacity category. Types of cost shown are (a) capital, (b) study, (c) operation and maintenance (O&M), and (d) annual reporting. Only one project in the 50 to <100 MW capacity category reported study costs; in the same capacity category, only one project reported O&M costs. Two projects in the 100 MW and larger capacity category reported zero O&M costs, two other projects in the same capacity category reported zero annual reporting costs, and the single project in the 50 to <100 MW capacity category reported an annual reporting cost of zero.

requirement of 90 cfs. **Cost Range: $744,657 to $1,766,100.**

100 MW and Larger. Neither of the two projects in this category has any capital costs because of instream flow releases. They both release through their powerhouse. One project has a minimum yearly flow requirement of 3,900 cfs. The average annual flow at this project, however, is 29,000 cfs. The second project has a minimum flow requirement of 450 cfs. The first project's minimum flow objective is for water quantity, not quality. The second and smaller project's objectives include water temperature and quality, recreation, vegetation, and the flushing of sediment. **Cost: $0.**

Study Costs for Instream Flow Requirements. A graphical summary (Figure 4-5b) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for instream flow study costs.

<1 MW. The project with the highest study costs performed the following types of studies: IFIM, HEP, wetted perimeter, and specified flow duration standard. A second project did not disclose the reasons for its costs. A third project, at $1,079, performed IFIM, water temperature, or quality studies. The fourth project, at $8,634, studied the wetted perimeter. **Cost Range: $1,079 to $43,519.**

1 to <10 MW. The seven projects with the highest costs in this category all performed IFIM studies. The flip side of this is that of the eight projects with the lowest study costs that included the kind of studies performed, six projects did not perform IFIM studies. Although perhaps not conclusive statistical confirmation of relative IFIM cost, this association was interesting to note. Three projects, all performing IFIM studies, had costs of more than $100,000. Removal of these three projects' costs results in an average study cost of $18,870. The project with the highest study costs in this category, at $446,794, reported the following breakdown of costs for performing an IFIM study: biologists, 45%; attorneys, 30%; engineers, 23%; and miscellaneous, 2%. Nine projects reported costs below $10,000. Combinations of single studies and multiple studies were performed, including the following: IFIM, HEP, aquatic baseflow standard, wetted perimeter, water temperature and quality, and a 1 day field effort series of controlled releases with federal and state biologists. Another study, at $10,792, verified the nonexistence of crayfish on a river reach. **Cost Range: $1,288 to $446,794.**

10 to <50 MW. All four projects performed IFIM studies. The highest reported study costs, at $767,209, included IFIM and wetted perimeter studies as well as initial fisheries studies to gain license approval. **Cost Range: $21,584 to $767,209.**

50 to <100 MW. This project's study costs were for the following studies: wetted perimeter, Tennant or Montana method, and 4 years of operational fisheries monitoring study. **Cost: $1,083,530.**

100 MW and Larger. There are not any projects reporting instream flow study costs in this capacity category. **Cost: no data.**

Of the 12 projects with the most expensive study costs in all of the instream flow capacity categories, 11 projects report performing IFIM studies exclusively or in conjunction with another type of study. Of the 16 least expensive projects in all capacity categories, 6 did not provide study types, 3 performed IFIM studies and 7 did not perform IFIM studies.

Operation and Maintenance Costs for Instream Flow Requirements. A graphical summary (Figure 4-5c) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for instream flow O&M costs.

<1 MW. Eight projects in this group of 12 appear to have instream flow requirements in a diverted reach. The average cost for this group is $780. Two projects release via the turbines and 1 of these projects' cost for O&M is $0, and the other project's cost is $10,792. This second project uses a multilevel outlet tower for instream flow releases. Another project has release requirements downstream of the plant as well as in a diverted reach. This project's reported O&M cost is $574. **Cost Range $0 to $10,792.**

1 to <10 MW. Four projects indicate that their O&M annual costs are $0. It appears that 3 of these 4 projects pass minimum flows via the powerhouse and the fourth via a diverted reach. The project with the most expensive O&M costs, at $32,376, has a constant minimum flow, eight to ten hours a day minimum flows from June through September, run-of-river releases for boating on weekends and holidays from Memorial Day through Labor Day, and run-of-river releases on weekends after Labor Day. Seventeen projects have O&M costs below the average, and 9 projects have O&M costs above the average. **Cost Range: $0 to $32,376.**

10 to <50 MW. Three projects have costs below the group average and four are above the group average. The only project that releases exclusively through the powerhouse has an O&M cost of $0. One project has release requirements through the powerhouse and a diverted reach at an O&M cost of $17,807. The five projects with a diverted reach release requirement have an average O&M cost of $6,977. **Cost Range: $0 to $17,807.**

50 to <100 MW. The $5,122 O&M cost for this project is for a minimum flow unit. **Cost: $5,122.**

100 MW and Larger. One project has a minimum flow of 450 cfs and it has an actual average flow of 9,600 cfs via the turbines. The second project also releases via the turbines, and its minimum flows are 3,500 cfs for 3.5 months, 5,000 cfs for 3.5 months, 7,500 cfs for 1 month, and 10,000 cfs for 1 month. This project's average annual flow is 29,000 cfs. Neither of these two projects indicated any O&M costs. **Cost: $0.**

Annual Reporting Costs for Instream Flow Requirements. A graphical summary (Figure 4-5d) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for instream flow annual reporting costs.

<1 MW. Six of the 11 projects in this category reported they did not have any annual reporting costs. Two of the six reported not having any monitoring requirements. One of the six did not provide sufficient information to determine this project's situation. Of the remaining three projects with $0 costs, all performed visual checks on a weekly basis. One of these three reported using a reference mark on a ledge. The project with the highest costs, at $5,122, reported monitoring a V notch weir in a diverted reach and the use of an automatic electronic gauge every 15 minutes. **Cost Range: $0 to $5,122.**

1 to <10 MW. Three projects reported $0 costs. Two of the three did not monitor, and the third project reported daily monitoring by the operators but the annual reporting costs were negligible. The project with the highest costs, at $10,792, measures fish and habitat quality on a daily basis. This project also logs flow measurements, and annual reports are sent to FERC and fisheries agencies. The project with the second highest cost, at $7,171, uses a United States Geological Service instream flow monitoring station, and the information is telemetered to a main dispatch station for real-time, continuous monitoring. Other measures employed by various projects include the continuous measurement by a stage recorder, the measurement of flows four times a year, a river gauging station downstream of a diversion, and the recording hourly in the powerhouse via a pressure transmitter of the data, and monthly summaries of minimum flows. **Cost Range: $0 to $10,792.**

10 to <50 MW. The project with the most expensive annual reporting cost, at $42,089, monitors flow continuously and performs an enumeration of salmon. The second most expensive cost, at $30,733, is for a project that performs continuous monitoring at the intake and uses a bypass notch configuration flow meter. A single project reports $0 costs. This project monitors only during ponding, after flashboard repairs. One project, at $5,396, performs salmon incubation and preemergent sampling. **Cost Range: $0 to $42,089.**

50 to <100 MW. It appears some type of monitoring is performed by this project but the owner estimates an annual reporting cost of $0. **Cost: $0.**

100 MW and Larger. One project indicates some monitoring is done several times during the fall and winter. The other project performs some monitoring in the tailrace on a varied scheduled. **Cost: $0.**

Lost Generation for Instream Flow Requirements. It is difficult to ascertain the practices associated with the generation losses resulting from instream flow releases. A few projects reported no losses because releases are via the turbines. Another project with zero losses indicated instream flow release requirements are met by normal leakage past the floodgates. To present more accurate information for the individual projects would require more assumptions than we were willing to make in this initial report. Table 4-5 provides lost generation averages for projects with instream flow mitigation.

<1 MW. Two projects reported zero losses. Six of the ten projects reported losses from 16,000 to 70,000 kWh, at an average loss of 48,000 kWh. The entire category's average is skewed by the largest project. **Loss Range: 0 to 1,125,000 kWh.**

1 to <10 MW. Five projects report 0 kWh losses. Twelve projects reported generation losses in excess of one million kWh. **Loss Range: 0 to 13,960,000 kWh.**

10 to <50 MW. **Loss Range: 450,000 to 32,205,000 kWh.**

50 to <100 MW. **Loss Range: 2,728,520 to 6,200,000 kWh.**

100 MW and Larger. **Loss Range: 0 kWh.**

Dissolved Oxygen Costs

This section contains a breakdown of all costs associated with DO mitigation requirements. It must be recognized that the capital and study costs may not be for the same projects. For example, respondents may have provided capital costs for DO only or study costs for DO only or both capital and study costs for DO. Four projects have provided capital costs for DO in the 1 to <10 MW capacity category, but only two projects provided study costs for DO in the same capacity category. Similarly, the O&M costs and the annual reporting costs may be for different projects, but they are also summed. Capital and study costs for DO mitigation are summarized by project capacity categories in Table 4-8. O&M and annual reporting costs are summarized in Table 4-9.

Capital Costs for Dissolved Oxygen Mitigation. A graphical summary (Figure 4-6a) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for DO mitigation capital costs.

<1 MW. Only one project reported a DO requirement in the <1 MW class. The reason for the capital costs is unknown. The DO requirement is $\geq$5.0 mg/l or equal to the DO level in the upstream reach when it is <5.0 mg/l. When mitigation is necessary, this project stops the turbine and measures the DO level in the bypass reach. **Cost: $1,099.**

1 to <10 MW. The four projects in this category have an average DO capital cost of $29,925. One project noted that its DO capital cost was for the purchase of a DO meter. Two projects noted DO requirement levels of 5.0 mg/l, and a third project had a 6.0 ppm DO requirement. Two projects use spill flows when necessary to raise the DO levels. The third project uses spray devices, aeration in the turbine, and aeration of the weir in the discharge channel. The fourth project, while having a DO

Table 4-8. Average capital and study costs for dissolved oxygen mitigation, provided by capacity categories. Because not all of the 141 projects in the database provided complete information, the number of projects reporting data in the table will often be less than 141.

	Capacity category					
	<1 MW	1 to <10 MW	10 to <50 MW	50 to <100 MW	100 MW and larger	Summary
Capital costs:						
Average per project	$1,099	$29,926	$19,375	$11,191	$1,079,352	$161,754
Average per KW capacity	$7.33	$9.48	$1.11	$0.14	$3.49	$2.91
Number of projects	1	4	7	1	2	15
Study costs:						
Average per project	$1,000	$33,940	$25,654	N/A	$307,328	$50,526
Average per KW capacity	$2.50	$13.42	$1.06	N/A	$0.60	$0.81
Number of projects	1	2	7	0	1	11
Totals:						
Average per project	$2,099	$63,866	$45,029	N/A	$1,386,680	$212,280
Average per KW capacity	$9.83	$22.89	$2.17	N/A	$4.09	$3.72

requirement level of 5.0 mg/l, has never had DO levels below this minimum since 1975, and there was not any indication of the type of action that would be used if DO minimums were to fall to unsuitable levels. **Cost Range: $0 to $107,921.**

10 to <50 MW. The DO requirements generally range from 4.0 mg/l to 6.0 mg/l. The 6.0 mg/l DO requirement on one project was required only if the water temperature was higher than 10°C. One project is required to measure DO levels only if river flow is below 300 cfs. (The average river flow is 2,500 cfs). Thisproject would employ spill flows as would most projects in this capacity category. One project uses aeration in the turbine and uses spill flows when the aeration is insufficient to meet minimum DO requirements of 5.5 mg/l for 4 months a year and 5.0 mg/l the other 8 months. **Cost Range: $0 to $62,170.**

50 to <100 MW. The single project in this class has a 5.0 mg/l DO requirement that is met, when action is required, by shutting off the flow through the plant. **Cost: $11,191.**

100 MW and Larger. These two large projects both have DO requirements of 5.0 mg/l. At one of these projects the 5.0 mg/l requirement is the average daily minimum requirement and 4.0 mg/l is the absolute DO minimum. This project uses turbine aeration to met DO requirements. The second project employs the following practices, when necessary and in the stages listed, to meet DO requirements: First, the turbine aeration systems present in the six of seven units are activated; second, the project continues turbine aeration and shuts down the nonaerated seventh unit; third, when steps one and two fail, this project will shut down all seven units and spill water via a regulating gate at a rate of 4,000 cfs. This project noted that it can also employ intake aeration, but it was unclear when this practice is employed. **Cost Range: $109,854 to $2,048,851.**

Table 4-9. Average operation and maintenance, and annual reporting costs for dissolved oxygen mitigation, provided by capacity categories. Because not all of the 141 projects in the database provided complete information, the number of projects reporting data in the table will often be less than 141.

	Capacity category					
	<1 MW	1 to <10 MW	10 to <50 MW	50 to <100 MW	100 MW and larger	Summary
Operation & maintenance:						
Average per project	$706	$1,420	$4,204	$4,610	$5,396	$3,415
Average mills per KW capacity	0.77	0.12	0.05	0.01	<0.01	0.03
Number of projects	1	3	7	1	1	13
Annual reporting:						
Average per project	$1,413	$1,941	$3,556	$512	$19,668	$5,141
Average mills per KW capacity	1.54	0.16	0.03	<0.01	0.02	0.02
Number of projects	1	3	7	1	2	14
Totals:						
Average per project	$2,119	$3,361	$7,760	$5,122	$25,064	$8,556
Average mills per KW capacity	2.30	0.28	0.08	0.01	0.03	0.05

Study Costs for Dissolved Oxygen Mitigation. A graphical summary (Figure 4-6b) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for DO mitigation study costs.

<1 MW. This project has had both pre- and postlicense studies done. It is unknown what the cost represents. **Cost: $1000.**

1 to <10 MW. Both of these projects had identical study costs, and neither performed prelicensing studies. Both projects performed postlicensing DO and water temperature studies. **Cost: $33,940.**

10 to <50 MW. The project with the highest study cost, at $83,718, conducted prelicensing studies in conjunction with a state resources agency. The DO, water temperature, pH, and specific conductance were all measured. Five of the study costs in this category were postlicensing studies. Four of the five measured DO and water temperature levels. **Cost Range: $3,238 to $83,718.**

50 to <100 MW. There are not any projects reporting DO study costs in this capacity category. **Cost: no data.**

100 MW and Larger. Only one project of this magnitude provided study costs. DO and water temperature studies were funded. **Cost: $307,328.**

Operation and Maintenance Costs for Dissolved Oxygen Mitigation. Little information was available that explained what the DO O&M costs encompassed. It is generally not known if the O&M costs are for the facilities to actually maintain DO levels or for another purpose such as the O&M of monitoring equipment. It is assumed here that the O&M costs are for the facilities to maintain minimum DO levels. However, in either case the costs

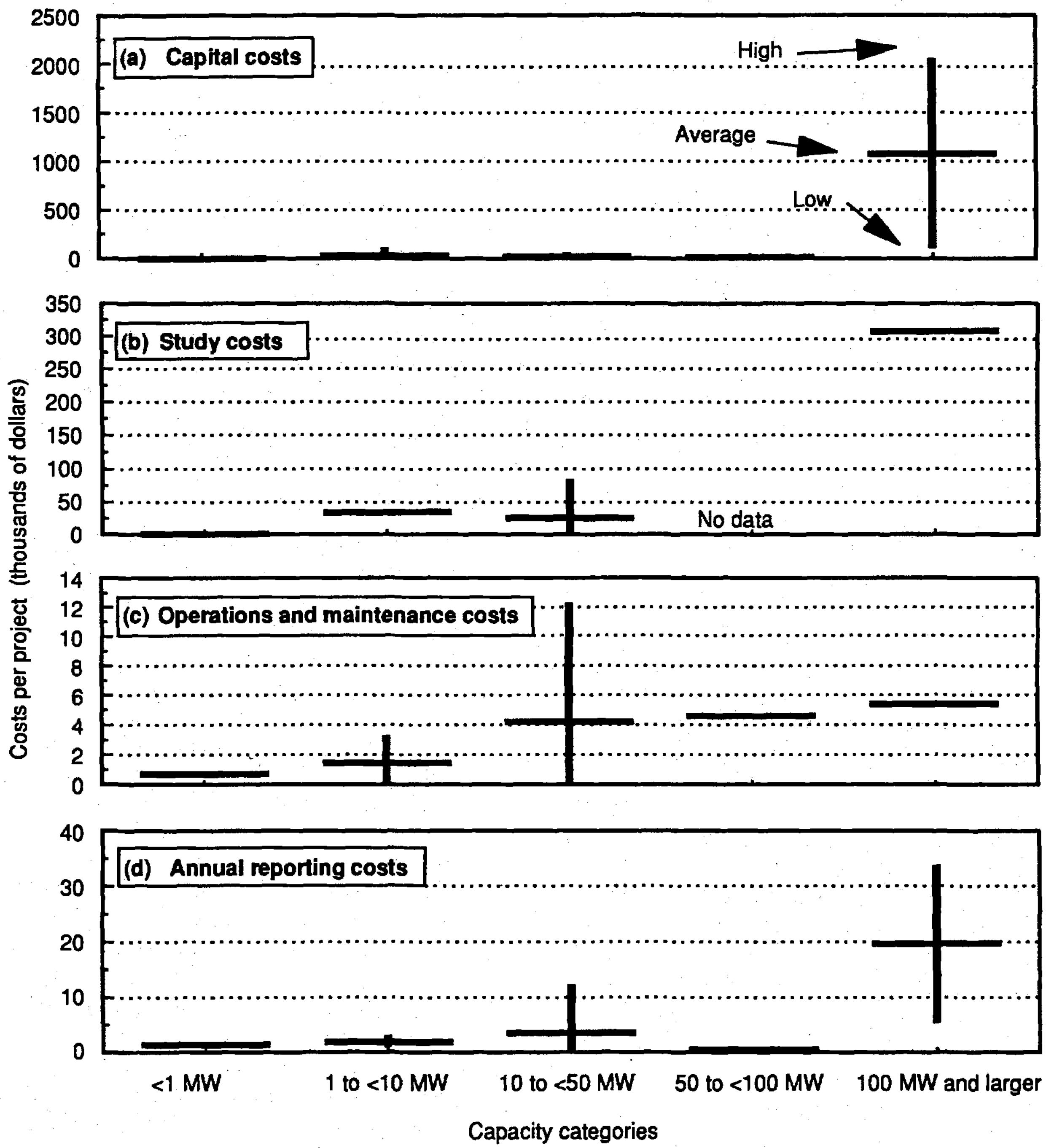

Figure 4-6. Range and average costs per project for dissolved oxygen (DO) mitigation, by project capacity category. Types of cost shown are (a) capital, (b) study, (c) operation and maintenance, and (d) annual reporting. Only one project in both the <1 MW and in the 50 to <100 MW capacity categories reported capital costs; only one project in both the <1 MW and in the 100 MW and larger capacity categories reported study costs. Both projects in the 1 to <10 MW capacity category reported the same study costs. Only one project in each of the <1 MW, the 50 to <100 MW, and the 100 MW and larger capacity categories provided O&M costs. Only one project in both the <1 MW and in the 50 to <100 MW capacity categories reported annual reporting costs.

presented are costs that are imposed on the owner because of DO mitigation requirements. A graphical summary (Figure 4-6c) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for DO mitigation O&M costs.

<1 MW. Only one project fit this category. This project did not have to take any action to meet minimum DO requirements. The mitigation method that would be employed, if necessary, is not mentioned. **Cost: $706.**

1 to <10 MW. One project, with $0 costs, has a minimum DO level, but no DO levels below the minimum have been measured since 1975. It is unknown what type of methods would be employed if necessary. The other two projects both use spill flows, and the higher cost project also uses aeration in the turbine and an aeration weir in the discharge channel. **Cost Range: $0 to $3,237.**

10 to <50 MW. All seven projects use spill flows when action is required to maintain minimum DO levels. One project, with a yearly O&M cost of $4,856, employs turbine aeration as well as spill flows. The $0 cost project has not needed to employ spill flows as the DO minimum level has not be attained. The removal of the highest cost project, at $12,293, reduces the average for the remaining six projects to $2,856. This would result in a distribution of three projects below and three projects above the average. **Cost Range: $0 to $12,293.**

50 to <100 MW. This single project shuts off flow through the plant when necessary to maintain DO requirements. **Cost: $4,610.**

100 MW and Larger. The single project providing O&M costs reported using turbine aeration as its DO mitigation method. **Cost: $5,396.**

Annual Reporting Costs for Dissolved Oxygen Mitigation. A graphical summary (Figure 4-6d) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for DO mitigation annual reporting costs.

<1 MW. **Cost: $1,413.**

1 to <10 MW. **Cost Range: $1,024 to $3,073.**

10 to <50 MW. One of the projects in this group of seven reports an annual reporting cost of $0. This project is required to monitor DO levels when the minimum flow drops below 300 cfs. Spill flows would be used for mitigation if necessary. However, the project has a minimum instream flow requirement of 300 cfs, and consequently, they do not currently monitor DO levels. The project at the high end of the cost range, at $12,293, measures DO levels at the intake and tailrace. Continuous meters that record on a chart and translation by hand are the methods used by the project operator at this second project. This process is done on a daily basis. **Cost Range: $0 to $12,293.**

50 to <100 MW. This project reports that DO levels are measured hourly, and the data is stored in a computer system. It is unknown if the data is measured manually or by computer. The low reported cost for annual reporting and monitoring conflicts with the indication that measurements are taken hourly. It may be that the computer time is not included in the costs, or the $512 represents the time to compile a report on monitoring but not the actual cost of monitoring itself. The actual situation is unknown, and the $512 figure should be used cautiously. **Cost: $512.**

100 MW and Larger. The project with the annual reporting cost of $33,940 measures DO levels every 15 minutes during the May to October period. This project provides data to its state Department of Natural Resources and the state Department of Energy. The other project in this group, reporting costs of $5,396, measures DO levels in the tailrace using continuous monitors from May through October. **Cost Range: $5,396 to $33,940.**

Lost Generation for Dissolved Oxygen Mitigation. Table 4-5 provides lost generation averages for projects with DO mitigation.

<1 MW. The project with the 17,520 kWh generation loss maintains a half-inch spill flow over its dam for DO and aesthetic reasons. The 75,000 kWh loss is associated with a 3 cfs spill flow. **Loss Range: 17,520 - 75,000 kWh.**

1 to <10 MW. Three projects report 0 kWh generation losses. Two of these three projects do not have to take mitigation action to meet DO levels. One of the projects indicates that DO levels have not fallen to the minimum level since 1975. No information is provided for the circumstances associated with the third, 0 kWh generation loss or the project with the 50,000 kWh generation loss. **Loss Range: 0 to 50,000 kWh.**

10 to <50 MW. One project reports 0 kWh losses because no mitigation action was taken as DO levels are acceptable. The 35,000 and 1 million kWh losses at two projects are for spill flows. **Loss Range: 0 - 1 million kWh.**

50 to <100 MW. There are not any projects reporting DO generation losses in this capacity category. **Loss: no data.**

100 MW and Larger. Both projects use turbine aeration when necessary for DO mitigation. **Loss: 0 kWh.**

Upstream Fish Passage Costs

This section contains a breakdown of all of the costs associated with upstream fish passage mitigation. It must be recognized that the capital and study costs may not be for the same projects. For example, respondents may have provided capital costs for upstream fish passage only or study costs for upstream fish passage only or both capital and study costs for upstream fish passage. Four projects have provided capital costs for upstream fish passage in the 1 to <10 MW capacity category, but only two projects provided study costs for upstream fish passage in the same capacity category. Similarly, the O&M costs and the annual reporting costs may be for different projects, but they are also summed. Capital and study costs for upstream fish passage are summarized by project capacity categories in Table 4-10. O&M and annual reporting costs are summarized in Table 4-11.

Capital Costs for Upstream Fish Passage. A graphical summary (Figure 4-7a) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for upstream fish passage capital costs.

<1 MW. The one project in this class uses a fish ladder for its upstream fish passage requirements. **Cost: $42,721.**

1 to <10 MW. The three projects in this class all employ fish ladders. The costs are $22,000, $43,000, and $183,000. The project with the $22,000 capital cost for upstream fish passage has a design head of 244 feet and an average annual flow of 42 cfs. The project with the $43,000 cost did not provide design head or flow information. The project with a cost of $183,000 has a design head of 33 feet and an average flow of 500 cfs. Although the flow size for the $183,000 project is larger than the $22,000 project, no correlation should be drawn from such a limited sample of two projects. However, it may be worthwhile to investigate correlations between capital costs and flow rates and/or design head during future analysis. **Cost Range: $21,584 to $183,090.**

10 to <50 MW. Of these six projects, two projects use fish ladders at an average capital cost of $380,000; two projects use fish elevators at an average cost of $1.5 million; one project is currently trapping and hauling fish with a truck at a capital cost of $154,000 while designing a fish ladder to replace this method; and the sixth project is using navigation locks which are operated by the state and are opened approximately seven times a day during navigation season. The opening of the locks is dependent on boat traffic, and the locks were installed for transportation. The blue back

Table 4-10. Average capital and study costs for upstream fish passage mitigation, provided by capacity categories. Because not all of the 141 projects in the database provided complete information, the number of projects reporting data in the table will often be less than 141.

	Capacity category					
	<1 MW	1 to <10 MW	10 to <50 MW	50 to <100 MW	100 MW and larger	Summary
Capital costs:						
Average per project	$42,721	$82,614	$653,997	N/A	$24,745,007	$6,034,582
Average per KW capacity	$106.80	$72.49	$35.09	N/A	$31.62	$31.85
Number of projects	1	3	6	0	3	13
Study costs:						
Average per project	$3,238	$36,280	$97,786	N/A	N/A	$51,275
Average per KW capactiy	$8.10	$31.83	$5.99	N/A	N/A	$8.43
Number of projects	1	3	2	0	0	6
Totals:						
Average per project	$45,959	$118,894	$751,783	N/A	N/A	$6,085,857
Average per KW capacity	$114.90	$104.32	$41.08	N/A	N/A	$40.28

herring at the project that uses navigation locks for upstream fish passage are not naturally present; they were introduced by lock operators. An upstream capital cost of $22,000 is reported for this project. It is highly doubtful that this is the cost of the locks, and no information was provided to indicate what this cost represents. **Cost Range: $21,584 to $1,810,113.**

50 to <100 MW. There are not any projects reporting upstream capital costs in this capacity category. **Cost: no data.**

100 MW and Larger. Two of these three projects employ fish ladders. These projects have average flows of more than 100,000 cfs. One project has three fish ladders on-site, and the second project has a single fish ladder. The average upstream fish passage capital cost for these two projects is $30 million. The third project reporting capital costs in this category employs fish elevators as part of its trapping and hauling system. The fish are trucked around three other upstream dams. The capital cost of $15 million for this third project includes the two fish elevators used to raise the fish to sorting tanks. **Cost Range: $14,597,040 to $37,093,227.**

Study Costs for Upstream Fish Passage. A graphical summary (Figure 4-7b) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for upstream fish passage study costs.

<1 MW. This project did not provide study type information. **Cost: $3,238.**

1 to <10 MW. Of these three projects one did not provide study type data. At a second project, with a study cost of $2,698, the licensee and state fisheries agency performed fisheries studies. The third project, at $100,745, performed fisheries studies with the National Marine Fisheries Service and the state fish and

Table 4-11. Average operation and maintenance and annual reporting costs for upstream fish passage mitigation, provided by capacity categories. Because not all of the 141 projects in the database provided complete information, the number of projects reporting data in the table will often be less than 141.

	Capacity category					
	<1 MW	1 to <10 MW	10 to <50 MW	50 to <100 MW	100 MW and larger	Summary
Operations & maintenance:						
Average per project	$2,158	$9,308	$9,918	N/A	$717,080	$79,675
Number of projects	1	3	5	0	1	10
Average mills per kWh capacity	2,158.00	2.26	0.12	N/A	0.41	0.37
Number of projects	1	2	4	0	3	10
Annual reporting:						
Average per project	$1,619	$3,853	$7,964	N/A	$78,536	$25,513
Number of projects	1	3	4	0	3	11
Average mills per kWh capacity	1,619.00	1.16	0.11	N/A	0.02	0.03
Number of projects	1	2	4	0	3	10
Totals:						
Average per project	$3,777	$13,161	$17,882	N/A	$795,616	$105,188
Average per KW capacity	3,777.00	3.42	0.23	N/A	0.43	0.39

wildlife department. **Cost Range: $2,698 to $100,745.**

10 to <50 MW. The highest cost project performed a mitigation study and the other project did not provide study information. **Cost Range: $5,122 to $190,451.**

50 to <100 MW. There are not any projects reporting upstream fish passage study costs in this capacity category. **Cost: no data.**

100 MW and Larger. There are not any projects reporting upstream fish passage study costs in this capacity category. **Cost: no data.**

Operation and Maintenance Costs for Upstream Fish Passage. A graphical summary (Figure 4-7c) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for upstream fish passage O&M costs.

<1 MW. This project uses a fish ladder. **Cost: $2,158.**

1 to <10 MW. All three of these projects use fish ladders. No specific evidence was present to indicate the reasons behind the range span. **Cost Range: $944 to $21,584.**

10 to <50 MW. Of these five projects, one uses a fish ladder at a yearly O&M cost of $1,024. Two projects use elevators at respective costs of $21,584 and $5,396. The fourth project uses a trapping and hauling system at a yearly

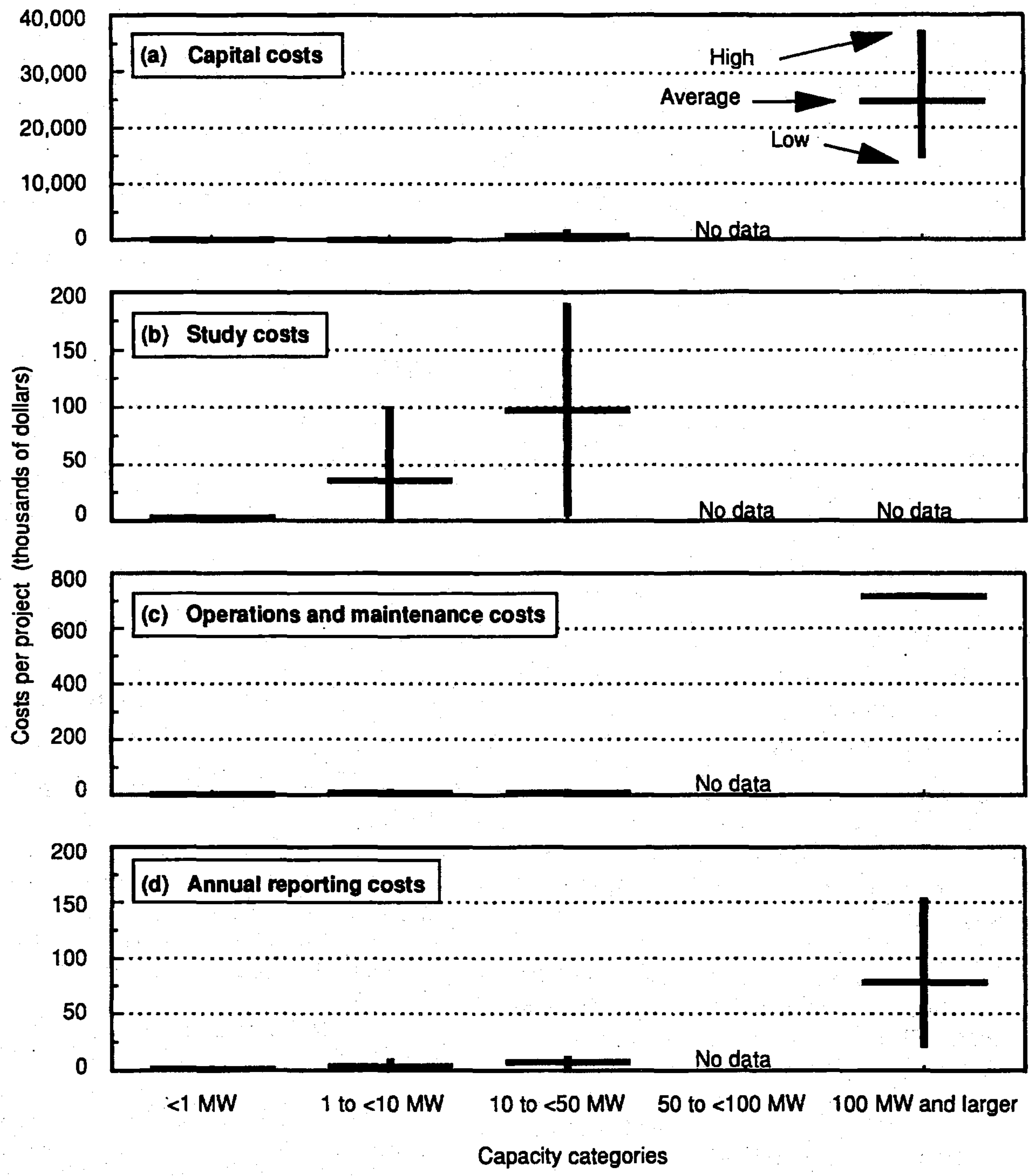

Figure 4-7. Range and average costs per project for upstream fish passage mitigation, by project capacity category. Types of cost shown are (a) capital, (b) study, (c) operation and maintenance, and (d) annual reporting. Only one project in the <1 MW capacity category provided capital costs. Only one project in the <1 MW capacity category provided study costs. Only one project in both the <1 MW and in the 100 MW and larger capacity categories provided O&M costs. Only one project in the <1 MW capacity category provided annual reporting costs.

O&M cost of $21,584. The fifth project reports a yearly O&M cost of $0. The upstream fish passage facility for this fifth project is a navigation lock. The operation of which is dependent on the amount of boat traffic for its operation schedule. The opening of the lock to allow upstream boat passage is the only way the blueback herring have of passing upstream. **Cost Range: $0 to $21,584.**

50 to <100 MW. There are not any projects reporting upstream fish passage O&M costs in this capacity category. **Cost: no data.**

100 MW and Larger. This project uses a fish elevator to raise the fish 40 feet to a sorting tank where biologists sort the fish to be hauled by truck upstream around this project as well as three additional upstream dams. This upstream fish passage facility is operated 6 hours per day, 2.5 months per year. **Cost: $717,080.**

Annual Reporting Costs for Upstream Fish Passage. A graphical summary (Figure 4-7d) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for upstream fish passage annual reporting costs.

<1 MW. This project checks the fish ladder once a month and logs fish passage rates. **Cost: $1,619.**

1 to <10 MW. The project with the $0 cost does not perform any monitoring. The project with the highest cost, at $10,792, monitors the fish passage rates. The third project did not disclose the reasons for its costs. **Cost Range: $0 to $10,792.**

10 to <50 MW. The project at the high end of the range monitors the fish passage rates and populations. The project at the low end of the cost range reports on its trapping and hauling program. Of the other two projects in this category, one performs hydro-acoustic monitoring of passage rates and the other project stated it also monitors passage rates. **Cost Range $2,158 to $12,805.**

50 to <100 MW. There are not any projects reporting upstream fish passage O&M costs in this capacity category. **Cost: no data.**

100 MW and Larger. The project at the low end of the cost range monitors fish passage rates and population size. The middle cost project, at $61,456, monitors fish passage rates with a fish counting program running from April through November. This is done to evaluate the upstream fish passage design. The $61,456 cost also includes the counting of the anadromous and resident fish populations, and an annual fish facility operations report is filed. This project, which is located in the Pacific Northwest, uses a fish ladder. The project with the highest cost, at $153,664, is located in the Northeast. It has an annual fish passage counting program for April through November. Fish populations are also counted. Passage and population rates are counted for the evaluation of operating procedures. **Cost Range: $20,488 to $153,664.**

Lost Generation for Upstream Fish Passage. Little information was obtained concerning generation losses and upstream fish passage mitigation association. Additionally, with a single project or no project in each category, reporting the range is superfluous. Table 4-5 provides lost generation averages for projects with upstream fish passage mitigation requirements.

Downstream Fish Passage Costs

This section contains a breakdown of all costs associated with downstream fish passage mitigation. It must be recognized that the capital and study costs may not be for the same projects. Respondents, for example, may have provided capital costs for downstream fish passage only or study costs for downstream fish passage only or both capital and study costs for downstream fish passage. Four projects have provided capital costs for downstream fish passage in the 1 to <10 MW capacity category, but only two projects provided study costs for downstream fish passage in the same capacity category. Similarly, the O&M costs and the annual reporting costs may be for different projects, but they are also summed. Capital and study costs for downstream fish passage mitigation are summarized by project size category in Table 4-12. O&M and annual reporting costs are summarized in Table 4-13.

Capital Costs for Downstream Fish Passage. A graphical summary (Figure 4-8a) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for downstream fish passage mitigation capital costs.

<1 MW. Twelve projects fit this category, with an average capital cost of $26,000. However, seven projects report capital costs less than $8,000. Three projects report costs of less than $1,000. These three projects use angle bar racks to project fish from turbine entrainment. Two of these three angle bar rack facilities are for the protection of resident adult fish, and the third project protects anadromous adults. The median cost for all 12 projects is $5,000. Four of the 12 projects report costs over the $26,000 average. The average design head for the entire group is 159 feet and the average flow is 70 cfs.

Of the 12 projects in the <1 MW capacity category, 4 projects use only angle bar racks; 4 use angle bar racks in conjunction with another measure such as sluiceways/bypasses (2 projects), velocity limits (1 project), or angle bar racks and wedge wire 1/8-inch screens with traveling cleaning brushes. Two projects use other screens such as stationary screens (1 project), wedge wire cylinder screens (1 project), and velocity limits. Eight of the projects employ downstream fish passage facilities for resident fish, one for anadromous fish, and three projects provide protection for both resident and anadromous fish. **Cost Range: $416 to $122,060.**

Table 4-12. Average capital and study costs for downstream fish passage mitigation, provided by capacity categories. Because not all of the 141 projects in the database provided complete information, the number of projects reporting data in the table will often be less than 141.

	Capacity category					
	<1 MW	1 to <10 MW	10 to <50 MW	50 to <100 MW	100 MW and larger	Summary
Capital costs:						
Average per project	$25,912	$277,125	$650,025	N/A	$12,900,020	$958,596
Average per KW capacity	$80.02	$77.24	$35.45	N/A	$14.05	$17.39
Number of projects	12	15	8	0	2	37
Study costs:						
Average per project	$9,848	$80,047	$198,824	N/A	$5,850,713	$638,887
Average per KW capacity	$21.24	$22.87	$10.94	N/A	$6.37	$6.88
Number of projects	4	11	4	0	2	21
Totals:						
Average per project	$35,760	$357,172	$848,849	N/A	$18,750,733	$1,597,483
Average per KW capacity	$101.25	$100.11	$46.39	N/A	$20.43	$24.27

Table 4-13. Average operation and maintenance, and annual reporting costs for downstream fish passage mitigation, provided by capacity categories. Because not all of the 141 projects in the database provided complete information, the number of projects reporting data in the table will often be less than 141.

	Capacity category					
	<1 MW	1 to <10 MW	10 to <50 MW	50 to <100 MW	100 MW and larger	Summary
Operation & maintenance:						
Average per project	$4,486	$11,182	$31,443	N/A	N/A	$13,946
Number of projects	11	13	8	0	0	32
Average mills per KW capacity	2.92	0.69	0.41	N/A	N/A	0.52
Number of projects	11	11	87	0	0	30
Annual reporting:						
Average per project	$1,058	$1,640	$4,157	N/A	N/A	$1,985
Number of projects	8	10	5	0	0	23
Average mills per KW capacity	1.10	0.11	0.06	N/A	N/A	0.09
Number of projects	8	9	5	0	0	22
Totals:						
Average per project	$5,544	$12,822	$35,600	N/A	N/A	$15,931
Average mills per KW capacity	4.02	0.81	0.47	N/A	N/A	0.62

1 to <10 MW. Of these 15 projects, 3 projects use sluiceways or bypasses exclusively to satisfy downstream fish passage requirements, 2 projects use screens meeting the California Department of Fish and Game screen standards, and 4 projects use another type of fish screen. One project has modified its sequence of operating its three units (2 Kaplans and 1 Francis) to protect fish. Five projects use a combination of methods such as angle bar racks and other screens or a velocity limit on intake screens. One project employs angle bar racks, a velocity limit on intake screens, and sluiceways or bypasses, all at a reported capital cost of $3,238. This project's protection facilities are designed for resident fish. The most expensive facility, at $2,374,268, employs angle bar racks and a velocity limit on intake screens to protect both anadromous and resident juvenile fish. Eight projects employ facilities to protect resident fish, four to protect anadromous fish, two to protect both types and one project's protection intents are unknown.

The average for this category ($277,125) is heavily influenced by a single project. Removing the largest project's cost of $2,374,268 produces an average of $127,329. At the actual average of $277,125, the dispersal of costs is skewed with 12 projects under the average and three over. At the reconfigured $127,329 average, eight projects are under the average and six are above the average. Initial observation does not lead to a correlation between costs and methods employed. The $3,238 cost project employs angle bar racks, velocity limits, and sluiceways or bypasses. The $2,374,268 project employs angle bar racks and velocity limits on intake screens. Future analysis may provide greater insight into the relationship

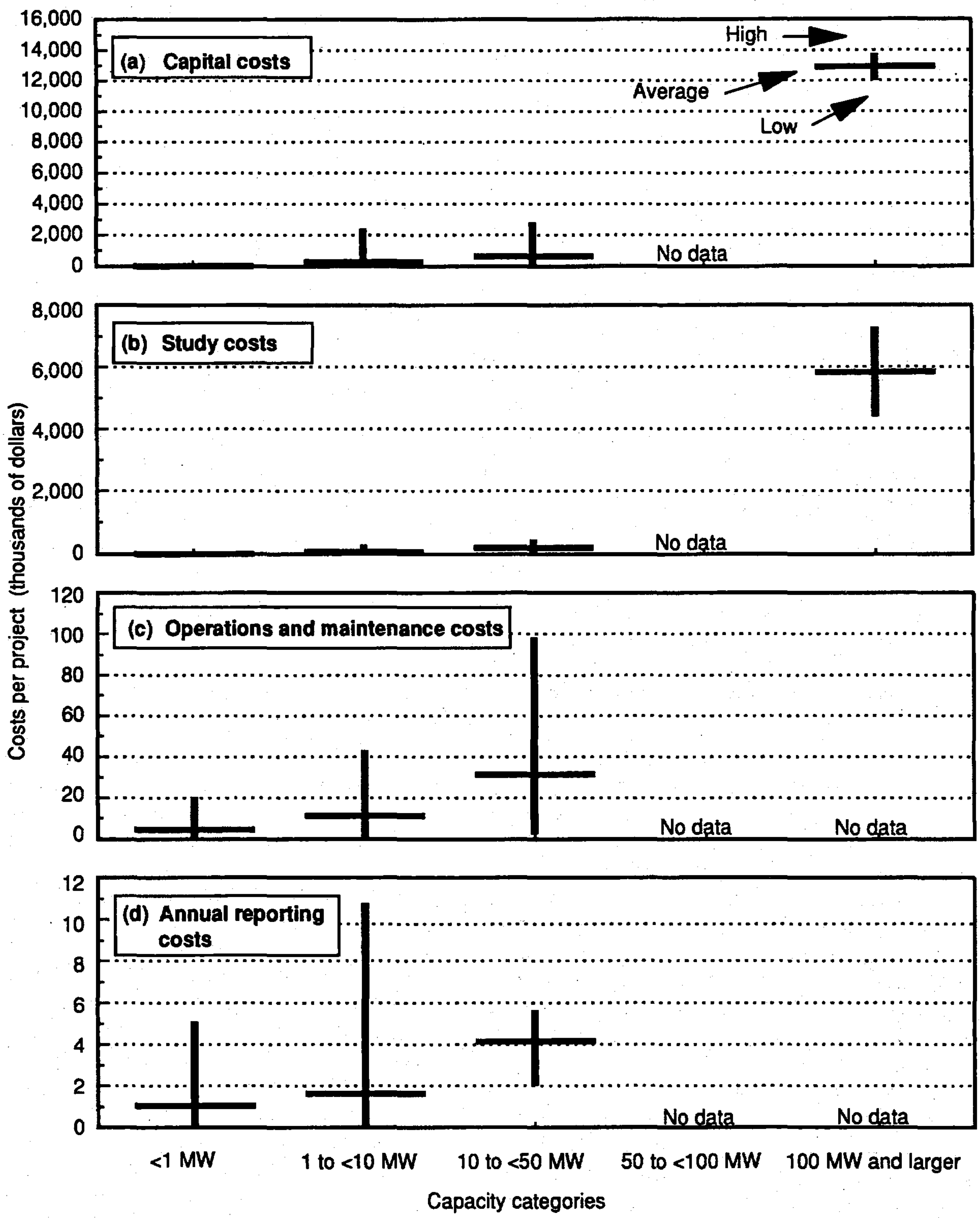

Figure 4-8. Range and average costs per project for downstream fish passage mitigation, by project capacity category. Types of cost shown are (a) capital, (b) study, (c) operation and maintenance, and (d) annual reporting.

among costs, methods used and benefits. Cost **Range: $0 to $2,374,268.**

10 to <50 MW. The most expensive mitigation cost in this category is almost three times more expensive than the next expensive downstream fish passage cost. Removal of this single $2,807,381 cost lowers the average to $341,832. This project uses as its downstream protection facility a static angled wedge wire screen, sluiceways or bypasses, and a velocity limit on intake screens to protect anadromous and resident fish. The lowest cost facility employs barrier nets, at $92,996, for downstream protection of resident Kokanee. One product employs a punch plate and overflow screening device, at $614,655, to protect resident fish. One project uses sluiceways or bypasses, at $215,843, to protect anadromous and resident fish. Five projects, including the most expansive project, apply a combination of methods, including angle bar racks, velocity limits, sluiceways or bypasses, and fish screens for downstream fish passage. **Cost Range: $92,996 to $2,807,381.**

50 to <100 MW. There are not any projects reporting downstream fish passage capital costs in this capacity category. **Cost: no data.**

100 MW and Larger. Only two projects, employing similar downstream fish passage methods, indicated they have capital costs as a result of downstream fish passage requirements. The cost range reflects the relative similarity in characteristics. Both projects report that the capital costs are for fish hatcheries that are the imposed downstream fish passage mitigation requirement. Additionally, both projects indicate fish screens are being developed and prototypes have been tested. Both employ spill flows, one project for 12 hours per night, at 20% of the daily average flow, during the period from April 20 to June 1. The second project spills 10 hours per night, at 10% of daily average flow, from April 20 to May 20. Both projects indicated their imposed downstream fish passage requirements are for juvenile anadromous fish. **Cost Range: $12,022,430 to $ 13,777,611.**

Study Costs for Downstream Fish Passage. A graphical summary (Figure 4-8b) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for downstream fish passage mitigation study costs.

<1 MW. Minimal specific information detailing the activities associated with downstream fish passage study costs was accumulated. Any pertinent information provided by the respondents will naturally be conveyed. **Cost Range: $3,238 to $21,584.**

1 to <10 MW. One project's study costs, at $16,970, was to study the mortality rates of brown trout passing through the downstream bypass facility. The highest cost study, at $281,428, was a licensee-conducted study of the turbine impact on fish passage. Another study, at $102,443, used radio telemetry to measure the percentage of smolts bypassing the turbine. **Cost Range: $5,657 to $281,428.**

10 to <50 MW. Of these four projects only one, with a study cost of $259,515, indicated the type of study performed. This project used hydro acoustics, with a fixed beam in the penstock, to scan the intake/bypass area. **Cost Range: $18,428 to $455,888.**

50 to <100 MW. There are not any projects reporting downstream fish passage study costs in this capacity category. **Cost: no data.**

100 MW and Larger. The $4,408,831 study cost includes hydro acoustic studies of spill efficiency, powerhouse passage, and orifice/bypass channel efficiency. The other study cost was for hydro acoustic studies of spill efficiency and powerhouse passage. **Cost Range: $4,408,831 to $7,292,595.**

Operation and Maintenance Costs for Downstream Fish Passage. A graphical summary (Figure 4-8c) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for downstream fish passage mitigation O&M costs.

<1 MW. The majority of these projects employ angle bar racks or angle bar racks and sluiceways or bypasses. The two projects with the highest O&M costs in this category employ different methods of fish protection. The most expensive project, at $20,489, uses stationary screens and a wiper system. The second highest O&M cost, at $8,195, is for a project that uses angle bar racks, wedge wire screens, a traveling brush to clean screens, and sluiceways or bypasses. **Cost Range: $216 to $20,489.**

1 to <10 MW. Two projects report $0 costs. One of these projects uses angle bar racks and sluiceways or bypasses. The second project with $0 O&M costs modifies the sequence of the operations of its three turbines to provide downstream fish passage. Most of the projects in the 1 to <10 MW category use sluiceways or bypasses. Two projects, at O&M costs of $10,792 each, use screens that meet California Department of Fish and Game screen standards. The most expensive cost, at $43,169, is for the O&M of stationary screens, and sluiceways or bypasses while attempting to limit fish mortality to zero. Of the two projects with the next highest reported O&M costs, both at $21,584, one employs traveling screens and a hydraulic trash rack, whereas the other project uses another type of fish screen. **Cost Range: $0 to $43,169.**

10 to <50 MW. The three lowest O&M costs, all less than $10,000, are at projects that use sluiceways or bypasses exclusively or in conjunction with spill flows. The project at the high end of the cost range, at $98,532, employs a static angle wedge wire screen. The second costliest project, at $51,221 uses angle bar racks, velocity limits, and sluiceways or bypasses. The third highest project uses a punch plate and an overflow screening device. One project, at $23,562, installs 3250 feet of barrier nets at the beginning of each irrigation season, which runs ~5 months a year. **Cost Range: $2,561 to $98,532.**

50 to <100 MW. There are not any projects reporting downstream fish passage O&M costs in this capacity category. **Cost: no data.**

100 MW and Larger. There are not any projects reporting downstream fish passage O&M costs in this capacity category. **Cost: no data.**

Annual Reporting Costs for Downstream Fish Passage. A graphical summary (Figure 4-8d) is provided in this section, as well as descriptive narrative detailing the ranges, averages and project characteristics for downstream fish passage mitigation annual reporting costs.

Unfortunately, suitable data was not obtained that would exemplify the types of annual reporting functions performed in association with the reported costs. For this reason only the ranges are provided below with minimal explanation.

<1 MW. Four projects reported $0 costs. **Cost Range: $0 to $5,122.**

1 to <10 MW. Four projects reported $0 costs. **Cost Range: $0 to $10,792.**

10 to <50 MW. **Cost Range: $2,049 to $5,657.**

50 to <100 MW. There are not any projects reporting downstream fish passage annual reporting costs in this capacity category. **Cost: no data.**

100 MW and Larger. There are not any projects reporting downstream fish passage annual reporting costs in this capacity category. **Cost: no data.**

Lost Generation for Downstream Fish Passage. Table 4-5 provides lost generation averages for projects with downstream fish passage mitigation requirements.

<1 MW. Five projects reported 0 kWh generation losses. The average generation loss of the three projects reporting generation losses exceeding zero is 233,000 kWh. **Loss Range: 0 to 500,000 kWh.**

1 to <10 MW. Four projects reported 0 kWh generation losses. Four projects reported generation losses in the 150,000 to 320,000 kWh range. The highest loss, at 3,240,000 kWh, is ten times the loss of the next highest loss. The four mid-range generation losses average 233,000 kWh. **Loss Range: 0 to 3,240,000 kWh.**

10 to <50 MW. One project reported a 0 kWh generation loss. **Loss Range: 0 to 565,000 kWh.**

50 to <100 MW. There are not any projects reporting downstream fish passage generation losses in this capacity category. **Loss: no data.**

100 MW and Larger. These two projects, both in the Pacific Northwest, reported extremely similar and very significant generation losses resulting from downstream fish passage mitigation practices. A generation loss of the magnitude of 64.5 million kWh equates to a yearly dollar loss, assuming $0.05/kWh, of $3,225,000. **Loss Range: 64,197,000 to 64,974,000 kWh.**

Data Assumptions

The following are the assumptions and considerations in screening, identifying, and reporting the data:

Annual Reporting. It is sometimes difficult to accurately differentiate what specific functions are being performed in conjunction with the annual reporting costs that were provided by the project owners. It appears that the distinction between annual reporting and study costs may be ambiguous. Additionally, the respondents were not specifically queried to provide an explanation of annual reporting costs. Consequently, the cost data will be presented as gathered, with minimal explanation provided.

A conclusion some may draw concerning annual reporting costs is that, generally, the fiscal demands for annual reporting of mitigation measures are not substantial especially when compared with the other mitigation costs. It might be assumed that the developers do not view the reporting costs as distinct, exorbitant costs, and as a result, they are not tracked precisely.

Capital Costs. Two owners included the capital cost of a fish hatchery as their downstream fish passage capital cost because construction and operation of a fish hatchery is a downstream fish passage requirement. This cost was employed as presented by the owners.

Several project owners provided data on projects planned for the future. These projects were discarded because the costs are estimates that may be pure conjecture. The estimated environmental mitigation costs may be based on the results of studies that have yet to be concluded, if even inaugurated. Future costs are subject to unknown constraints (i.e. licensing requirements), and they are too unreliable to use. Also, a project may never be built because of some factor such as financing shortages. It would have been a dubious practice to use these potentially phantom projects.

Costs. Some costs may have been unobtainable because many projects do not have accurate cost figures broken down.

Cost Normalization. All costs were converted to the base year of 1991. The March issues of Business Conditions Digest for the years 1988 through 1991 were used to construct a price index based (Table 4-14) on the consumer price index.

Cost Years. If the year that a cost was incurred was not provided by the developer, it was assumed that the year the cost was incurred was 1989 for the sake of establishing the present value of the respective cost. For the costs that had associated years, the average years that the various costs were incurred were pre-

Table 4-14. Present value adjustment index used to equate all study costs to 1991 dollars.

Year	Consumer price index[70]	Multiplier index
1991	133.79	1.0000
1990	130.60	1.0244
1989	123.97	1.0792
1988	118.26	1.1313
1987	113.63	1.1774
1986	109.61	1.2206
1985	107.60	1.2434
1984	103.90	1.2877
1983	99.60	1.3433
1982	96.50	1.3864
1981	90.90	1.4718
1980	82.40	1.6237
1979	72.60	1.8428
1978	65.20	2.0520
1977	60.60	2.2078
1976	56.90	2.3513
1975	23.80	2.4868
1974	49.30	2.7138
1973	44.40	3.0133
1972	41.80	3.2007
1971	40.50	3.3035
1970	38.80	3.4482
1969	36.70	3.6455
1968	34.80	3.8445
1967	33.40	4.0057
1966	32.40	4.1293
1965	31.50	4.2473
1964	31.00	4.3158
1963	30.60	4.3722
1962	30.20	4.4301

1989. For the lack of better information, 1989 was used to better reflect reality.

Future Costs 1992–2010. The future costs of mitigation have been estimated for the time period 1992-2010 and provided in the cost conclusion section (Section 6). Some 436 projects have been identified as due to expire during this period and it is estimated another 1316 new projects will be licensed. As was mentioned previously in this report (Figure 3-2), the number of projects having mitigation requirements escalated during the 1980's and there is every likelihood that this trend will continue in the future. For the purpose of estimating future mitigation costs it has been estimated that the frequency of mitigation requirements during the 1990's will be: DO - 31%, instream flows - 73%, upstream fish passage - 12%, and downstream fish passage - 48%. It was assumed that the frequency of mitigation requirements for the 2001-2010 time span will be: DO - 49%, instream flows - 95%, upstream fish passage - 14%, and downstream fish passage - 82%.

Instream Flows. It was apparent that some owners provided the percent of required release that flowed through the turbines, whereas others provided the percent of total flow through the turbines that was the required release. Thus, the data obtained concerning required release rates as a percent of the average annual flow through the turbines was not used for any analysis.

A few projects have been included that indicated that a part of or all of their instream flow requirements are for aesthetic reasons. This was not a clear issue, and for these few projects it is difficult to ascertain what percentage of instream flow requirements were for aesthetic reasons only, versus a combination of fish mitigation issues and aesthetic reasons. However, it is felt that only 2 to 5 projects have this possible conflict, and no attempt was made to segregate these projects.

Mitigation Study Requirements. One owner indicated a preimplementation study was performed, and it was determined that it was not necessary to take any mitigation action based on the results of the study.

Plant Factors. Plant factors for the database were computed in an effort to identify projects that had obviously erroneous data. The formula used was as follows: (Annual Energy (MWh) X 1000) / (Plant Capacity x 8760). Four plants had a plant factor of zero because of missing data. Closer examination of these four projects did not provide any evidence of erroneous data. Two projects exhibited plant factors under 1%. The circumstances surrounding these two plants explained the low plant factors (i.e., no water at a project in California). Three projects had plant factors over 85%. Again these appear to be legitimate values, such as, municipal power systems. The range of plant factors is 0.03% to 93.4%. The average plant factor is 53.9%. The extreme plant factors do not appear to be the result of data errors, rather, the results of low water flows and municipal water systems, respectively.

Pumped Storage. Projects identified as being pumped storage were excluded from the database. The operating mode of these projects would skew the data, they are not conventional hydroelectric projects, and they may be closed or semiclosed systems without any associated mitigation issues.

Study and Annual Reporting Clarity. It is difficult to determine if a study was a preimplementation study to determine mitigation needs as required by an agency or if the study was performed after mitigation implementation and the study was a follow-up study to determine the success of the mitigation issue. Additionally, the distinction between monitoring and annual reporting is blurred. The only option available was to report the data as obtained.

Study Costs. The costs provided by the owners appear to represent the costs of single studies as well as the combined costs of several studies. This report has attempted to present all of the study costs associated with a mitigation issue. Regardless of whether the study costs presented by the project owners represent single or numerous studies, the costs are presented as the study costs associated with the respective mitigation practices.

It was attempted to measure the study costs required for project licensing and for the design of mitigation requirements. These costs are provided, but it appears other study costs are included. For instance, studies that measured the effectiveness of mitigation implementation and studies that were requested by state agencies but not FERC, were included in the study costs provided by the developers. These are costs that were imposed on the developer in conjunction with mitigation requirements, and they have not been excluded. It also would be extremely difficult to distinguish between prelicense and postlicense study costs as provided by the developers. Several owners indicated that various agencies continue to require various studies unrelated to the license conditions.

The study costs are not always the cost of a single specific study; rather, they are the study costs associated with a specific mitigation issue. The study may have taken place over several years, or a licensee may have been required to complete more than one study by more than one agency.

If an owner did not indicate a study was done, it cannot be assumed that no study occurred. It may be that a study was done but the developer is unaware of the cost. It was felt that when the responsibility to conduct a study was not assigned to the developer, the cost of a study cannot be zero to the developer since the developer is not responsible for the study cost.

Study Years. If multiple years for a study are provided, each year's cost is converted to 1991 dollars and entered into the database as a single sum amount but no date is provided in the database to avoid the appearance that it is a hard, single date. Dates are noted on the work sheets.

Work Hours. Annual O&M Costs, and Annual Reporting Costs were reported for several projects in terms of work hours expended per year. This data was converted to dollars per year so it would be in an usable media (dollars). A per-hour figure of $25 was used to represent salary, benefits, any overhead charges, and any inefficiencies involved in such small function tasks.

Zero Costs. Considerable discussion transpired concerning the indication of no capital cost (zero) in the database. A DO requirement, for example, may be satisfied through the application of spill flows and not involve any additional capital structure, thus no capital costs. If the developers indicated this was the situation, a zero was entered into the database in the DO capital cost field. Each cost field in the database has an associated logic field to indicate if the cost field contains pertinent data. The setting of the DO capital cost logic field to true indicates that a zero value (or any other cost for that matter) was an actual depiction of the capital cost associated with DO.

It may be argued that zero costs should not be included in a sum or average measurement. However, it has been attempted to measure the costs associated with the respective mitigation methods, not to purely measure the costs of specific acts such as the building of a capital structure to meet a DO requirement. If a project complies with DO requirements without additional capital expenditures, then that project's true capital cost is zero.

An exception to the general treatment for the handling zeros is study costs. Several projects reported that a study was done but the cost was zero. The true cost of the study was, in reality, unknown to the developer. Thus, only actual study costs greater than zero were used. The entire matter of how to handle study costs is compounded by the fact that pre- and postimplementation study costs, monitoring costs, and reporting costs were not acutely defined.

5. MITIGATION BENEFITS AND EFFECTIVENESS

For the purposes of this study, mitigation benefits are defined as any positive responses, measured in either monetary or nonmonetary values, in the natural resources that are the subject of mitigation requirements. The evaluation of mitigation benefits does not require that dollar values be placed on all environmental attributes, and in many situations monetary values are either inappropriate or impossible to calculate (e.g., endangered species, non-game species, or biodiversity values).

Introduction

The benefits of mitigation include a continuum of values (Figure 5-1), depending on the nature of the impact that is being mitigated. For example, as instream flows are implemented, the benefits derived may include wetted surface area of the river channel, suitable habitat for fish, higher standing crops of harvestable sport fish, and ultimately, an increase in the economic value of a downstream fishery. Similarly, the benefits of DO mitigation may include the concentration of oxygen in a river, higher productivity of the downstream aquatic ecosystem, greater survival and reproduction of individual fish, and, again, an economic increase in a fishery. Fish passage requirements may also lead to benefits such as increases in survival and reproduction of individual fish, more robust fish populations, and greater economic value of fisheries. The appropriate measures of mitigation benefits depend on local resource management objectives and resource management targets (e.g., an endangered species vs a put-and-take fishery). Available data can also be a serious limitation to the types of benefits that can be evaluated.

One important goal of this study is to determine the degree to which available information allows mitigation benefits to be evaluated. This current volume answers this question at a generic level, while more detailed case studies are planned for later reports from this study (see Section 1 for plans). Unfortunately, the results of the study to this point lead to the conclusion that for most hydropower projects that have been licensed recently, there is insufficient information to conduct any quantitative analysis of benefits.

Instream Flow Benefits

Mitigation for IFN, defined as the flow of water required below a dam to avoid adverse impacts on downstream fish and other aquatic biota, may be the most universal and costly issue in relicensing hydroelectric plants. Most states now recognize the need to protect instream flows and their associated values, including fishing and recreation. Under the new regulatory policies established by ECPA, environmental constraints such as IFN are more likely than ever to place operational restrictions on hydropower projects. The FERC expects that environmental analysis and mitigation (e.g., minimum flows) will be the keys to effective relicensing. Many of the hydro projects subject to relicensing will be faced with the question of IFN for the first time.

Previous Studies and Evaluation Methods. Very few studies have been able to quantify the benefits derived from instream flow requirements. This problem is the basis for the frequent challenges to established instream flow methodology.[6,71-73] One interesting study that did estimate economic fishery benefits was done on the John Day River in the Columbia River Basin.[74] These results indicated that increased summer flows to enhance fishing had a marginal value of ~$2.40 per acre-ft, but they also suggested that the value may be 10 times higher if other methods were used. Another study[75] examined the trade-offs between agricultural water use and IFN and estimated that instream flow values ranged from $14 to $27 per acre-foot. Both these studies used a marginal value approach, and neither looked at instream flows in the context of hydropower trade-offs. A

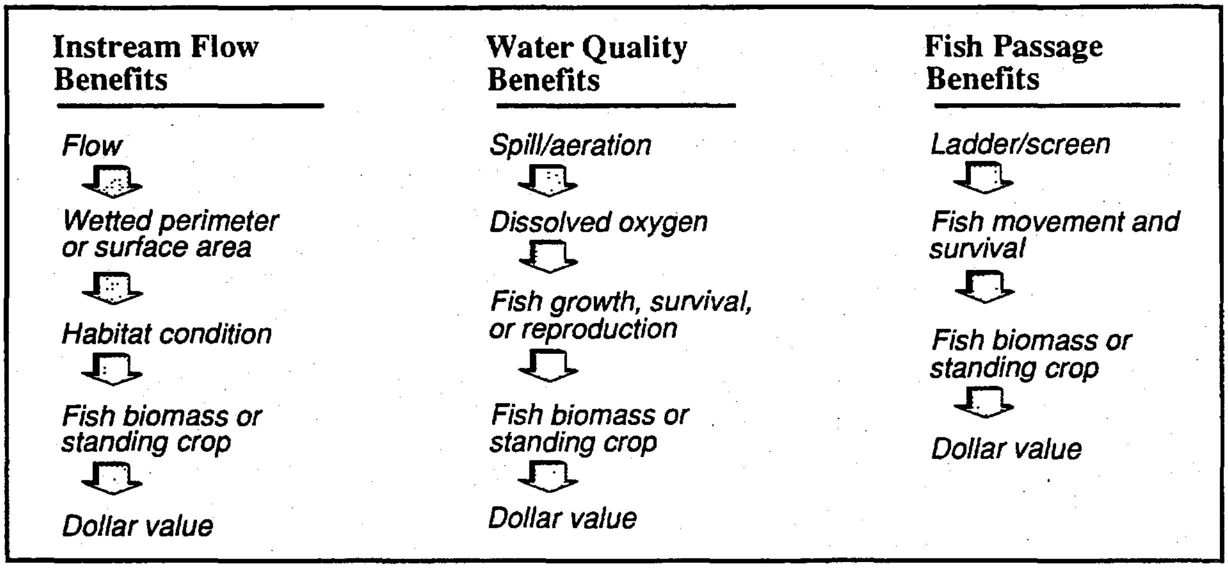

Figure 5-1. Series of benefits resulting from each of the three types of hydropower mitigation.

literature search for more studies of this type did not uncover any other significant contributions.

Although they are few in number, there have been some successful demonstrations of instream flow benefits to fish. For example, new minimum flow requirements at Rob Roy Dam (a non-hydro water supply project) on Douglas Creek in Wyoming were studied to determine fish response.[76] Below the point of water diversion on Douglas Creek, as minimum flows were increased from 1 cfs to 5.5 cfs, wetted stream width increased by a factor of 2, Weighted Usable Area (WUA) for adult brown trout increased by a factor of 5, and brown trout numbers increased from four- to sixfold. These fish benefits were attenuated several miles downstream as unregulated tributaries entered the stream. Another study of biological response to instream flows on the Susquehanna River below Conowingo Dam[77] demonstrated up to a 100-fold increase in macroinvertebrate abundance when minimum flows were increased from essentially zero to 5000 cfs. This study below Conowingo Dam did not quantify fish response. These and other successful case studies are planned to be presented in later volumes of this DOE mitigation study.

Quantifying Mitigation Benefits. To estimate the benefits of instream flow releases, the units by which benefits will be measured must be defined. Since maintaining fish populations is usually the ultimate objective of instream flow releases, population size (i.e., numbers, weight, or productivity) should be the primary measure of instream benefits. However, it is often more feasible to relate instream flows to physical habitat than to population sizes, and therefore physical habitat is the resource value most commonly used to determine instream flow requirements. When physical habitat is used as the primary resource value, an assumption that habitat value is proportional to population value is also implicit. Other resource values may nevertheless sometimes be appropriate measures of the benefits of instream flows.

Physical Habitat. Physical habitat is commonly used as a measure of instream benefits to fish. This is largely because physical habitat is more easily related to flow rates than are fish populations. Many methods using physical habitat as an indicator of instream flow benefits have been developed.[5] One of the earliest of these methods[78] defined the area of usable habitat as the stream area having usable depths and current velocities. The diversity of fish species in streams and rivers has been related to the diversity of physical habitat, as defined by depth, velocity, and substrate type.[79,80]

The physical habitat indexes that are currently used include stream width and wetted perimeter (indicating only the area or volume of stream available for fish), and the WUA parameter used by the IFIM. The WUA parameter combines the stream surface area, depth, velocity, and substrate type with habitat requirements specific to fish species and life stages. The value of WUA is intended to represent the aggregate quality and amount of space in a stream that is usable by a particular life stage of a fish. Physical habitat indexes are commonly evaluated by using hydraulic models and, in the case of the IFIM, a fish habitat suitability model. These models allow prediction of the amount of habitat over a range of instream flows. Measured instream flow rates can be used with a model-generated relation between flow and habitat index to develop a time series of physical habitat. If models are not used, physical habitat indexes can be measured for individual flow rates in the stream.

Uncertainties in the value of the habitat index arise from inaccuracies in the models used to estimate the relationship between flow rate and the physical habitat index. Errors in the hydraulic modeling as a result of (a) errors in the parameters used in the specific application and (b) systematic errors that result from the approximations and assumptions built into the model. These hydraulic modeling errors can be checked by comparing results with field data. Uncertainty in evaluation of WUA also arises from the suitability function used for each fish species and life stage for each of the hydraulic parameters. Important issues in the development of suitability functions include (a) interpretation of field data to develop suitability functions that can accurately represent a fish's selection among available habitat types, (b) the validity of using suitability functions in streams or regions other than where the field data they were developed from were collected, and (c) the effects of interspecific competition on suitability functions.[81-83]

As an indicator of instream flow benefits to fish, it is desirable to use a habitat measure that is related to fish populations as closely as possible. There are uncertainties in how physical habitat indexes such as WUA can best be related to fish populations, either at the level of a specific stream reach or a longitudinal mosaic of different types of reaches, each of which may respond differently to stream flows. For example, investigators sometimes try to predict populations as a function of the WUA present at the time populations were measured and sometimes try to predict populations as a function of the WUA occurring over some past time period. As discussed below, some field studies have shown that fish populations are best related to some function of minimum habitat availability.

Relations Among Physical Habitat, Flow, and Fish Populations. When WUA is used as an indicator of biological benefits of instream flows, the issues of how WUA is related to instream flow rates and to fish populations become critical. Although the relationship between WUA and flow varies among study sites and fish species, WUA typically rises to a peak as flows increase from zero, and then decreases at relatively high flows.[84] Therefore, there is not a linear relationship between physical habitat and flow, and increases in flow cannot be assumed to always provide an increase in physical habitat.

Under current theory, the amount of WUA in a stream should have a strong effect on fish populations during (and only during) times when physical habitat limits population size.[83] Such times may include either periods of peak runoff (typically in spring), when juvenile life stages that are unable to swim well are present and are susceptible to being washed away; or periods of low flows (typically in late summer and fall), when there may be inadequate habitat space for adults. During other times populations may be controlled by factors other than physical habitat, such as food availability, fishing mortality, and predation. Therefore, relations between WUA and fish populations are frequently complex and difficult to identify.[83]

Fish Population Benefits. Stream fish populations are most commonly evaluated by the number of fish and sometimes weight (biomass) of fish per unit of stream length or surface area. Field measurements, along with common data analysis techniques, provide these data. Field measurements of fish numbers and weight taken periodically at the same location can also be used, with more elaborate analysis techniques,[85,86] to estimate the biomass production of a stream fish population. Production estimates indicate not only the numbers of fish but also their growth and reproductive success. To examine the success of instream flow requirements at hydro projects, estimates of fish population sizes, biomass, and production can be compared with values measured prior to construction of a project or values in undisturbed and similar stream reaches.

One source of uncertainty in the use of fish population data is the uncertainty in the population measurements. In small streams fish populations can be measured relatively accurately, although variation over time and stream length in populations commonly introduces considerable uncertainty into estimates of long-term population size and production rates. Data analysis techniques allow for quantification of these uncertainties.[86] In streams too large to block off with fish barrier nets and to wade in, fish populations may be measured using other methods such as mark-and-recapture, which usually produce results with even higher uncertainties.

When fish populations are used as a measure of instream flow benefits, the question of what is an adequate or desirable population arises. Measured fish populations at a site affected by a hydroelectric project are most likely to be compared with populations at the site prior to development of the project (if such information is available) or to populations at nearby sites that are similar and unaffected. Before it can be determined whether an instream flow provides acceptable fish populations, an acceptable population level (including consideration of variability and measurement uncertainties) must be defined. Unfortunately, reliable estimates of fish populations and carrying capacity are generally not available, even for undisturbed streams. Lack of adequate data is a serious limitation to fisheries managers.

A number of other important uncertainties and complications occur in the use of fish population parameters as a measure of instream flow benefits. Complications generally arise because flow rates may control population size only some of the time, and the times when flow rates exert greatest control on fish populations can change. If fish populations are adequately high, it can be concluded that instream flows are sufficient. If populations are low, factors other than low flows, such as water quality or short-duration high flows, may be the cause. For these reasons, it is difficult to determine from population data alone if an instream flow is too low. However, additional studies, such as monitoring of feeding habits, water quality, and temperature, can be used to identify causes of low fish populations. In general, fish population data, without other studies, can show that (1) fish populations are adequate, so it can be assumed that instream flows are not too low (and possibly higher than necessary), or (2) fish populations are lower than desired, and inadequate instream flows are one of several possible reasons. Additional studies can be used to determine with greater confidence whether instream flows are higher or lower than necessary to maintain a target fish population.

Other Measures of Instream Benefits to Fish. In some cases, measures of instream flow benefits other than fish populations or physical habitat are appropriate.[87] On streams that provide important recreational fisheries, fishing use rates (e.g., fishing visits per day) and fishing success rates (e.g., fish caught per fishing day) can be monitored to determine if instream flows are successful. Fish harvests are important benefit measures where instream flows affect commercial fisheries, especially salmon. In streams where preservation of certain fish species or populations (which may be rare, threatened, or endangered) is an important fisheries management objective, the continued presence of self-sustaining populations of the target species is an appropriate indicator of instream flow benefits. These and other measures of benefits are appropriate in some cases but are not given detailed consideration in this study.

Available Data on Instream Flow Benefits. Monitoring the benefits of instream flow releases appears to be relatively uncommon. Figure 5-2 shows the percentage of operating projects with instream flow requirements that conduct monitoring of different resources. (Monitoring practices of projects that are licensed but not yet operating are generally unknown.) Nearly half of the projects monitor flow rates, although flows are measured only occasionally at some of these. Only about 20% of the projects reported any monitoring of fish populations that could indicate whether the instream flow mitigation is biologically successful. Monitoring of habitat quality, sediments, and water quality is conducted even less frequently.

It is possible that some projects providing information for this study chose not to report their monitoring practices out of concern with license compliance issues. However, the results do illustrate that many projects appear unable to verify that the required flows are provided. The benefits of instream flows to fish populations are measured at relatively few projects, which is at least partially a result of the expenses and uncertainties of fish population monitoring. State respondents did identify 13 specific FERC-licensed projects at which instream flow monitoring is being conducted to quantify the response of fish populations or habitat to flow alternation. The monitoring activities at these projects will be examined in more detail in future volumes of this study.

The FWS recently completed an independent study to identify IFIM applications where instream flows were established[10] and to evaluate their success. This study estimated that 616 IFIM studies have been conducted since the IFIM was developed (approximately 1976) and that only 6 of these studies included any followup information on the response of fish populations. This FWS study concluded that the degree of protection provided by IFIM studies was essentially unknown. The primary reasons for this uncertainty were that (a) very little post-project monitoring has been conducted, and (b) negotiated flow requirements do not appear to be implemented in many cases.

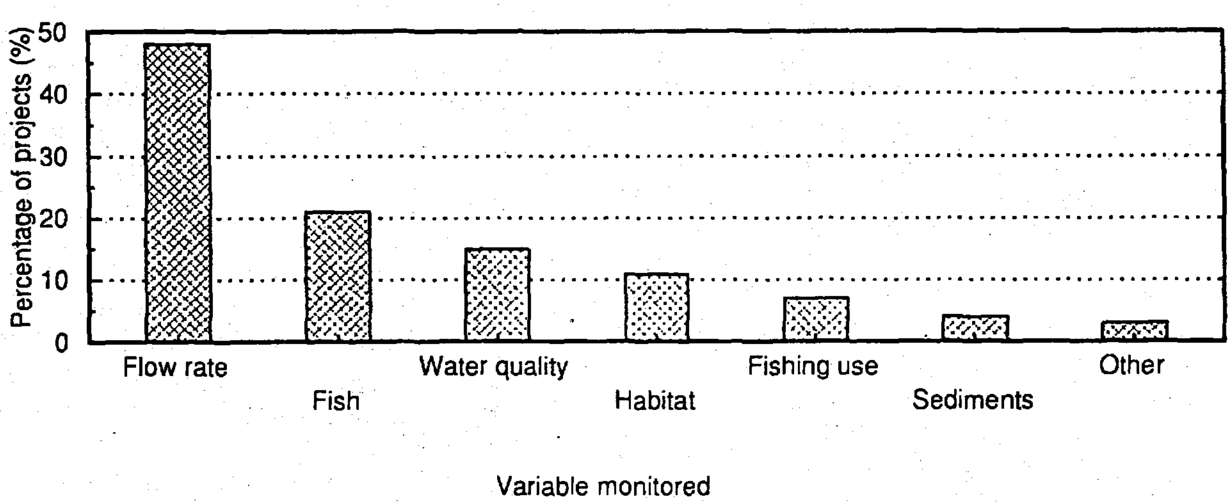

Figure 5-2. Monitoring at operating projects with instream flow requirements.

Dissolved Oxygen Benefits

The effectiveness of DO mitigation can be measured at several points along the continuum of benefits (Figure 5–1). Mitigation–induced increases in DO concentrations can be measured, and the effectiveness of mitigation then expressed as increases in average summer DO concentrations or other physico–chemical terms. DO conditions can in turn affect aquatic organisms at all levels of biological organization, from algae and zooplankton to mollusks, snails, crayfish, and other macroinvertebrates to fish.

As specific indicators of stream ecosystem condition, benthic macroinvertebrates have significant advantages over fish. Their greater species diversity makes changes in species composition easier to detect and interpret. In addition, because they are substantially less mobile than fish are, responses can be better linked to the location where samples are taken. A variety of specific endpoints may be evaluated. Useful endpoints are those expected to respond to improvements in DO. For invertebrates, occurrence and relative abundance of species (or higher taxon) are most relevant. Interpretation is based in part on knowledge of the relative sensitivity of different types of invertebrates to low DO concentrations.

Fish are of particular importance for economic and recreational reasons. Also, because they tend to be at the top of the food web, they serve as biological integrators of system function. Besides species occurrence and abundance of fish, endpoints expected to respond to changes in DO concentrations include growth rates and condition factors (e.g. plumpness).

In short, there are a number of endpoints that can be used to measure the effectiveness of DO mitigation. The following sections (1) review previous research on this subject, focussing on biological research, and describe scientific methods available to investigate biological benefits, and (2) discuss the extent to which benefits of mitigation have been measured at U.S. hydropower sites, based on information on monitoring activity provided by hydropower developers and resource agencies.

Previous Studies and Evaluation Methods. Researchers in the past several years have attempted to relate improvements in DO concentrations to enhancement of biological resources in streams. Some reports for example have described measures to provide DO mitigation and have presented observations on subsequent fishery improvements. Efforts have also been made to more rigorously examine biological responses to changing DO regimes by subjecting fishery and benthological data sets to statistical and other analytical examinations. Finally, other studies have employed biological models to translate changes in DO conditions into changes in such biological endpoints as fish growth over one or more seasons. The following paragraphs summarize published research found by a literature search covering the period 1985–1991, and collected from agencies and developers providing information on their work regarding DO mitigation as described in Section 3.

A report on DO mitigation in the St. Croix river basin between Maine and New Brunswick, Canada, provides interesting qualitative information on biological benefits of mitigation.[88] Pulp and paper mill effluents and river regulation transformed the lower 14 km of the St. Croix river from an exceptionally prolific salmon stream to a waterway virtually unable to support fish populations. In the late 1970s, treatment of mill effluents was much upgraded and summer DO concentrations dramatically increased. In the early 1980s, prompted by improvements in river water quality, steps were taken to restore the stream's anadromous fishery. These steps included construction of fishways at dams on the lower St. Croix and fish stocking programs. Counts of returning salmon and alewives through the 1980s suggest that restoration has succeeded. The author emphasizes that the coexistence of both a reviving fishery as well as much increased pulp and paper production was almost unimaginable in the 1950s, when it was felt that development of environmental resources and paper products industry were incompatible. The author reported that the contribution of DO improvements to the fishery restoration was crucial although it would be difficult to separate the contribution of DO improvement from other factors such as removal of barriers to fish passage.

Occasional fish kills in the tailwaters of USACE dams in eastern Oklahoma spurred efforts by USACE staff to develop DO and water temperature mitigation measures for these projects. A report on measures to mitigate critical fishery conditions at two USACE hydroelectric projects in eastern Oklahoma describes preliminary benefits of mitigation efforts.[89] At Eufaula Lake, a 90 MW reservoir with maximum depth of 28 m and surface area of 43,000 ha, a continuous low-level sluice release of .7 m^3/sec considerably raised tailwater DO during a test of this summer release scheme. The volume of water used in this regime was found to be insignificant compared to evaporative losses for the same period. Similarly, at Fort Gibson Lake, a 45 MW reservoir with a maximum depth of 15 m and surface area of 8,000 ha, continuous sluice releases, with some releases from tainter gates, were selected to mitigate critical fish habitat conditions in four small stilling basin bays below the spillway. During the summer-long tests, no fish mortalities were reported. Based on these results, the USACE plans to regularly implement the release schemes to prevent future fish mortality.

A case study was performed in Missouri to measure the impacts of changing DO conditions both in biological and economic terms.[90,91] The economic value of a trout fishery in the tailwater of Table Rock Dam, a 200 MW USACE-operated project, was estimated using several alternative economic valuation approaches.[90] The economic cost of annual DO declines in the tailwater was then estimated, using a quantitative model of the relationship between summertime DO depletion and declines in fishing success in the tailwater.[90] Summertime DO depletion caused by hydropower operation led to losses of between \$270,000–\$430,000, or roughly 4% of the local economy. The authors speculated that reduced metabolic rates caused by low DO concentrations led to a decline in fish feeding activity. Lowered feeding activity in turn led to reduced angler success and diminished fishery value.

Management actions to aerate and stabilize flow regimes in the tailwater of Norris Dam, a 100 MW tributary storage project on the Clinch River in Tennessee, were related to changes observed in long-term data sets of benthic invertebrates and trout collected from the tailwater.[92] The tailwater changes were related to increased abundances of several invertebrate taxa known to be intolerant to low DO conditions. Although important conclusions regarding the improvements to benthic communities resulting from tailwater improvements were made, the study noted that a clearer picture was expected from future additional survey data on aquatic invertebrates. Among the samples of stocked rainbow and brown trout from the tailwater, the changes in tailwater conditions were associated with less severe summertime declines in condition, although it is not clear from the data to what extent this biological response was due to flow stabilization, as opposed to DO improvements.

A model of the energy transformation processes of fish that result in growth was used to explore possible effects of varying annual DO regimes on the growth of brown trout *(Salmo trutta)*.[93] The model included algorithms to account for the effects of both DO and water temperature on food consumption and respiration. DO and water temperature data from a TVA hydroelectric project from periods both prior to and following the start of turbine aeration at the dam were used as inputs to the model. Small growth improvements were simulated as a result of increased DO concentrations in the post aeration model run; however, weight loss was simulated in both runs in late summer as increasing water temperature raised fish DO requirements beyond the available concentrations. Although the model was not calibrated or validated against field data, the authors suggest that its results can potentially produce valuable information for better mitigation and management of tailwater resources. Several key research needs were identified, including (a) further research on DO impacts on energy transformation processes of fish, (b) consideration of other habitat variables such as streamflow velocity in the model, and (c) procurement of high quality fishery, benthological, and water quality data sets to use in calibrating and validating the model.

Available Data on Dissolved Oxygen Benefits. Nearly 75% of the developers in the DO sample described in Section 3 reported that water quality monitoring is performed at their project. Parameters monitored included DO in all cases, frequently included water temperature, and occasionally included others such as biological oxygen demand. It is not surprising that DO monitoring is so frequently performed, as FERC generally requires such monitoring when DO mitigation is required at a project.[13]

In sharp contrast, only 4% of the developers with DO mitigation requirements in the sample conduct biological monitoring in the tailwater. In order to account for biological studies that may have been performed by state and federal natural resource agencies, information on such studies was requested from resource agencies from each state and from the EPA, FWS, and NMFS.

State resource agencies more frequently conduct biological monitoring studies at hydropower projects with DO requirements (Table 3–3). Thirteen percent of state agencies providing information for this study said that biological monitoring had been performed; among these, four reports on this biological work were identified, two of which were obtained and discussed in previous paragraphs.[90,91,27] On the other hand, federal agency respondents did not cite any studies on the effectiveness of mitigation (Table B-4). Because a limited number of federal agency offices were contacted, it is likely that a systematic search through listings of the agencies' technical studies, and inquiries to a greater number of field offices would likely produce additional reports.

This exploratory collection of information through a literature search, through contact with hydro developers and resource agencies, reveals several points. First, some field and modeling research has been performed to increase the understanding of biological responses to DO mitigation. These studies demonstrate that biological benefits that could accrue from DO mitigation can be clear and substantial (as in the case of the Table Rock dam tailwater fishery) but may be difficult to describe with certainty, depending on confounding factors operating in the tailwater and lack of sufficient post mitigation biological data (as in the case of the Norris Dam tailwater studies).

The research discussed above has several limitations. Of the field reports on biological responses to changing DO conditions, most were performed at relatively large (50–200 MW) projects, rather than at smaller projects (1–50 MW) that characterize the bulk of the currently regulated hydropower community. Most of the studies available lack adequate fishery, benthological, and water quality data sets from which strong quantitative empirical conclusions about biological responses to DO mitigation can be drawn. Finally, while water quality data are more abundant, modeling methods to translate DO changes into biological responses are in the early stages of development.

Fish Passage Benefits

The specific purpose of fish passage mitigation is to reduce the barrier to fish movement that a hydropower project presents. The results of achieving this purpose can include expanding the range and enhancing the populations of anadromous fish species, allowing migration of other species, and reducing entrainment and mortality in the turbines.

Benefits of fish passage facilities are commonly measured using such methods as counts of anadromous fish in the passage facility (either adults moving upstream to spawn or juveniles moving downstream to the ocean); population measurements of anadromous, migratory, or other species that are affected by a project, and counts of fish being entrained in a turbine or being passed successfully through a downstream passage facility. Many of the uncertainties associated with quantifying the fish population benefits of instream flows are also relevant to fish passage mitigation.

Evaluation Methods.

Upstream Fish Passage. The benefits of effective upstream fish passage measures, while potentially great, are not always easily quantified. In some river systems, fish passage measures may restore the upstream distribution of anadromous fish runs that were extirpated many decades ago. These are intangible benefits of a species restoration effort that, like benefits of preserving endangered species, are not readily translated into dollars. At most projects, effective upstream fish passage can increase the numbers and standing crops of fish populations above the dam, which may enhance the commercial and recreational fisheries.

Many resource agencies consider an upstream fish passage measure to be effective if it presents no obvious barrier to movement, as determined by aggregations of fish in the tailwaters. Such a performance objective is difficult to quantify (and comply with), because upstream-migrating fish may stop at the base of a dam for periods of hours or even days before finding and successfully moving up a fish ladder. Strictly speaking, such a delay represents a barrier to fish movement, although natural areas of congregation in the absence of physical barriers are well known. More important, the significance to subsequent reproductive success of whatever energy the fish loses during this delay is unknown.

Another criterion for success is whether the upstream fish passage measure is able to transport enough fish to saturate upstream spawning and rearing habitat. It may be unnecessary to design and construct a fish ladder that can pass large numbers of spawners if upstream spawning habitat or water quality is poor. This is a reasonable upper limit to the number of migrating fish that need to be transported for a measure to be considered effective, but such goals are also very difficult to measure. Further, the numbers may change as other improvements in the watershed create more potential egg and juvenile habitat, resulting in a mitigative measure no longer able to pass enough fish to comply with the changing performance goals.

Downstream Fish Passage. The benefits of a downstream fish passage measure may be expressed as the ability of the mitigation measure to extend the upstream range of an anadromous fish species by allowing the life cycle to be completed safely. Also, benefits may be expressed as the ability to pass a particular number or percentage of downstream-moving fish, or the increase in fish population numbers or biomass as a result of operation of the device. For example, the effectiveness of fish bypass systems at the USACE Bonneville Dam is judged not only by the survival of juvenile salmon transported to the tailwaters, but also by the numbers of adult salmon returning years later. The benefits of downstream fish passage measures are directly related to the additional numbers of fish that are safely transported to the tailwaters. Resident fish that are lost from the reservoir may still support a tailwater fishery. Attempts to restore anadromous fish runs by developing upstream fish passage facilities could be nullified by the lack of a method to subsequently transport juvenile life stages safely past the turbines.

Performance goals for screens and other measures used to prevent turbine passage are rarely expressed in a way that would allow quantification of benefits. Objectives may be expressed in terms of safely passing a given percentage of downstream migrants, which can then be compared with management goals or the value of a downstream fishery. An implicit assumption in determining the benefit of a downstream passage device is that the mortality associated with the mitigative measure is significantly less than the mortality associated with turbine passage. This assumption has not always been borne out at hydroelectric power plants with large, efficient turbines (where turbine passage mortality may be low), but is likely to be reasonable at many small-scale hydropower facilities.

Available Data on Fish Passage Benefits.

Upstream Fish Passage. In addition to developing specific, verifiable objectives, it is desirable to monitor the operational performance of fish passage facilities. Without performance monitoring, neither an objective evaluation of site-specific mitigation effectiveness nor the application of knowledge gained at that site to other sites is possible. According to the licensees contacted for this study, performance monitoring at nonfederal hydroelectric projects has been relatively neglected. Many of the projects with upstream fish passage monitoring requirements are recently licensed or constructed, and results of monitoring studies are not yet available. Among the 30 operating projects that provided information, 17 (57%) have not monitored the performance of the upstream fish passage measure (Figure 5-3). Those projects that have monitored the success of upstream passage generally quantify passage rates or, less commonly, fish populations. Forty percent of operating facilities monitor fish passage rates; these are generally fishway counts that are conducted by either the licensee or a fishery resource agency. Although monitoring studies determine the number of fish that passed through the facility, they rarely provide information about the numbers of fish that were unable to successfully negotiate the facility, and therefore are not useful for comparing effectiveness of different devices or at different sites.

Where two or more proximal, mainstream dams have upstream fish passage facilities, fishway counts may provide useful information about passage effectiveness. In this case, fishway counts at the lower dam may be good estimates of the number of fish available for passage at the nearby, upstream dam. When appropriately corrected for natural and fishing mortality in the river between the dams and straying into tributaries, the efficiency of the upper dam fishway can be determined by dividing the fishway counts at the upper dam by the counts at the lower dam.

A smaller number of operating projects (23%) monitor the specific fish populations that are protected by the mitigation measure. Population monitoring studies provide a longer-term view of the success of a mitigative measure because they can estimate whether the fish populations have been maintained or enhanced during the operation of the facility. Because other factors may influence fish numbers or standing crops,

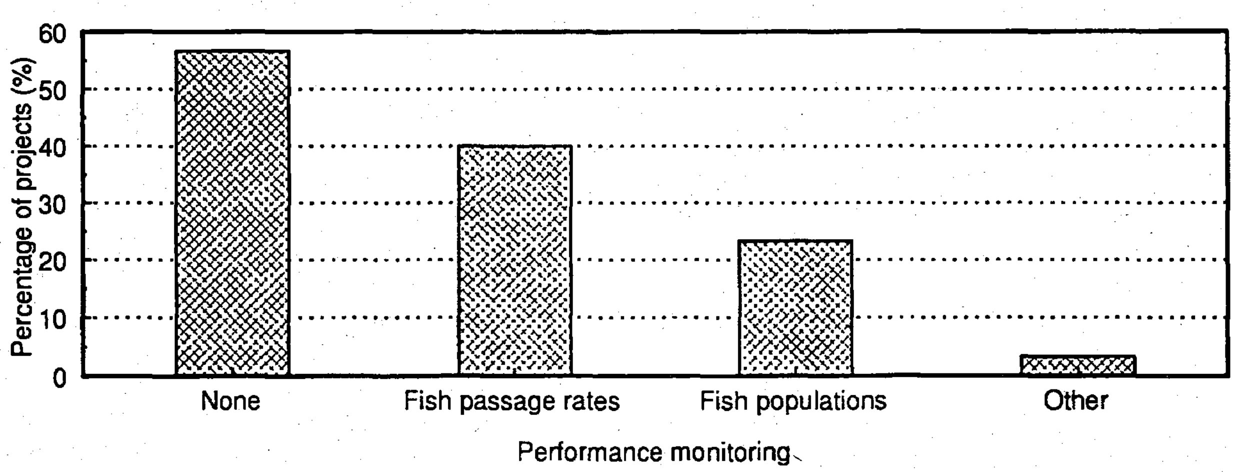

Figure 5-3. Relative frequency of performance monitoring of upstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers.

however, fish population monitoring by itself may not yield widely transferable information about the effectiveness of a device.

Downstream Fish Passage. The degree of performance monitoring for operating downstream fish passage facilities at the nonfederal projects examined in this study is relatively low. At 79% of the 66 projects with operating downstream fish passage measures, no performance monitoring was reported (Figure 5-4). The expected performance of the most commonly installed downstream fish passage mitigative measure, the angled bar rack (Section 3), appears to be based on the results of a single study.[52]

Among the 14 projects that have conducted operational monitoring, 11 monitor passage rates, 10 estimate mortality rates, and 1 monitors fish populations.

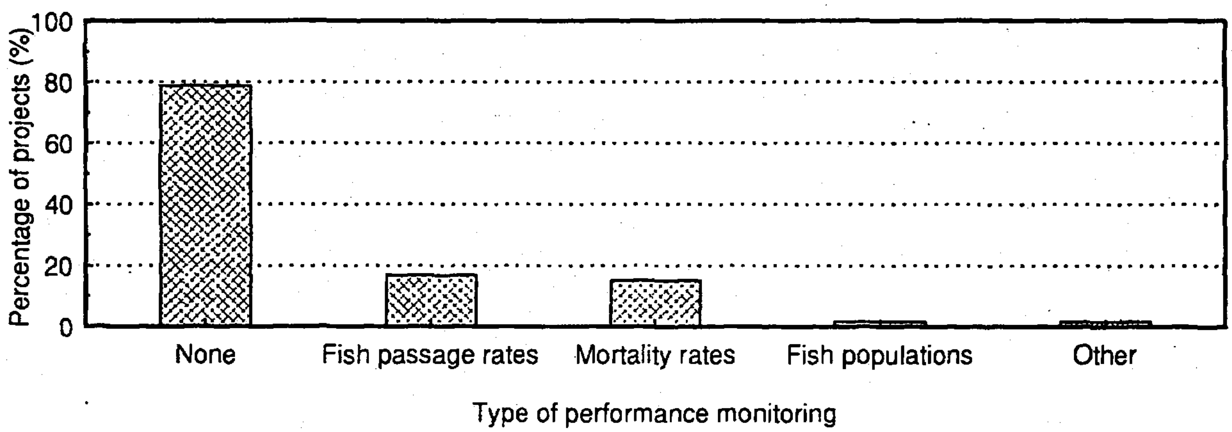

Figure 5-4. Relative frequency of performance monitoring of downstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers.

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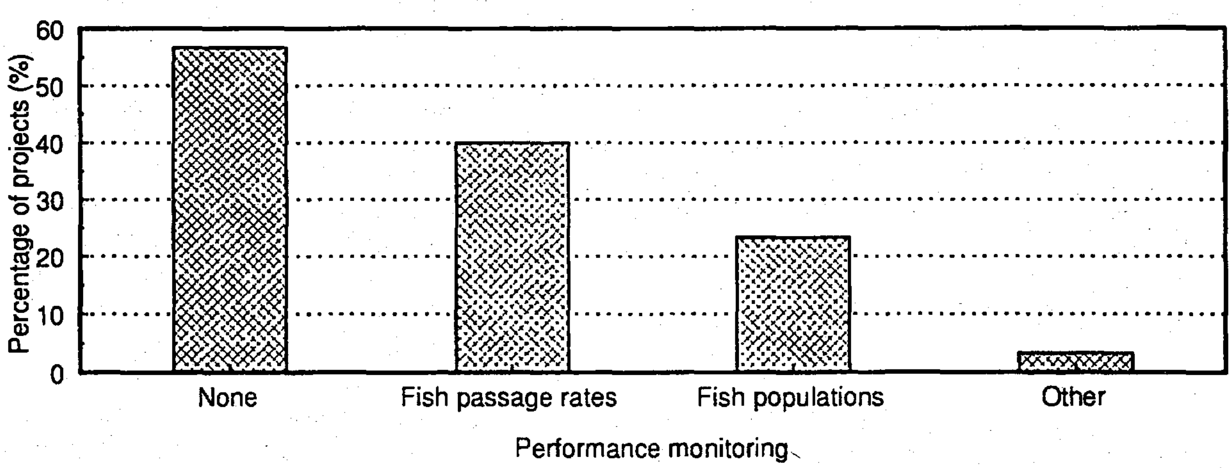

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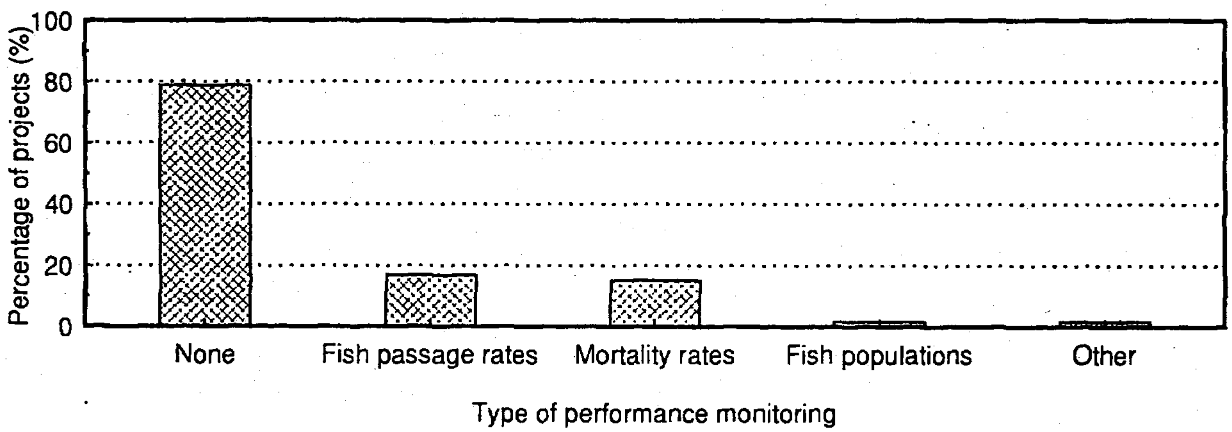

Figure 5-4. Relative frequency of performance monitoring of downstream fish passage measures at nonfederal hydroelectric projects, based on information provided by developers.

6. SUMMARY AND CONCLUSIONS

The importance of environmental mitigation at hydroelectric projects is growing for two reasons. First, ~22,000 MW of existing hydro capacity will require relicensing by the year 2010. The relicensing process will undoubtedly involve changes (often increases) in mitigation requirements that can result in reductions in existing hydropower production. Second, plans for expanding the nation's renewable energy resources, including the NES, call for development of significant new hydro resources. The magnitude of undeveloped hydropower resources is still being investigated, but preliminary DOE estimates indicate it to be as much as 52,000 MW. The amount of this new renewable energy that can eventually be developed will depend, in part, on mitigation costs and their effect on project economics.

Through the use of a systematic examination of projects developed over the past decade, costs and benefits of three important environmental issues (instream flows for fish, DO, and fish passage) have been studied. This section presents the conclusions to date from the Environmental Mitigation Study, including an extrapolation of total costs to past and future projects and recommendations for additional research.

Current Practices

Based on information obtained from hydropower developers and resource agencies, the following trends are apparent in mitigation for IFN, DO, and fish passage.

Instream Flow. Instream flow requirements are the most common mitigation practice applied to hydropower projects. Since the passage of ECPA, this type of mitigation has been required at more than 65% of the projects examined in this study (non-federal projects licensed in the past decade). Although instream flow requirements are more frequent in the western states, their frequency of application is increasing everywhere in the country.

Most instream flow requirements for fisheries are intended for maintenance of reproducing populations of sport or commercial fish. Few projects (7%) have involved threatened or endangered species. Therefore, if applicability to a wide range of hydro projects is desired, then further development of mitigation methods should focus on sport and commercial species. However, the importance of threatened or endangered species may change in the future (e.g., salmon stocks in the Columbia River Basin have recently been listed as endangered).

Of the established methods for assessing instream flow needs, the IFIM is most commonly used, so research on improving instream flow assessment methods should focus on this suite of methods. However, many project operators believe that their instream flow requirements were set without the application of any established method. This belief may arise because agencies have been unsuccessful in communicating the methods they use to recommend instream flows. It appears, though, that a substantial proportion of projects are licensed without a site-specific assessment of instream flow needs. Project applicants would benefit from guidance on what studies they should conduct, in the absence of studies by agencies, to avoid conservatively high-flow release requirements.

Factors affecting physical habitat that are not usually incorporated in the WUA physical habitat index of the IFIM, such as sediment transport, temperature, and water quality, are recognized as important instream flow benefits at many projects. Likewise, instream flow needs for recreation and riparian vegetation are recognized at many sites. Methods for assessing instream flow needs for sediments, recreation, and riparian vegetation are less well developed than those for fisheries and water quality. Further evaluation of these other mitigation benefits, and appropriate assessment methods, is planned for later stages of this mitigation study.

Approximately half of the active projects with instream flow requirements reported that they monitor the instream flow rate. Therefore, many projects do not conduct this basic level of monitoring and would be unable to verify that they provide the flow rates required by their licenses. This problem was independently identified by a FWS survey of instream flow compliance in Colorado, Montana, and Wyoming.[94,95]

A minority of operating projects (~20%) report any biological monitoring of the benefits of their instream flow releases. Ecological theory and a review of current literature indicate that the relations between fish population measurements and instream flow releases are complex. However, fish population data can be used successfully in some cases to conclude that an instream flow requirement is sufficient to protect fish resources. Adaptive instream flow management techniques that base future flow releases on biological monitoring results may eventually play a more dominant role in hydropower regulation. Guidance for developers on the potential benefits of conducting biological monitoring would be useful. However, such real-time management of instream resources will require a better understanding of the response of fish to altered flows than currently exists.[73,96]

Dissolved Oxygen. In the years since the enactment of ECPA, DO mitigation requirements have been increasing at hydropower projects. As hydropower projects at large reservoirs come up for relicensing, mitigation of DO problems will become an even more important environmental issue for the hydropower industry. Fortunately, a substantial body of federal and industry research has developed numerous DO mitigation technologies applicable to a wide range of project configurations. The unresolved problems with DO mitigation are (a) determining appropriate DO targets to protect aquatic biota and (b) quantifying the tradeoffs between mitigation costs and benefits.

The analysis of FERC data reveals that most projects currently with water quality requirements have capacities from < 1 to 50 MW and are most frequently in the northeast, southeast and southwest, in that order. In contrast, hydropower development in general has been most active in the northeast, southwest, and northwest, in that order.

The sample of nonfederal FERC-licensed projects indicates that spill flows are used for DO mitigation far more frequently than other mitigation methods (e.g., selective withdrawal, tailrace weirs, and reservoir destratification). This preference can be explained in part by a bias in the sample toward hydro projects in the northeast, where spill flows are used with exceeding frequency. This trend may also be explained by the usefulness of spill flows for meeting concurrent instream flow requirements, by FERC policies encouraging spill flows, and by financial constraints preventing small projects from investing in expensive or high-risk technologies.

In the sample of projects, there is a tendency for smaller projects to operate mitigation at all times, and larger projects to mitigate only when necessary. This may be due to agency or FERC requirements, or by developer choice.

The results show that DO mitigation is required generally to meet the primary objectives of state water quality, site-specific, or antidegradation standards, or explicit fish and wildlife objectives. State numerical DO criteria range from 4 to 7 mg/L.

In addition, among the sample of developers studied in this report, water quality monitoring is used at over half of the projects, alone or in combination with other measures such as modeling studies or professional judgment, to set DO requirements. The information also shows that investment in pre- and post-operational water quality studies can be a cost-effective way to help identify optimum DO mitigation strategies.

Many states report having written policies that are applicable to DO mitigation at hydropower projects, and most of these pertain to state water quality or antidegradation standards. The FWS also has written policies clarifying the agency's position on hydropower mitigation and its commitment to protecting and conserving important fish and wildlife resources while facilitating balanced development of the nation's natural resources. The results presented in Section 3 suggest that although federal and state agencies can and do play a clear and vigorous role in setting DO mitigation objectives, they do not do so consistently across agencies, states, or regions.

The effectiveness of DO mitigation can be measured at several points along a continuum of responses ranging from simple increases in DO concentrations in the tailwater to measurements of response in biological variables such as benthic macroinvertebrate biomass and species occurrence, and fishery endpoints (e.g. growth rates and condition factors). The results of the literature review presented in Section 5 indicate that researchers in the past several years have related mitigation–induced improvements in DO conditions to enhancements in biological resources. Both field and modeling approaches have been applied, and the biological benefits that could accrue from DO mitigation have been described. It is clear from the literature that methods, case study opportunities, and incentives exist to produce valuable information about how to optimize management of tailwaters for biological resources and to provide quantitative data on biological benefits of DO changes that can aid regulatory decisions associated with balancing power and nonpower resources. It does not appear, however, that past studies have benefitted from adequate fishery, benthological, and water quality data sets. General conclusions about biological responses to DO mitigation that can be developed from available data are limited. Also, biological modeling methods are as yet in early stages of development.

Another limitation to the usefulness of prior research for the hydropower community is that there have been few studies at smaller projects (1 to 50 MW) that characterize the bulk of the currently regulated hydropower community. At the same time, studies at large projects will be of increasing importance because many of the projects that are coming up for relicensing are large.

Within the population of hydropower projects with DO mitigation, it appears that although DO and other water quality parameters are commonly monitored in project releases, biological monitoring is rarely performed. State resource agencies appear to perform studies on biological relationships to mitigation more frequently than developers, but there is still relatively little research in this area. Review of federal agency technical report listings may reveal more federal activity in this area.

Fish Passage. Upstream fish passage requirements are applied to nonfederal, FERC-licensed hydro projects relatively less frequently than are downstream fish passage requirements, and both are more common in the western states than in the east. Downstream fish passage requirements have grown in recent years to become the second most common mitigation issue at hydropower projects after instream flow requirements.

Upstream Passage. The blockage of upstream fish movements by hydroelectric dams may have serious impacts to species whose life history includes spawning migrations. Anadromous fish, catadromous fish, and some resident fish could all have upstream spawning migrations constrained by barriers such as hydroelectric dams. Upstream passage measures can be placed into three general categories: trapping and hauling, fishways, and fish lifts.

Trapping and hauling is a labor-intensive mitigation measure that can be used when fish need to be transported long distances upstream or around a large number of obstacles. Trapping and hauling (by trucks) of fish to upstream spawning locations is used at some older dams (15% of nonfederal, FERC-licensed projects), but in some projects this measure is being replaced by fish ladders or elevators.

Fishways (or fish ladders) are widely used to transport fish above single obstacles such as dams and may also be used to collect fish for hauling to upstream stocking locations. Fish ladders are by far the most common means of passing fish upstream at nonfederal hydroelectric dams, accounting for more than 70% of the upstream passage devices reported. Fish ladders are employed throughout the United States, and some are quite old, dating back to the turn of the century. Fish lifts (elevators) and fish locks rely less on active movement of the fish than do fishways, and consequently, they may be favored where restoration of such species as American shad and blueback herring is of paramount importance. Fish lifts are less common than fishways (fish lifts were reported for 12% of the nonfederal projects that provided information for this study), but most are relatively recent installations.

Upstream fish passage facilities are most frequently used to enhance the migration of anadromous fish, although some hydroelectric projects are required to maintain upstream movements of resident (nonanadromous) fish as well. Performance monitoring has been relatively neglected. Fifty seven percent of the operating projects that provided information have not monitored the performance of the upstream fish passage measure. Those projects that have monitored upstream passage generally quantified passage rates (i.e., fishway counts) or, less commonly, fish populations. Performance objectives of upstream fish passage measures are rarely specified precisely. Most developers indicated that "no obvious barriers to upstream movement" was one of the criteria used to judge effectiveness; 50% of the respondents felt that this was the sole criterion. Only small percentages of the projects are required to pass a specified percentage or a specified number of migratory adults.

Downstream Passage. A variety of devices have been employed to prevent fish from becoming entrained in the turbine intake flows. The spill flows that may be used to increase DO concentrations or provide instream flows can also transport fish over the hydropower dam rather than through the turbines. Higher technology options also exist, including sophisticated physical screens and light- or sound-based guidance measures that are being studied to bypass downstream moving fish with a minimal loss of water that could otherwise be used for power generation.

The angled bar rack is the single most frequently required downstream fish passage device, particularly in the Northeast. Angled bar racks are used by 38% of the nonfederal, FERC-licensed hydroelectric projects that provided information for this study. Other types of fixed screens were installed at 34% of such projects. Traveling screens similar to the vertical traveling screens used at steam electric power plants have been installed in the upper portion of the turbine intake gatewells of some Columbia River dams, but have been used at only 4% of the nonfederal projects.

Intake screens of all kinds may have a maximum approach velocity requirement and a sluiceway or some other type of bypass. Twenty-four percent of projects have a velocity limit on the intake flows and 22% have a sluiceway or some other form of bypass.

Downstream fish passage facilities were most frequently designed to protect adult resident fish at the nonfederal hydro projects examined in this study; juvenile resident fish and juvenile anadromous fish were also important targets for these mitigative measures. Downstream fish passage facilities are rarely required to protect fish eggs and larvae. The amount of performance monitoring for operating downstream passage facilities is relatively low. This study indicated that there are no performance monitoring requirements for 79% of the projects with operating downstream fish passage measures. Those projects that have conducted operational studies monitor passage rates, mortality rates, or fish populations. Seventy percent of the projects with downstream fish passage facilities indicated that no performance objectives had been specified for their mitigation requirement.

Mitigation Costs

This study examined several different types of environmental mitigation costs that are incurred by hydropower developer. At this stage of the DOE Environmental Mitigation Study it is not possible to provide highly specific, unqualified costs for mitigation practices and project types, because costs have been found to be too variable. Attempts to apply the average costs presented in this report to specific projects may be misleading. For example, capital costs for upstream fish passage have an average cost of $6 million and a cost range of $21,000 to $37 million. None of these three figures would be a fair representation of the costs a developer would likely encounter because of the site-specific nature of mitigation requirements. Therefore, it is strongly recommended that the average mitigation costs presented here not be applied to individual projects. The most appropriate way to view these cost estimates is by capacity size categories (Section 4). Average costs are presented primarily to give a broad picture of the economics of environmental mitigation.

Opinions will vary as to whether the costs presented here are underestimated or overestimated, and these opposing views have already been received, in equal amounts, during the technical review of this report. The costs reported here are presented as objectively as possible. The scope of this volume dictated that cost data be described as they were obtained with minimal analysis except for filtering out obvious errors. Several assumptions, however, were required to calculate the target population's total cost of environmental mitigation as well as the estimated future costs of environmental mitigation. These assumptions include the extrapolation of the frequencies of mitigation requirements from the sample population to the target population (see the next two subsections and Section 2). The frequencies of future (1992 to 2010) mitigation requirements were estimated based on temporal historical trends of mitigation frequencies.

Costs to Developed Projects. The following procedure was used to estimate the mitigation costs of the target population: (a) the average costs are those presented in Section 4 by capacity category (i.e., based on 141 projects that provided usable cost data); (b) the frequency of mitigation requirements in the target population (707 projects) was based on the frequency of mitigation requirements in the sample (280 projects); (c) the average costs for each mitigation requirement, capacity category, and cost type were multiplied by the anticipated frequencies of the target population projects with mitigation requirements; and (d) for the annually occurring costs (O&M and annual reporting), a time period of five years, or half the study period, was used. Table 6-1 provides a summary of the various mitigation costs.

The total cost of the target population's hydropower mitigation requirements during the study period is estimated at ~$500 million (Table 6-1). This does not include the cost of lost generation which, if an energy value of $0.05/kWh is assumed, amounts to ~$33 million yearly (Table 6-2). Using an average five-year time span (some projects incur losses for 1 year, some for 10 years, depending on when mitigation is implemented), the target population's generation loss from 1980 to 1990 is ~$165 million ($33 million/yr for 5 years). It must be emphasized that $665 million ($500 million + $165 million) is not the total cost to the nation for hydropower mitigation requirements. These costs are only for the projects identified as the target population (Section 2). This set of 707 projects is only about one-third the total number of all federal and nonfederal hydropower projects currently operating in the United States. This is not to suggest that the remaining two-thirds of the operating hydropower projects in this country have similar mitigation requirements and costs; rather, that the remaining two-thirds of the projects were not within this study's target population, but they definitely do have additional, non-zero mitigation costs.

Table 6-1. Average mitigation costs per project and total mitigation costs for the target population of hydropower projects by mitigation issue (N = 707; all costs in thousands of 1991 dollars). The total costs are a function of the frequency of mitigation requirements in the target population (see Appendix C for more details).

	Instream flows	Dissolved oxygen	Upstream fish passage	Downstream fish passage	Totals
Average cost per project	$216	$145	$3,409	$708	$615,000
Total costs 1980-1990	$85,810	$20,614	$252,234	$141,642	$500,229

Table 6-2. Average annual and total generation losses by mitigation issue for the target population of hydropower projects (N = 707; energy values assumed to be $0.05/kWh; dollar values in thousands of 1991 dollars). All losses in this table are for yearly generation losses. The total generation lost is a function of the estimated frequency of the target population's generation losses (see Appendix C for details).

	Instream flows	Dissolved oxygen	Upstream fish passage	Downstream fish passage	Totals
Average annual generation loss (MWh per project)	2,489	107	1,122	6,139	2,464
Total generation lost (MWh)	301,192	2,997	11,221	343,804	659,214
Total generation lost ($1000)	$15,060	$150	$561	$17,190	$32,961

Costs to Future Projects. Attempts to measure the future costs of hydropower mitigation involve many assumptions and uncertainties. It is relatively easy to identify the numbers and sizes of projects that will require relicensing, but the relicensing outcomes and requirements, including the frequency of environmental mitigation requirements, are difficult to predict. The number of new projects that will be developed is also uncertain and highly dependent on future trends in energy prices and regulatory requirements. While temporal trends of mitigation requirements are evident for the 1980's, it is not certain whether these trends will increase, decrease, or stagnate in the future. Nevertheless, recent experience strongly suggests that the number of projects with mitigation requirements will increase in the future. The frequencies assumed for future mitigation requirements are discussed in the cost assumptions section (Section 4). The time span used for future cost estimation is 1992 to 2010. The magnitude of the future costs of mitigation is influenced by the substantial number of large hydropower projects due for relicensing during the next 18 years.

The following procedure was used to estimate the future costs of mitigation: (a) the past mitigation costs used were those estimated from the 141 projects with usable cost data (Section 4); (b) it was assumed that the frequency of mitigation requirements would increase and that all 436 projects due for relicensing[97] would be relicensed; c) the number of new projects issued licenses was estimated at 1316[3,98]; (d) for the projects licensed from 1992 to 2000, a time period of 15 years was used for annually occurring costs (O&M and annual reporting); (e) for the projects licensed from 2001 to 2010, a time period of 5 years was used for annually occurring costs (O&M and annual reporting); (f) the estimated number of future new projects (1316) are only those estimated future new projects that will be successfully licensed by the FERC licensing process and in operation, which corresponds to the target population (Section 2) criterion; and (g) the effects of inflation on mitigation costs were not applied; unadjusted 1991 costs were used.

The concept of generation lost due to mitigation requirements is controversial, and uncertainties are unavoidable in determining the amount of this generation loss. The cost estimates and projections presented here did not attempt to resolve these uncertainties. Rather, it was chosen not to compound this uncertainty with additional assumptions of the future frequencies of generation losses. Instead, the frequency of past generation losses (1980 to 1990) were simply used as the frequency of future generation losses.

The estimated future cost of hydropower mitigation for the period 1992 to 2010 is ~$2 billion (Table 6-3). This does not include the cost of lost generation which amounts to ~$81 million annually if an energy value of $0.05/kWh is assumed (Table 6-4). The future

Table 6-3. Future mitigation costs projected for the period 1992 to 2010, including relicensed and new license projects (all costs in thousands of 1991 dollars). The number of relicensing projects and new projects successfully licensed is estimated. The average project costs are based on the mitigation costs for the time period 1980 to 1990 (see Section 4). The total costs are a function of the estimated frequency of future mitigation requirements (see Appendix C for details).

	Instream flows	Dissolved oxygen	Upstream fish passage	Downstream fish passage	Totals
Total costs, 1992-2000	$97,432	$13,969	$17,291	$139,589	$268,281
Total costs, 2001-2010	$255,884	$73,083	$239,679	$1,177,964	$1,746,609
Total costs, 1992-2010	$353,316	$87,052	$256,970	$1,317,553	$2,014,890

time span of interest is 19 years (1992 to 2010). The specific years that these future projects will come online or be relicensed, and mitigation generation losses incurred, is not known. However, an 8-year average time period is assumed for total generation losses. This assumption means that lost generation for 1992 to 2010 is ~$650 million ($81 million/yr for 8 years). It must be emphasized that the total cost of future mitigation, $2.65 billion ($2 billion + $650 million), is not the total future cost of mitigation to the nation. This is the estimated mitigation cost only for projects subject to FERC licensing. Possible future rule changes such as exempting projects < 5 MW from the FERC licensing process may influence mitigation costs in unknown ways.

Recommendations

One of the important objectives of examining current trends in mitigation practices is to identify areas deserving additional study. Several such areas have been identified in the past by various interests[6,7,10,73,96], but the results of this report hopefully provide a more current and more broadly based justification for research directions.

Instream Flow. Overall, more research is needed to make IFN assessment methods more predictive and objective. A long-recognized need in instream flow management is the development of ways to relate physical habitat, which is usually the focus of an instream flow study, to fish populations. This linkage is badly needed in the balancing decisions that FERC must make in its licensing process. More predictive methods would allow instream flows to be released when they are most beneficial to fish and conserved when such flows would be less beneficial. Eventually, as such methods are developed, greater flexibility in licensing requirements would be needed to allow instream flow releases to be varied according to measured or modeled states of the fish population.

Many projects, especially small diversions where instream flow costs are high, have flow requirements set without the use of formal studies. The mitigation costs for these smaller projects are also disproportionately higher than for larger projects. Guidance for hydropower

Table 6-4. Estimated annual average generation losses for the time span 1992 to 2010 (436 relicensed projects and 1316 new projects; energy values assumed to be $0.05/kWh; all costs in thousands of 1991 dollars). The frequency of past generation losses (1980 to 1990) was used to estimate future generation losses. The total generation lost is a function of this frequency (see Appendix C for details).

	Instream flows	Dissolved oxygen	Upstream fish passage	Downstream fish passage	Totals
Average annual generation loss (MWh per project)	2,489	107	1,122	6,139	2,464
Total generation lost (MWh)	746,756	7,386	28,053	847,232	1,629,426
Total generation lost ($1000)	$37,338	$369	$1,403	$42,362	$81,471

developers in selecting cost-effective studies could help avoid arbitrary or excessively conservative instream flow requirements that do not provide benefits commensurate with their costs.

Dissolved Oxygen. Continuing hydropower development and upcoming relicense negotiations will require adequate information on effective, efficient DO mitigation options. For this reason, more field applications of promising DO mitigation technologies need to be demonstrated and the results disseminated to the hydropower industry through, for example, annual open literature reviews on this subject. Field applications at both federal and nonfederal projects would be desirable covering a range of project sizes, regions, and configurations.

There is a need for better biological and physico–chemical data from which to develop an understanding of relationships between DO mitigation and biological response. The results of this study suggest that two kinds of efforts may be needed: (a) more extensive searches through state and federal resource agency technical report listings to identify suitable data sets, if any, and (b) support for biological monitoring at both nonfederal and federal hydropower project tailwaters. For example, biological monitoring programs could be initiated at selected new and relicensed projects that are required to provide DO mitigation.

Finally, the frequency of required, post–operational release water quality monitoring at hydropower projects with DO mitigation requirements suggests that considerable data on DO concentrations below regulated hydropower projects is available. Policy–level analyses of the effects of recent hydropower mitigation policies on tailwater resources could therefore be performed, comparable to a study sponsored by DOE in 1981 measuring the DO impacts of small– and large–scale hydropower development throughout the United States.[99] The results of such a study could be used to measure the success or failure of new hydropower regulation policies in balancing objectives of ongoing power development and environmental protection.

Fish Passage. Despite considerable efforts in recent years to design and install fish passage devices at hydroelectric power plants, there is still a great need for field studies to evaluate the biological effectiveness of these mitigative measures. The lack of information about biological effectiveness is a particular problem for downstream fish passage measures, where designs are more recent and varied, and where there has been less practical operating experience than, for example, at fish ladders. Fish passage mitigation may be required at sites where the biological benefits are uncertain (e.g., at sites without clearly migratory fish species).

There is also a need to conduct performance monitoring in a way that would yield information that could be applied to the design of fish passage measures at other sites. Most studies of fish ladders and elevators simply count the numbers of a target species that have successfully used the passage device. However, not all fish that reach the vicinity of a fish passage device are able to use it. For example, one study of a fish elevator indicates that an average of 50% (and as little as 18%) of the available fish are transported.[47] Operational monitoring studies of upstream and downstream fish passage measures should estimate both the numbers of fish that successfully used the device and the numbers that failed. In large rivers it is often difficult to even roughly quantify the fish population available for passage. However, some river systems have multiple mainstem dams in close proximity, such that counts of upstream migrating fish at the downstream ladder provide a reasonable estimate of the fish subsequently available for passage at the next upstream fish ladder. It is important to use a standardized parameter (e.g., the percent utilization of a fish passage measure) to compare the cost-effectiveness of different installations.

Wherever possible, the economic value of the fish transported around a previously impassable barrier could be estimated and compared to the mitigative measure's construction and maintenance costs. This information could be used to guide future recommendations at other hydropower sites. Such comparisons must be made with caution, however, because there may not be a commercial or recreational fishery for species that are being protected or are undergoing restoration. In such cases the benefit of a successful fish passage device will be difficult to quantify in dollar terms. The value of a mitigative measure in these circumstances depends on the degree to which the upstream distribution of a fish species is extended (by transporting adults upstream or safely passing juveniles downstream) or the resulting expectation of a future fishery, neither of which is easily predicted.

Cost and Engineering Analyses. The total economic costs of environmental mitigation at hydropower projects will continue to grow as mitigation requirements become more frequent in both relicensing and new development. Where hydropower becomes uneconomical, generation losses must be replaced by conservation or other power sources. Replacement power sources have their own notable environmental effects when energy resources are extracted, transported, and consumed and any residue waste is processed.

The hydropower developer can quantify the hydropower mitigation costs, and like any business person, the developer will want to know the benefits, or payback, associated with these costs. Unfortunately, this attempt to measure tradeoffs can lead to confrontations between the developer and the various agencies involved in the regulation of hydropower operations, because the developer is sometimes encouraged to practice various mitigation methods with unknown benefits. This is not to suggest that the hydropower environmental mitigation costs are unreasonable or that they must have an economic payback; rather, the costs of mitigation and substitute power generation should be rationally measured. Additionally, greater emphasis should be placed on attempts to quantify the benefits derived from mitigation practices. This would enable the evaluation of which methods of mitigation provide the best usage of scare resources, resources that can be water, land or other commodities with economic or noneconomic value.

This study concentrated on gathering hydropower environmental mitigation cost data as it relates to the hydropower developer. Several additional mitigation costs were not measured. These additional costs include the expanded licensing hearings, procedures and paperwork that is required of FERC because of hydropower mitigation requirements. The various state agencies' costs of studying proposed hydropower sites and practices, and the associated possible impacts on terrestrial and aquatic species, and recreation also were not measured. These costs, as well as all other mitigation-related agency costs, should be studied more explicitly in future volumes. All of these costs are eventually, through one channel or another, passed on to the consumers of this country.

Additional effort should be placed on understanding mitigation costs. Specifically, future analyses should include scatter plots and regression analysis; the investigation of potential trends; and, the examination of potential dependencies of, for example, DO and instream flow costs as a function of stream flows. Regional subgroups of the respective mitigation methods should be studied. Projects with DO turbine aeration or DO spill flows, for instance, should be examined independently to determine their respective costs, practices and benefits. Selected projects should be examined on a case-by-case basis to provide a detailed examination of the operations, benefits and costs of environmental mitigation. This study has identified potential sources of additional cost data and future work should include obtaining and analyzing these data. The lessons learned obtaining information and data analysis during this study should be applied to future volumes.

Valuation of Environmental Benefits. Two factors limit the feasibility of monetary benefit-cost analyses of mitigation practices: (a) the lack of information to measure the response between mitigation actions and natural resources[87] and

(b) the fact that dollar values are often inappropriate in evaluating natural resources like fisheries. Nevertheless, efforts should be increased to try to develop and demonstrate benefit-cost applications for hydro projects. The ECPA reinforces FERC's mandate to apply an "equal consideration" standard in finding a balance between power and nonpower resources in its licensing decisions. This mandate is very difficult to meet when all resources cannot be evaluated in some comparable units. Further development of generic valuation techniques for the mitigation types studied in this report would be very beneficial to the hydropower industry and to its regulators.

Biological Monitoring and Analysis. The strongest conclusion from this report is that, although mitigation costs are measurable and often large, mitigation benefits are essentially unknown. Benefits are unknown because they are difficult to measure and the necessary data usually do not exist. Given the apparent lack of quantitative information on mitigation benefits, the hydropower industry is faced with an important question: what kind of biological information would allow the effectiveness of mitigation measures to be determined? Some answers can be provided based on current knowledge, but additional study is also needed.

Three kinds of biological studies are considered to be of clear value in addressing the effectiveness of mitigation. First, empirical analyses of data obtained from multiple sites can provide a strong basis for inferring the importance of particular factors to biological communities, even when data from any single site may be inadequate to support such analyses. Second, where a single factor can be varied in isolation from other factors, controlled experiments can circumvent the problem caused by interference from other factors (e.g., evaluating the effects of DO and other environmental factors on benthic invertebrate communities[100]). A third kind of study is one in which detailed observations both within and between years are incorporated into mechanistic models that eventually can be used to make population-level inferences of the effects of hydropower production. All of these approaches are data-intensive and therefore expense to conduct.

Hydropower in the U.S. is at a critical point in its history. In 1993, the original FERC licenses for more than 170 projects will expire at essentially the same time. Other federal agencies, such as TVA[20] and the Bureau of Reclamation, are planning major operational changes and equipment upgrades to their hydroelectric facilities, many of which will result in significant environmental benefits. These imminent changes represent truly unique opportunities to gain a broad new set of information on mitigation benefits, if the proper monitoring is designed and conducted at these sites. While it is certain that a large number of site-specific monitoring programs will be instituted in the near future, there is no evidence that any coordination or synthesis of these studies will take place. These activities should be coordinated so that the information content is not lost. Consultations among FERC and other interested parties should be held as soon as possible to determine the feasibility of establishing new, coordinated monitoring programs at relicensed projects and other federal sites to evaluate mitigation benefits.

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APPENDIX A

SUMMARY OF INFORMATION RECEIVED FROM DEVELOPERS

Table A-1. Items common to more than one mitigation requirement.

Items common to more than one mitigation requirement	Mitigation requirement type			
	DO	IFR	UFP	DFP
Projects having the requirement/facility	59	185	34	85
Studies conducted prior to licensing:				
Modeling/fisheries study by licensee	10	—	7	19
Modeling/fisheries study by resource agency	4	—	6	8
Modeling by Federal Energy Regulatory Commission (FERC) staff	2	—	—	—
Professional judgment by resource agency	11	39	17	43
Professional judgment by FERC	3	—	—	—
Others	3	22	—	1
No studies	6	—	8	22
Current status of requirement/facility:				
Implemented/completed	32	—	2	17
In process/under construction	11	—	—	5
In operation	—	—	29	58
Postproject monitoring studies/reports done	20	74	12	14
Postproject monitoring studies/reports not done	—	66	17	52
Project unconstructed	—	36	4	19
Timing of need identification or imposition of requirement:				
During licensing	—	—	17	36
After license issued	—	—	5	16
Other	—	—	9	20

DO = dissolved oxygen
IFR = instream flow requirement
UFP = upstream fish passage
DFP = downstream fish passage

Table A-1. (continued).

Items common to more than one mitigation requirement	Mitigation requirement type			
	DO	IFR	UFP	DFP
Point of requirement/facility application/intended effect:				
Immediately below project	20	68	—	—
At a specified distance downstream	13	—	—	—
Over a length of stream	5	97	—	—
Other	4	16	—	—
Objectives of mitigative measure:				
Meet state water quality standards	43	—	—	—
Meet state antidegradation standards	5	—	—	—
Meet state site-specific water quality standards	5	—	—	—
Meet other resource agency objectives	21	—	—	—
Meet FERC parameter levels required by FERC independently from other agencies	6	—	—	—
Objectives not stated or clarified during license process	2	14	—	—
Protect/enhance fish population	—	111	—	—
- Sport/commercial species, adults	—	8	—	—
- Sport/commercial species, all life stages	—	101	—	—
- Anadromous fish, all life stages	—	—	23	—
- Anadromous fish, adults	—	—	—	17
- Anadromous fish, juveniles	—	—	—	21
- Migratory resident fish, all life stages	—	—	13	—
- Migratory resident fish, adults	—	—	—	47
- Migratory resident fish, juveniles	—	—	—	35
- Migratory resident fish, egg or larval	—	—	—	7
- Nongame species	—	48	—	—

DO = Dissolved oxygen
IFR = Instream flow requirement
UFP = Upstream fish passage
DFP = Downstream fish passage

Table A-1. (continued).

Items common to more than one mitigation requirement	Mitigation requirement type			
	DO	IFR	UFP	DFP
- Threatened/endangered species	—	13	—	—
- Others	—	—	4	—
Fish habitat	—	144	—	—
Nonfisheries objectives:				
- Protect/enhance water temperature	—	26	—	—
- Protect/enhance water quality	—	52	—	—
- Protect/enhance recreation	—	44	—	—
- Protect/enhance riparian vegetation	—	26	—	—
- Flushing of sediments	—	18	—	—
- Other objectives	3	16	—	—
Postproject study types:				
Monitoring of passage rates	—	—	12	11
Monitoring of fish populations	—	—	7	1
Measurement of mortality rates	—	—	—	10
Others	—	—	1	1
Organization conducting postproject studies:				
Resource agency	—	—	5	2
Licensee	—	—	6	13
Both agency and licensee	—	—	—	1
Others	—	—	1	1

DO = Dissolved oxygen
IFR = Instream flow requirement
UFP = Upstream fish passage
DFP = Downstream fish passage

Table A-2. Items particular to dissolved oxygen.

Items particular to dissolved oxygen	
DO monitoring by licensee	30
DO monitoring by resource agency	6
DO mitigation methods:	
Spill flows	37
Spray devices	3
Intake level controls	5
Improvements to reservoir water quality	3
Aeration of reservoir	1
Aeration in the turbine	16
Aeration in the tailrace	5
Others	8
Water quality/biological parameters monitored:	
DO	43
Temperature	39
BOD	1
Others	8
Fish populations	1
Benthic populations	1
Other biological parameters	1

Table A-3. Items particular to instream flow requirement.

Items particular to instream flow requirement	
Ramping rate restrictions part of IFR	21
Method of determining IFR objectives	
Fish sampling by applicant	32
Fish sampling by resource agency	29
Use of existing data from resource agency	30
Professional judgment of resource agency	116
Existing agency policy	30
Others	21
Types of studies used to determine IFR:	
IFIM	44
HEP	11
Wetted perimeter	17
Tennant or Montana method	3
Aquatic baseflow standard	21
Specified flow duration standard	16
Water temperature/quality	18
Other studies or assessment methods	22
Post-project parameters monitored:	
Flows	71
Habitat quality	16
Fish population by project operator	20
Fish population by resource agency	12
Fishing usage	10
Water quality and temperature	22
Sediment and substrate type and distribution	6
Others	5

Table A-3. (continued).

Items particular to instream flow requirement	
Performance objectives for fish passage facility	
Pass specified percentage of migratory adults	1
Present no obvious barriers to upstream movement	17
Others	5
None Specified	9

Table A-4. Items particular to upstream fish passage.

Items particular to upstream fish passage	
Type of facility/method in use	
Trapping and hauling	5
Fish ladder	24
Fish elevator	4
Other	3
Performance objectives specified by resource agencies	
Pass a specified % of migratory adults	1
Present no obvious barriers to upstream movement	17
Other	5
None specified	9

Table A-5. Items particular to downstream fish passage.

Items particular to downstream fish passage	
Duration/timing of facility use	
Always	48
Specified seasons	18
Specified seasons and times of day	3
Types of compensation for turbine passage losses of fish	
Financial compensation to resource agencies	3
Support of stocking or hatcheries	3
Other	2
Performance objectives specified by resource agencies	
Specified % fish entrainment exclusion	4
Specified fish mortality level	3
Other	14
None specified	50

APPENDIX B

SUMMARY OF INFORMATION RECEIVED FROM AGENCIES

Table B-1. Responses of state resource agencies to agency information request regarding instream flow mitigation.

State	Written mitigation policy	Accepts off-site mitigation	Instream flow requirements	More than one instream flow assessment method	Operational monitoring conducted	Non-fishery instream flow values
AL	NR	NR	NR	NR	NR	NR
AK	Y	Y	Y	Y	Y	Y
AZ	N	Y	N	NR	NR	NR
AR	N	Y	Y	NR	N	Y
CA	Y	NR	Y	Y	Y	Y
CO	Y	Y	Y	Y	Y	Y
CT	NR	NR	NR	NR	NR	NR
DE	NA	NA	NA	NA	NA	NA
FL	N	NR	NR	NR	NR	NR
GA	N	NA	Y	N	N	Y
HA	NR	NR	NR	NR	NR	NR
ID	Y	Y	Y	N	N	Y
IL	N	N	NR	NR	NR	NR
IN	N	N	Y	N	N	Y
IA	N	NA	N	NA	NA	NA
KS	NR	NR	NR	NR	NR	NR
KY	N	Y	Y	N	N	Y
LA	N	N	N	NA	NA	NA
ME	Y	Y	Y	Y	Y	Y
MD	NR	NR	NR	NR	NR	NR
MO	N	N	N	NR	NR	NR
MT	Y	Y	Y	Y	N	Y

Y = Yes
N = No
NR = No response
NA = Not applicable

Table B-1. (continued).

State	Written mitigation policy	Accepts off-site mitigation	Instream flow requirements	More than one instream flow assessment method	Operational monitoring conducted	Non-fishery instream flow values
NE	N	N	NR	NR	NR	NR
NV	N	NR	Y	N	N	NR
NH	N	N	Y	N	N	Y
NJ	Y	N	Y	Y	Y	Y
NM	NR	NR	NR	NR	NR	NR
NY	NR	NR	NR	NR	NR	NR
NC	N	N	Y	Y	N	Y
ND	NR	NR	NR	NR	NR	NR
OH	N	Y	Y	N	N	Y
OK	NR	NR	NR	NR	NR	NR
OR	NR	NR	NR	NR	NR	NR
PA	Y	N	Y	NR	NR	NR
RI	NR	NR	NR	NR	NR	NR
SC	Y	Y	Y	Y	Y	Y
SD	N	N	NA	NA	NA	NA
TN	N	Y	NR	Y	Y	Y
TX	N	N	Y	Y	N	Y
UT	Y	Y	Y	Y	N	Y
VT	NR	NR	NR	NR	NR	NR
VA	NR	NR	NR	NR	NR	NR
WA	Y	Y	Y	Y	Y	Y
WV	N	Y	Y	Y	N	Y
WI	NR	NR	NR	NR	NR	NR
WY	NR	NR	NR	NR	NR	NR

Y = Yes　　N = No
NR = No response　　NA = Not applicable

Table B-2. Responses of federal resource agencies to agency information request regarding instream flow mitigation.

Agency, region	Instream flow mitigation policy?	Instream flow requirements for FERC-licensed projects?	Type of study to determine need for mitigation?	Objectives of instream flow mitigation?	Suggested mitigation technologies?	Studies of mitigation effectiveness?
EPA, III	N	NA	D	G	F,D	D
EPA, VII	N	Y (2)	C	G,WF,M	C	Y (2)
FWS, TX	MP	Y (2)	D	WWF	IFIM	NR
FWS, OK	N	N	NA	NA	IFIM	NR
FWS, NM	N	N	NA	NA	IFIM	NR
FWS, OR	HP,MP	Y (many)	GF,NNL	AF,CWF	IFIM,T,OT	N
FWS, VI	HP,MP	Y (many)	IFIM,D,ETS, GF,F,ROR	WWF,CWF, M,WF	IFIM,OT,FS, F,O	N
FWS, III	HP,MP	Y (many)	SS	G,SS	IFIM,T,O	N
FWS, GA	HP,MP	Y (many)	SS,FS,F	G,AF,ETS	IFIM,WP,T,F	Y (2)
FWS, MA	MP,NFP	NR	NFP,SS	GF,AF	IFIM,F	NR
FWS, PA	N	Y (many)	NNL,ROR	G,GF	WP,ABF	N
NMFS, SE	N	NA	NA	NA	NA	NA
NMFS, CA	N	NR	D	SS,AF	IFIM	NR

ABF = Aquatic Base Flow method
AF = Anadromous fish
C = Consultation with other state/federal agencies
CWF = Coldwater fish
D = Defer to other state/federal agencies
ETS = Endangered or threatened species
F = Flow data
FS = Fish survey
G = General aquatic life
GF = General fisheries
HP = Hydropower Policy of the U.S. FWS
IFIM = Instream Flow Incremental Methodology
M = Macroinvertebrates
MP = Mitigation Policy of the U.S. FWS
N = No
NA = Not Applicable
NFP = New England Flow Policy of the U.S. FWS, Region 5
NNL = No net loss of aquatic habitat
NR = No Response
O = Other instream flow methods
OT = Other transect methods
ROR = Run-of-River requirement
SS = Site-specific studies
T = Tennent or Montana Method
WF = Waterfowl
WP = Wetted perimeter method
WWF = Warmwater fish
Y = Yes

Table B-3. Responses of state resource agencies to agency information request regarding dissolved oxygen.

State	Written DO mitigation policy	DO requirements for FERC-licensed projects	Type of study to determine need for fitigation	Objectives of DO mitigation	Suggested DO mitigation technologies	Studies of mitigation effectiveness
AL	Y	Y	MN, MD, PJ	SWQ	OP	N
AK	Y	N	O	O	NR	NA
AZ	Y	N	MD, O	SWQ	I, R, OP	WQ
AR	Y	N	MD	SWQ	NONE	BIOL
CA	Y	NR	NR	AD	NR	BIOL
CO	N	NR	NR	NR	NR	NR
CT	NR	NR	NR	NR	NR	NR
DE	NA	NA	NA	NA	NA	NA
FL	N	N	NR	NR	NR	N
GA	N	NR	O	SWQ	OP, T	N
HI	NR	NR	NR	NR	NR	NR
ID	Y	Y	MN	SWQ	NONE	N
IL	N	Y	MN	SWQ	NONE	N
IN	N	Y	O, PJ	AD	S	N
IA	Y	Y	MN	SWQ, AD	Z	N
KS	NR	NR	NR	NR	NR	NR
KY	Y	Y	O	AD	O	Y

AD = Antidegradation standards
BIOL = Biological monitoring/studies
FW = Other fish and wildlife objectives
I = Intake level control
MD = Modeling
MN = Monitoring
N = No
NA = Not applicable
NR = No response
O = Other
OP = Method determined by operator
PJ = Professional judgment
R = Improvements to reservoir water quality
S = Spill flows
SP = Spray devices
SWQ = State water quality standards
T = Turbine aeration
WQ = Water quality monitoring/studies
Y = Yes
Z = Cease operating

Table B-3. (continued).

State	Written DO mitigation policy	DO requirements for FERC-licensed projects	Type of study to determine need for mitigation	Objectives of DO mitigation	Suggested DO mitigation technologies	Studies of mitigation effectiveness
LA	N	N	NA	NA	NA	NA
ME	Y	NR	MN, MD	SWQ	S, SP, I, R	NR
MD	NR	NR	NR	NR	NR	NR
MA	N	Y	NR	FW	NR	N
MI	Y	Y	MN	SWQ, FW	S, O	N
MN	Y	Y	MN, MD	SWQ, AD	S, T, I, O	N
MS	N	NA	NA	NA	NA	NA
MO	N	NA	O	FW	S, T	BIOL, WG
MT	N	N	NR	NR	NR	NR
NE	N	Y	O	O	SP	WQ, BIOL
NV	N	Y	PJ	FW	NONE	N
NH	N	N	O	AD, SWQ	S, R	N
NJ	Y	Y	MN, MD	SWQ	S, T	Y
NM	NR	NR	NR	NR	NR	NR
NY	NR	NR	NR	NR	NR	NR
NC	N	Y	MN	SWQ	S, I	Y
ND	NR	NR	NR	NR	NR	NR

AD = Antidegradation standards
BIOL = Biological monitoring/studies
FW = Other fish and wildlife objectives
I = Intake level control
MD = Modeling
MN = Monitoring
N = No
NA = Not applicable
NR = No response
O = Other
OP = Method determined by operator
PJ = Professional judgment
R = Improvements to reservoir water quality
S = Spill flows
SP = Spray devices
SWQ = State water quality standards
T = Turbine aeration
WQ = Water quality monitoring/studies
Y = Yes
Z = Cease operating

Table B-3. (continued).

State	Written DO mitigation policy	DO requirements for FERC-licensed projects	Type of study to determine need for mitigation	Objectives of DO mitigation	Suggested DO mitigation technologies	Studies of mitigation effectiveness
OH	N	Y	O	AD, FW	S, O	N
OK	NR	NR	NR	NR	NR	NR
OR	NR	NR	NR	NR	NR	NR
PA	Y	Y	NR	SWQ, AD	NR	NR
RI	NR	NR	NR	NR	NR	NR
SC	N	N	MN	SWQ	R, I, O	Y
SD	N	NA	NA	NA	NA	NA
TN	N	NA	MD	SWQ	NONE	Y
TX	N	Y	PJ, MN, MD, O	SWQ, AD	OP, I, T, S	WQ
UT	N	NR	NR	NR	NR	NR
VT	NR	NR	NR	NR	NR	NR
VA	NR	NR	NR	NR	NR	NR
WA	Y	NR	NR	NR	NR	NR
WV	N	Y	MN	AD, SWQ	S, SP, I, T, O	WQ
WI	NR	NR	NR	NR	NR	NR
WY	NR	NR	NR	NR	NR	NR

AD = Antidegradation standards
BIOL = Biological monitoring/studies
FW = Other fish and wildlife objectives
I = Intake level control
MD = Modeling
MN = Monitoring
N = No
NA = Not applicable
NR = No response
O = Other
OP = Method determined by operator
PJ = Professional judgment
R = Improvements to reservoir water quality
S = Spill flows
SP = Spray devices
SWQ = State water quality standards
T = Turbine aeration
WQ = Water quality monitoring/Studies
Y = Yes
Z = Cease operating

Table B-4. Responses of federal resource agencies to agency information request regarding dissolved oxygen mitigation.

Agency, region	Dissolved oxygen mitigation policy?	Dissolved oxygen requirements for FERC-licensed projects?	Type of study to determine need for mitigation?	Objectives of dissolved oxygen mitigation?	Suggested DO mitigation technologies?	Studies of mitigation effectiveness?
EPA, III	N	NR	REVIEW	SSS, AD	S, SP, I, R, O	NR
EPA, VII	N	Y	REVIEW	SWQ, AD	S, SP, I, R, O	N
FWS, TX	N	Y	REVIEW, PJ	SWQ, FW	O	NR
FWS, OK	N	Y	REVIEW	SWQ	OP	N
FWS, NM	N	Y	REVIEW	SWQ	S, I, O	N
FWS, OR	N	Y	REVIEW	SWQ	SP, O	N
FWS, VI	N	Y	NR	NR	I, SP, O	WQ
FWS, III	N	Y	REVIEW	FW, O	S	NR
FWS, GA	N	Y	MN, BIOL, REVIEW	FW	SP, O, OP	N
FWS, MA	N	NR	REVIEW	FW	S, T	NR
FWS, PA	N	Y	REVIEW	AD	S, SP, I, R, O	N
NMFS, SE	N	NA	NA	NA	NA	NA
NMFS, CA	N	NR	REVIEW	AD, O	O	NR

AD = Antidegradation Standards
BIOL = Biological Monitoring/Studies
FW = Other Fish and Wildlife Objectives
I = Intake Level Control
MD = Modeling
MN = Monitoring
N = No
NA = Not Applicable
NR = No Response
O = Other
OP = Method Determined by Operator
PJ = Professional Judgment
R = Improvements to Reservoir Water Quality
REVIEW = Reviews existing studies
S = Spill Flows
SP = Spray Devices
SSS = State Site-Specific
SWQ = State Water Quality Standards
T = Turbine Aeration
WQ = Water Quality Monitoring/Studies
Y = Yes
Z = Cease Operating

Table B-5. Responses of state resource agencies to agency information request regarding upstream fish passage.

State	Written mitigation policy	Accept off-site mitigation	Passage requirements for FERC-licensed projects	Required for anadromous fish	Required for resident fish	Performance objectives quantified	Operational performance monitored
AL	N	N	NR	NR	NR	NR	NR
AK	Y	Y	N	NR	NR	NR	NR
AZ	N	NR	NR	NA	NR	NR	NR
AR	N	Y	N	NA	N	N	N
CA	Y	NR	NR	NR	NR	NR	NR
CO	Y	Y	N	NA	Y	N	N
CT	NR	NR	NR	NR	NR	NR	NR
DE	NA	NA	NA	NA	NA	NA	NA
FL	N	NR	NR	NR	NR	NR	N
GA	N	NR	NR	NR	NR	NR	NR
HA	NR	NR	NR	NR	NR	NR	NR
ID	Y	Y	Y	Y	Y	N	N
IL	NR	NR	NR	NR	NR	NR	NR
IN	N	N	Y	NA	Y	N	N
IA	N	NA	N	NA	NR	NR	NR
KS	NR	NR	NR	NR	NR	NR	NR
KY	N	Y	N	NA	NR	NR	NR
LA	N	N	N	NA	NA	NA	NA
ME	Y	Y	Y	Y	N	Y	Y
MD	NR	NR	NR	NR	NR	NR	NR
MA	N	N	Y	Y	N	Y	Y
MI	Y	Y	Y	Y	N	N	Y
MN	NR	NR	NR	NR	NR	NR	NR
MS	NA	NA	NA	NA	NA	NA	NA
MO	N	N	N	NA	NA	NA	NA

Y = Yes
N = No
NR = No response
NA = Not applicable

Table B-5. (continued).

State	Written mitigation policy	Accept off-site mitigation	Passage requirements for FERC-licensed projects	Required for anadromous fish	Required for resident fish	Performance objectives quantified	Operational performance monitored
MT	N	Y	N	N	N	N	N
NE	N	N	NR	NR	NR	NR	NR
NV	N	NR	N	NA	N	N	N
NH	N	N	Y	Y	N	Y	Y
NJ	Y	N	N	N	N	N	NR
NM	NR	NR	NR	NR	NR	NR	NR
NY	NR	NR	NR	NR	NR	NR	NR
NC	N	N	NR	NR	NR	NR	NR
ND	NR	NR	NR	NR	NR	NR	NR
OH	N	Y	NR	NR	NR	NR	NR
OK	NR	NR	NR	NR	NR	NR	NR
OR	NR	NR	NR	NR	NR	NR	NR
PA	Y	NR	NR	NR	NR	NR	NR
RI	NR	NR	NR	NR	NR	NR	NR
SC	N	Y	Y	Y	N	Y	Y
SD	N	N	NR	NR	NR	NR	NR
TN	N	Y	NR	NR	NR	NR	NR
TX	N	N	N	NA	NA	NA	NA
UT	N	Y	NR	NR	NR	NR	NR
VT	NR	NR	NR	NR	NR	NR	NR
VA	NR	NR	NR	NR	NR	NR	NR
WA	Y	N	Y	Y	N	Y	Y
WV	N	Y	N	NA	NA	NA	NA
WI	NR	NR	NR	NR	NR	NR	NR
WY	NR	NR	NR	NR	NR	NR	NR

Y = Yes
N = No
NR = No response
NA = Not applicable

Table B-6. Responses of state resource agencies to agency information request regarding downstream fish passage.

State	Written mitigation policy	Accept off-site mitigation	Passage requirements for FERC-licensed projects	Required for anadromous fish	Required for resident fish	Performance objectives quantified	Operational performance monitored
AL	N	N	NR	NR	NR	NR	NR
AK	Y	Y	N	NR	NR	NR	NR
AZ	N	NR	NR	NA	NR	NR	NR
AR	N	Y	N	NA	N	N	N
CA	Y	NR	NR	NR	NR	NR	NR
CO	Y	Y	Y	NA	Y	N	N
CT	NR	NR	NR	NR	NR	NR	NR
DE	NA	NA	NA	NA	NA	NA	NA
FL	N	NR	NR	NR	NR	NR	N
GA	N	NR	NR	NR	NR	NR	NR
HA	NR	NR	NR	NR	NR	NR	NR
ID	Y	Y	Y	Y	Y	N	N
IL	NR	NR	NR	NR	NR	NR	NR
IN	N	N	Y	NA	Y	N	N
IA	N	NA	N	NA	NR	NR	NR
KS	NR	NR	NR	NR	NR	NR	NR
KY	N	Y	N	NA	NR	NR	NR
LA	N	N	N	NA	NA	NA	NA
ME	Y	Y	Y	Y	N	Y	Y
MD	NR	NR	NR	NR	NR	NR	NR
MA	N	N	Y	Y	N	Y	Y
MI	Y	Y	Y	Y	Y	Y	Y
MN	NR	NR	NR	NR	NR	NR	NR
MS	NA	NA	NA	NA	NA	NA	NA
MO	N	N	N	NA	NA	NA	NA

Y = Yes
N = No
NR = No response
NA = Not applicable

Table B-6. (continued).

State	Written mitigation policy	Accept off-site mitigation	Passage Requirements for FERC-licensed projects	Required for anadromous fish	Required for resident fish	Performance objectives quantified	Operational performance monitored
MT	N	Y	N	N	N	N	N
NE	N	N	NR	NA	NR	NR	NR
NV	N	NR	N	NA	N	N	N
NH	N	N	Y	Y	Y	N	Y
NJ	Y	N	Y	N	Y	N	NR
NM	NR	NR	NR	NR	NR	NR	NR
NY	NR	NR	NR	NR	NR	NR	NR
NC	N	N	NR	NR	NR	NR	NR
ND	NR	NR	NR	NR	NR	NR	NR
OH	N	Y	NR	NR	NR	NR	NR
OK	NR	NR	NR	NR	NR	NR	NR
OR	NR	NR	NR	NR	NR	NR	NR
PA	Y	NR	NR	NR	NR	NR	NR
RI	NR	NR	NR	NR	NR	NR	NR
SC	N	Y	Y	Y	N	NR	NR
SD	N	N	NR	NR	NR	NR	NR
TN	N	Y	NR	NR	NR	NR	NR
TX	N	N	N	NA	NA	NA	NA
UT	N	Y	NR	NR	NR	NR	NR
VT	NR	NR	NR	NR	NR	NR	NR
VA	NR	NR	NR	NR	NR	NR	NR
WA	Y	N	Y	Y	Y	Y	Y
WV	N	Y	Y	NR	NR	YA	N
WI	NR	NR	NR	NR	NR	NR	NR
WY	NR	NR	NR	NR	NR	NR	NR

Y = Yes
N = No
NR = No response
NA = Not applicable

Table B-7. Responses of federal regulatory and resource agencies to agency information request regarding fish passage mitigation.

Agency, region/state	Fish passage mitigation policy?	How were needs and objectives determined?	Studies of mitigation effectiveness?	Type of fish protected	Performance objectives
EPA, III	N	CONS	NR	ANAD, RES	BAR, EXC, MOR
EPA, VII	N	CONS	Y	ALL	BAR, MOR
FWS, TX	N	NA	NA	NA	NA
FWS, OK	N	NA	NA	NA	NA
FSW, NM	N	NA	NA	NA	NA
FWS, OR	N	REV	Y	ALL	BAR, MOR
FWS, VI	N	CONS	N	RES	EXC
FWS, III	N	REV	NA	ANAD, RES	N
FWS, GA	N	REV	NA	ANAD	BAR
FWS, MA	N	REV	Y	ANAD, RES	BAR, EXC
FWS, PA	N	REV	Y	ALL	BAR, MOR
NMFS, SE	N	NA	NA	NA	NA
NMFS, CA	N	REV	NR	ANAD	BAR, EXC

ANAD = Anadromous species
ALL = All species
BAR = No obvious barrier to upstream fish movement
CONS = Consultation with other agencies
EXC = Exclude a specified percentage of fish from entrainment
MOR = Limit mortality to a specified level
N = No
NA = Not applicable
NR = No response
O = Other
RES = Resident, migratory species
REV = Reivew of existing information and plans
Y = Yes

APPENDIX C

MITIGATION COST SUMMARY WORKSHEETS

Estimated Yearly Generation Losses 1980-1990

280 SAMPLE SIZE   707 POPULATION SIZE

Mitigation Method	No. of Projects in Sample	% of Samples	Estimated No. of Projects In Target Population	Average Generation Loss (kWh)	Total Generation Loss (kWh)	Estimated Generation $0.04 per kWh	Estimated Generation $0.05 per kWh	Estimated Generation $0.06 per kWh	Estimated Generation $0.08 per kWh	Estimated Generation $0.10 per kWh	Estimated Generation $0.15 per kWh
DO	11	3.93%	28	107,047	2,997,316	$119,893	$149,866	$179,839	$239,785	$299,732	$449,597
Instream Flow	48	17.14%	121	2,489,186	301,191,506	$12,047,660	$15,059,575	$18,071,490	$24,095,320	$30,119,151	$45,178,726
Upstream Fish Passage	4	1.43%	10	1,122,120	11,221,200	$448,848	$561,060	$673,272	$897,696	$1,122,120	$1,683,180
Downstream Fish Passage	22	7.86%	56	6,139,364	343,804,384	$13,752,175	$17,190,219	$20,628,263	$27,504,351	$34,380,438	$51,570,658
Yearly Lost Generation Totals at Various per kWh Costs						$26,368,576	$32,960,720	$39,552,864	$52,737,152	$65,921,441	$98,882,161
5 Years Total Loss						$131,842,881	$164,803,602	$197,764,322	$263,685,762	$329,607,203	$494,410,805

Estimated Yearly Generation Losses 1992-2010

436 No. of Relicenses
1316 No. of New Licenses
280 SAMPLE SIZE   1752 TOTAL

Mitigation Method	No. of Projects in Sample	% of Sample	Estimated No. Projects Future	Avearge Gneration Loss (kWh)	Total Generation Loss (kWh)	Estimated Generation $0.04 per kWh	Estimated Generation $0.05 per kWh	Estimated Generation $0.06 per kWh	Estimated Generation $0.08 per kWh	Estimated Generation $0.10 per kWh	Estimated Generation $0.15 per kWh
DO	11	3.93%	69	107,047	7,386,243	$295,450	$369,312	$443,175	$590,899	$738,624	$1,107,936
Instream Flow	48	17.14%	300	2,489,186	746,755,800	$29,870,232	$37,337,790	$44,805,348	$59,740,464	$74,675,580	$112,013,370
Upstream Fish Passage	4	1.43%	25	1,122,120	28,053,000	$1,122,120	$1,402,650	$1,683,180	$2,244,240	$2,805,300	$4,207,950
Downstream Fish Passage	22	7.86%	138	6,139,364	847,232,232	$33,889,289	$42,361,612	$50,833,934	$67,778,579	$84,723,223	$127,084,835
Yearly Lost Generation Totals at Various per kWh Costs						$65,177,091	$81,471,364	$97,765,637	$130,354,182	$162,942,728	$244,414,091
7 Years Total Loss						$456,239,637	$570,299,546	$684,359,456	$912,479,274	$1,140,599,093	$1,710,898,639

Estimated Yearly Generation Losses 1980-1990 and 1992-2010

(Includes 1980-1990 Projects for 5 Years + 19 Future Years, and 1992-2010 Projects for 7 Future Years)

	Estimated Generation $0.04 per kWh	Estimated Generation $0.05 per kWh	Estimated Generation $0.06 per kWh	Estimated Generation $0.08 per kWh	Estimated Generation $0.10 per kWh	Estimated Generation $0.15 per kWh
1980-1990 Licensed Projects @ 24 Years	$632,845,830	$791,057,287	$949,268,745	$1,265,691,660	$1,582,114,574	$2,373,171,862
1992-2010 Licensed Projects @ 7 Years	$456,239,637	$570,299,546	$684,359,456	$912,479,274	$1,140,599,093	$1,710,898,639
	$1,089,085,467	$1,361,356,833	$1,633,628,200	$2,178,170,934	$2,722,713,667	$4,084,070,500

Environmental Mitigation Costs 1980-1990 (1991 Constant Dollar Analysis)

Target Population Size	707	Years for Annual Costs	5
Sample Size	280		

	No. Sample Projects 280	Average Capital Costs	Average Study Costs	Average O&M Costs	Average Annual Reporting Costs	No. of Target Population 707	Target Population Capital Costs	Target Population Study Costs	5 Years Annual Target. Population O&M Costs	Target Population Report Costs	Total Costs
Dissolved Oxygen											
< 1MW	13	$1,099	$1,000	$706	$1,413	33	$36,267	$33,000	$116,490	$233,145	
1 & <10	17	$29,926	$33,940	$1,420	$1,941	43	$1,286,818	$1,459,420	$305,300	$417,315	
10 & <50	21	$19,375	$25,654	$4,204	$3,556	53	$1,026,875	$1,359,662	$1,114,060	$942,340	
50 & <100	2	$11,919	N/A	$4,610	$512	5	$59,595	$0	$115,250	$12,800	
100MW & <	3	$1,079,352	$307,328	$5,396	$19,668	8	$8,634,816	$2,458,624	$215,840	$786,720	
	56				Total Costs	142	$11,044,371	$5,310,706	$1,866,940	$2,392,320	$20,614,337
Instream Flow									5 Years Annual Costs		
< 1MW	48	$48,008	$14,279	$1,833	$1,305	121	$5,808,968	$1,727,759	$1,103,965	$789,525	
1 & < 10	75	$38,731	$46,636	$5,436	$2,121	189	$7,320,159	$8,814,204	$5,137,020	$2,004,345	
10 & <50	26	$183,689	$231,452	$8,956	$11,600	66	$12,123,474	$15,275,832	$2,955,480	$3,828,000	
50 & <100	3	$1,255,378	$1,083,530	$5,122	$0	8	$10,043,024	$8,668,240	$204,880	$0	
100MW & <	5	$0	N/A	$0	$0	13	$0	$0	$0	$0	
	157				Total Costs	397	$35,295,625	$34,486,035	$9,406,345	$6,621,870	$85,809,875
Upstream Fish Passage									5 Years Annual Costs		
< 1MW	5	$42,721	$3,238	$2,158	$1,619	13	$555,373	$42,094	$140,270	$105,235	
1 & < 10	14	$82,614	$36,280	$9,308	$3,853	35	$2,891,490	$1,269,800	$1,628,900	$674,275	
10 & <50	7	$653,997	$97,786	$9,918	$7,964	18	$11,771,946	$1,760,148	$892,620	$716,760	
50 & <100	0	N/A	N/A	N/A	N/A	0	$0	$0	$0	$0	
100MW & <	3	$24,745,007	N/A	$717,080	$78,536	8	$197,960,056	$0	$28,683,200	$3,141,440	
	29				Total Costs	74	$213,178,865	$3,072,042	$31,344,990	$4,637,710	$252,233,607
Downstream Fish Passage									5 Years Annual Costs		
< 1MW	24	$25,912	$9,848	$4,486	$1,058	61	$1,580,632	$600,728	$1,368,230	$322,690	
1 & < 10	38	$277,125	$80,047	$11,182	$1,640	96	$26,604,000	$7,684,512	$5,367,360	$787,200	
10 & <50	16	$650,025	$198,824	$31,443	$4,157	40	$26,001,000	$7,952,960	$6,288,600	$831,400	
50 & <100	0	N/A	N/A	N/A	N/A	0	$0	$0	$0	$0	
100MW & <	1	$12,900,020	$5,850,713	N/A	N/A	3	$38,700,060	$17,552,139	$0	$0	
	79				Total Costs	200	$92,885,692	$33,790,339	$13,024,190	$1,941,290	$141,641,511
								Total Costs - All Projects 1980-1990			$500,299,330

Environmental Mitigation Costs 1992-2000 (1991 Constant Dollar Analysis)

1992-2000	< 1MW	1 & <10	10 & < 50	50 & < 100	100MW & <	Total	Estimated Mitigation Requirements (15 Years of Annual Costs)	
Relicenses	39	131	51	13	4	238	31% DO	12% Upstream Fish Passage
New Licenses	83	67	15	2	1	168	73% Instream Flow	48% Downstream Fish Passage

	No. of Relicensed Projects	No. of New Licensed Projects	Total No. of Projects	1991 Average Capital Costs	1991 Average Study Costs	1991 Average O&M Costs	1991 Average Annual Reporting Costs	Total Capital Costs	Total Study Costs	Total O&M Annual Costs	Total Annual Reporting Costs	Total Costs
Dissolved Oxygen												
< 1MW	12	26	38	$1,099	$1,000	$706	$1,413	$41,762	$38,000	$402,420	$805,410	
1 & < 10	41	21	62	$29,926	$33,940	$1,420	$1,941	$1,855,412	$2,104,280	$1,320,600	$1,805,130	
10 & <50	16	5	21	$19,375	$25,654	$4,204	$3,556	$406,875	$538,734	$1,324,260	$1,120,140	
50 & <100	4	1	5	$11,919	N/A	$4,610	$512	$59,595	$0	$345,750	$38,400	
100MW & <	1	0	1	$1,079,352	$307,328	$5,396	$19,668	$1,079,352	$307,328	$80,940	$295,020	
	74	53	127				Total Costs	$3,442,996	$2,988,342	$3,473,970	$4,064,100	$13,969,408
Instream Flow												
< 1MW	28	61	89	$48,008	$14,279	$1,833	$1,305	$4,272,712	$1,270,831	$2,447,055	$1,742,175	
1 & < 10	96	49	145	$38,731	$46,636	$5,436	$2,121	$5,615,995	$6,762,220	$11,823,300	$4,613,175	
10 & <50	37	11	48	$183,689	$231,452	$8,956	$11,600	$8,817,072	$11,109,696	$6,448,320	$8,352,000	
50 & <100	9	1	10	$1,255,378	$1,083,530	$5,122	$0	$12,553,780	$10,835,300	$768,300	$0	
100MW & <	3	1	4	$0	N/A	$0	$0	$0	$0	$0	$0	
	173	123	296				Total Costs	$31,259,559	$29,978,047	$21,486,975	$14,707,350	$97,431,931
Upstream Fish Passage												
< 1MW	5	10	15	$42,721	$3,238	$2,158	$1,619	$640,815	$48,570	$485,550	$364,275	
1 & < 10	16	8	24	$82,614	$36,280	$9,308	$3,853	$1,982,736	$870,720	$3,350,880	$1,387,080	
10 & <50	6	2	8	$653,997	$97,786	$9,918	$7,964	$5,231,976	$782,288	$1,190,160	$955,680	
50 & <100	2	0	2	N/A	N/A	N/A	N/A	$0	$0	$0	$0	
100MW & <	0	0	0	$24,745,007	N/A	$717,080	$78,536	$0	$0	$0	$0	
	29	20	49				Total Costs	$7,855,527	$1,701,578	$5,026,590	$2,707,035	$17,290,730
Downstream Fish Passage												
< 1MW	19	40	59	$25,912	$9,848	$4,486	$1,058	$1,528,808	$581,032	$3,970,110	$936,330	
1 & < 10	63	32	95	$277,125	$80,047	$11,182	$1,640	$26,326,875	$7,604,465	$15,934,350	$2,337,000	
10 & <50	24	7	31	$650,025	$198,824	$31,443	$4,157	$20,150,775	$6,163,544	$14,620,995	$1,933,005	
50 & <100	6	1	7	N/A	N/A	N/A	N/A	$0	$0	$0	$0	
100MW & <	2	0	2	$12,900,020	$5,850,713	N/A	N/A	$25,800,040	$11,701,426	$0	$0	
	114	80	194				Total Costs	$73,806,498	$26,050,467	$34,525,455	$5,206,335	$139,588,755

Environmental Mitigation Costs 2001-2010 (1991 Constant Dollar Analysis)

5 Years of Annual Costs

2001-2010	< 1MW	1 & <10	10 & <	50 & < 100	100MW & <	Total	Estimated Mitigation Requirements	
Relicenses	29	68	34	10	44	185	49% DO	14% Upstream Fish Passage
New Licenses	508	483	125	22	10	1148	95% Instream Flow	82% Downstream Fish Passage

	No. of Relicensed Projects	No. of New Licensed Projejcts	Total No. of Projects	1991 Average Capital Costs	1991 Average Study Costs,	1991 Average O&M Costs	1991 Average Annual Reporting Costs	Total Capital Costs	Total Sutdy Costs	Total O&M Annual Costs	Total Annual Reporting Costs	Total Costs
Dissolved Oxygen												
< 1MW	14	249	263	$1,099	$1,000	$706	$1,413	$289,037	$263,000	$928,390	$1,858,095	
1 & < 10	33	237	270	$29,926	$33,940	$1,420	$1,941	$8,080,020	$9,163,800	$1,917,000	$2,620,350	
10 & <50	17	61	78	$19,375	$25,654	$4,204	$3,556	$1,511,250	$2,001,012	$1,639,560	$1,386,840	
50 & <100	5	11	16	$11,919	N/A	$4,610	$512	$190,704	$0	$368,800	$40,960	
100MW & <	22	5	27	$1,079,352	$307,328	$5,396	$19,668	$29,142,504	$8,297,856	$728,460	$2,655,180	
	91	563	654				Total Costs	$39,213,515	$19,725,668	$5,582,210	$8,561,425	$73,082,818
Instream Flow												
< 1MW	28	483	511	$48,008	$14,279	$1,833	$1,305	$24,532,088	$7,296,569	$4,683,315	$3,334,275	
1 & < 10	65	459	524	$38,731	$46,636	$5,436	$2,121	$20,295,044	$24,437,264	$14,242,320	$5,557,020	
10 & <50	32	119	151	$183,689	$231,452	$8,956	$11,600	$27,737,039	$34,949,252	$6,761,780	$8,758,000	
50 & <100	10	21	31	$1,255,378	$1,083,530	$5,122	$0	$38,916,718	$33,589,430	$793,910	$0	
100MW & <	42	10	52	$0	N/A	$0	$0	$0	$0	$0	$0	
	177	1092	1269				Total Costs	$111,480,889	$100,272,515	$26,481,325	$17,649,295	$255,884,024
Upstream Fish Passage												
< 1MW	4	71	75	$42,721	$3,238	$2,158	$1,619	$3,204,075	$242,850	$809,250	$607,125	
1 & < 10	10	68	78	$82,614	$36,280	$9,308	$3,853	$6,443,892	$2,829,840	$3,630,120	$1,502,670	
10 & <50	5	18	23	$653,997	$97,786	$9,918	$7,964	$15,041,931	$2,249,078	$1,140,570	$915,860	
50 & <100	1	3	4	N/A	N/A	N/A	N/A	$0	$0	$0	$0	
100MW & <	6	1	7	$24,745,007	N/A	$717,080	$78,536	$173,215,049	$0	$25,097,800	$2,748,760	
	26	161	187				Total Costs	$197,904,947	$5,321,768	$30,677,740	$5,774,415	$239,678,870
Downstream Fish Passage												
< 1MW	24	417	441	$25,912	$9,848	$4,486	$1,058	$11,427,192	$4,342,968	$9,891,630	$2,332,890	
1 & < 10	56	396	452	$277,125	$80,047	$11,182	$1,640	$125,260,500	$36,181,244	$25,271,320	$3,706,400	
10 & <50	28	103	131	$650,025	$198,824	$31,443	$4,157	$85,153,275	$26,045,944	$20,595,165	$2,722,835	
50 & <100	8	18	26	N/A	N/A	N/A	N/A	$0	$0	$0	$0	
100MW & <	36	8	44	$12,900,020	$5,850,713	N/A	N/A	$567,600,880	$257,431,372	$0	$0	
	152	942	1094				Total Costs	$789,441,847	$324,001,528	$55,758,115	$8,762,125	$1,177,963,615

Total Costs - All Projects 2001-2010 $1,746,609,327

Total Costs - All Projects 1991-2010 $2,014,890,151