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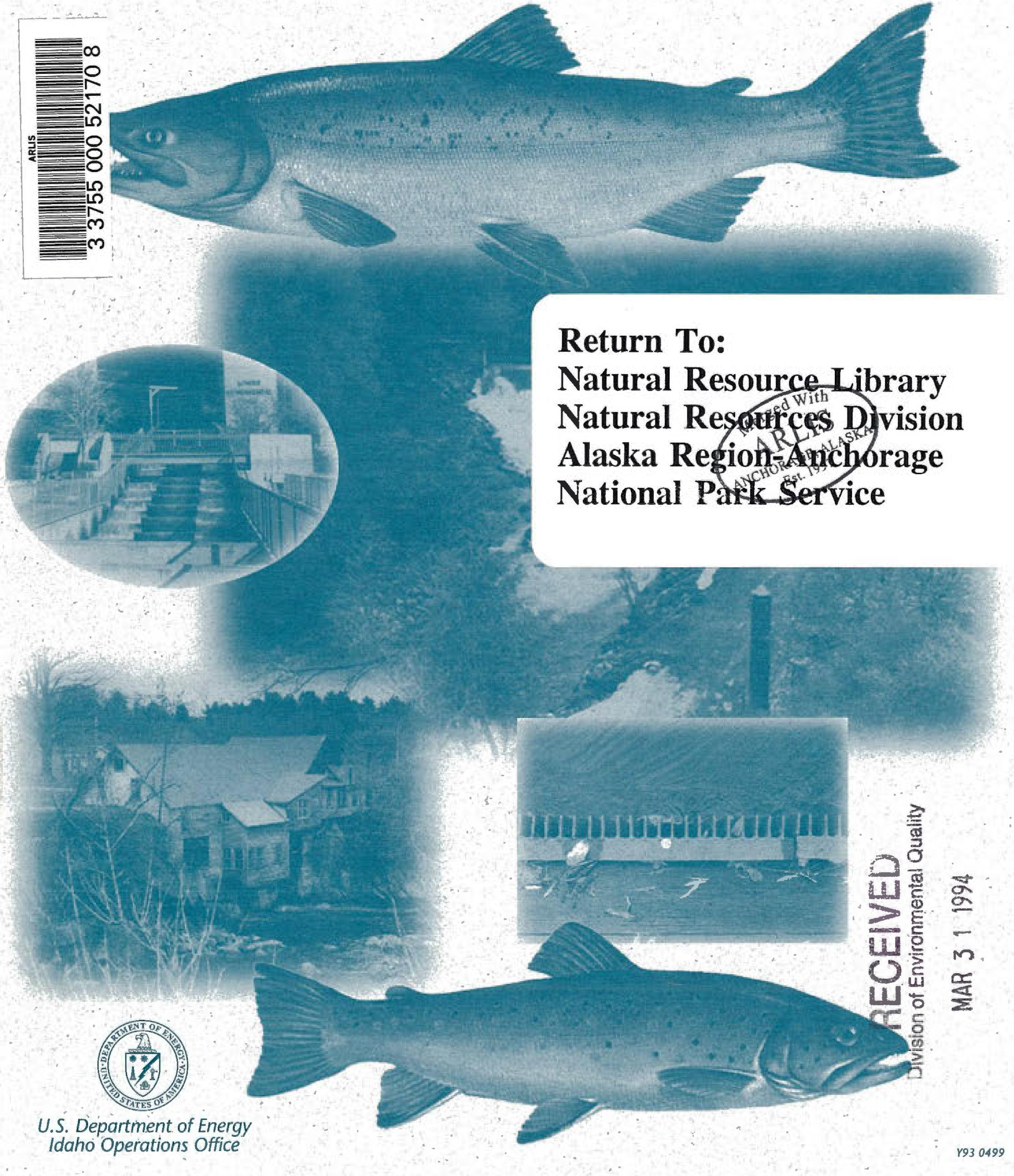
Environmental Mitigation at Hydroelectric Projects

Volume II. Benefits and Costs of Fish Passage and Protection



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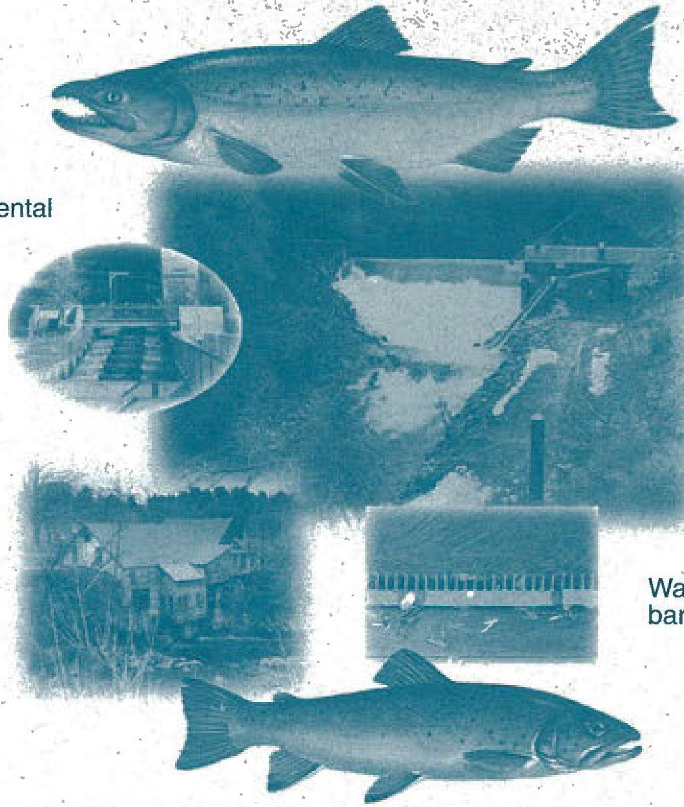
Chinook salmon
Lower Monumental right-bank fish ladder
Arbuckle Mountain diversion and fish ladder
Wadhams power plant
Wadhams angle bar rack
Brown trout

Environmental Mitigation at Hydroelectric Projects

Volume II. Benefits and Costs of Fish Passage and Protection

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b. Oak Ridge National Laboratory.
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ABSTRACT

This study examines environmental mitigation practices that provide upstream and downstream fish passage and protection at hydroelectric projects. The study includes a survey of fish passage and protection mitigation practices at 1,825 hydroelectric plants regulated by the Federal Energy Regulatory Commission (FERC) to determine frequencies of occurrence, temporal trends, and regional practices based on FERC regions. The study also describes, in general terms, the fish passage/protection mitigation costs at 50 non-Federal hydroelectric projects. Sixteen case studies are used to examine in detail the benefits and costs of fish passage and protection. The 16 case studies include 15 FERC licensed or exempted hydroelectric projects and one Federally-owned and -operated hydroelectric project. The 16 hydroelectric projects are located in 12 states and range in capacity from 400 kilowatts to 840 megawatts. The fish passage and protection mitigation methods at the case studies include fish ladders and lifts, an Eicher screen, spill flows, airburst-cleaned inclined and cylindrical wedgewire screens, vertical barrier screens, and submerged traveling screens. The costs, benefits, monitoring methods, and operating characteristics of these and other mitigation methods used at the 16 case studies are examined.

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The authors' gratitude to the case study participants cannot be overemphasized. The case study participants unselfishly provided hours of assistance, answering many questions and providing information. The authors take complete responsibility for any errors contained in this report. None of the case study plant owners are in any way responsible for the contents, conclusions, or suggestions in this report.

EXECUTIVE SUMMARY

The Department of Energy, through its hydropower program, is studying environmental mitigation practices at hydroelectric projects. The study of environmental mitigation practices is intended to provide greater understanding of environmental problems and solutions that are associated with conventional hydroelectric projects. This volume examines upstream and downstream fish passage/protection technologies and the associated practices, benefits, and costs. Fish passage/protection mitigation technologies are investigated by three methods: (a) national, regional (Federal Energy Regulatory Commission regions), and temporal frequencies of fish passage/protection mitigation are examined at 1,825 operating and conventional (excludes pumped storage) Federal Energy Regulatory Commission (FERC) regulated hydroelectric sites in the United States; (b) general fish passage/protection mitigation costs are discussed for 50 FERC regulated hydroelectric projects; and (c) 16 case studies are used to examine specific fish passage/protection mitigation practices, benefits, and costs.

MITIGATION FREQUENCIES

Upstream Fish Passage/Protection. Nationally, 9.5% of the 1,825 hydroelectric sites have some type of upstream fish passage/protection mitigation in place. This frequency varies regionally; in the Chicago region 2.2% of the 232 plants have upstream mitigation, and in the Portland region 22.5% of the 306 plants have upstream mitigation. Temporal trends of hydroelectric plants with upstream mitigation range from 11.4% for plants licensed during the 1970–1977 period, to 8.5% of the plants licensed during the 1986–1993 period. At projects with upstream mitigation, fish ladders are the most frequently used methods (62%). An assortment of other methods are also used, including trailrace screens and bar racks, trapping and hauling, fish lifts, bypass canals, and navigation locks. Multiple methods are sometimes used at individual sites.

Downstream Fish Passage/Protection. At the 1,825 hydroelectric plants, nationally 13.0% have downstream fish passage/protection mitigation. Regional frequencies range from 0.0% in the Chicago region to 22.5% in the Portland region. Temporal trends for downstream mitigation range from 5.1% of plants licensed during the 1970–1977 period to 17.6% of plants licensed 1986–1993. For plants with downstream mitigation, screens are used at 58.2% of the plants, bypasses are used at 27%, angled bar racks are used at 16.7%, and an assortment of methods are used at 18% of the plants. The percentages sum greater than 100% as some plants have more than one type of downstream mitigation method in place.

GENERAL FISH PASSAGE/ PROTECTION COST INFORMATION

The 50 FERC regulated plants use diverse mitigation methods including fish ladders (81% of plants with upstream mitigation), bypasses, trapping and hauling, fish lifts, barrier nets, penstock screens, and other screens and methods. The upstream mitigation capital costs range from $1,000 for a fish ladder at a 5 kilowatt capacity plant to $69.2 million for two fish ladders at an 881,000 kilowatt capacity plant. Downstream mitigation costs are similarly widespread. For example, a 40 kilowatt capacity plant reports using an angled bar rack at a capital cost of $500, while a 4,900 kilowatt capacity plant reports using an angled bar rack at a capital cost of $2.6 million. Study, operations and maintenance, and reporting costs for upstream and downstream mitigation at these 50 plants also exhibit significant cost ranges.

CASE STUDIES

The 16 hydroelectric projects used as case studies range in capacity from 0.4 to 840 megawatts, with a mean capacity of 146 megawatts and a median capacity of 15 megawatts (Table ES-1). Out of the 16 case studies, which are located in eight states, 12 have upstream mitigation and 14 have downstream mitigation in place.

Upstream Mitigation. At the 12 case studies with upstream mitigation, 10 use fish ladders (three projects have two ladders each), two use fish lifts, and one project uses a fish gate and bypass notch in the diversion weir. One case study has a ladder at its diversion dam and a fish lift at the powerhouse. Twenty-year total costs range from $75,000 to $46.1 million and costs per kilowatt-hour range from 0.05 to 10.6 mills. Half of the case studies have been successful at meeting their stated goals; others have not been monitored, or factors such as low stream flows have impacted mitigation success or impaired monitoring efforts (Table ES-2).

Downstream Mitigation. At the 14 case studies with downstream mitigation, five use bypasses or sluiceways, and nine use screens. Of those that use screens, three case studies use power canal screens, one case study uses eight cylindrical screens set on the penstock intake manifold, three use penstock screens (punched plate, Eicher, inclined wedgewire), one uses submerged traveling and vertical barrier screens, and one case study is replacing its horizontal traveling screen with an inclined wedgewire screen. The inclined wedgewire screen has an airburst cleaning system. The cylindrical and penstock wedgewire screens both have airburst cleaning systems. The 20-year total costs range from $48,000 to $96.2 million, and the costs per kilowatt-hour range from 0.04 to 8.7 mills. The majority of the case studies have no downstream monitoring programs, but three of the case studies have invested significant resources to quantify goals and to monitor the success of meeting mitigation goals (Table ES-3).

CONCLUSION

Forecasting if fish passage/protection mitigation will be a requirement at hydroelectric sites is not a probabilistic exercise as so many site-specific characteristics (i.e., fish species present, migratory habits, local values, physical obstructions such as waterfalls) make each hydroelectric site unique as to the probability of having a specific mitigation need. These mitigation needs are often met with specific technologies (fish lifts, trapping and hauling systems, or fish ladders). Once installed, the monitoring of mitigation performance is often not a requirement. Because there is frequently little information available as to effectiveness of specific mitigation technologies, determining new mitigation requirements (which can require significant economic resources) can prove to be an arduous process. This study provides information describing both historical and current mitigation efforts in the United States. The case studies provide detailed illustrations of mitigation practices, allowing readers involved with fish passage/protection mitigation decisions to understand the resource and economic requirements and ramifications of mitigation choices.

Table ES-1. Case studies general information. Costs are in 1993 dollars, per kilowatt-hour of generation, based on 20-year averages. All upstream and downstream mitigation-related costs are included.

Project name	Capacity (MW)	Annual energy production (MWh)	Diversion height (ft)	Average site flow (cfs)	State	Upstream mitigation	Downstream mitigation	Mitigation cost (mills/kWh)
Arbuckle Mountain	0.4	904	12	50	California	Y	Y	12.9
Brunswick	19.7	105,200	34	6,480	Maine	Y	Y	3.7
Buchanan	4.1	21,270	15	3,636	Michigan	Y	N	10.6
Conowingo	512	1,738,000	105	45,000	Maryland	Y	N	0.9
Jim Boyd	1.2	4,230	3.5	556	Oregon	Y	Y	21.1
Kern River No. 3	36.8	188,922	20	357	California	Y	Y	0.09
Leaburg	15	97,300	20	4,780	Oregon	Y	Y	5.2
Little Falls	13.6	49,400	6	n/a	New York	N[a]	Y	2.8
Lowell	15	84,500	15	6,450	Massachusetts	Y	Y	5.5
Lower Monumental	810	2,856,000	100	48,950	Washington	Y	Y	2.3
Potter Valley	9.2	57,700	63	331	California	Y	Y	n/a
T.W. Sullivan	16.6	122,832	45	23,810	Oregon	N[b]	Y	5.8
Twin Falls	24	80,000	10	325	Oregon	N	Y	0.9
Wadhams	0.56	2,000	7	214	New York	N	Y	1.2
Wells	840	4,097,851	185	80,000	Washington	Y	Y	1.0
West Enfield	13	96,000	45	12,000	Maine	Y	Y	3.9

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n/a—not available.

[a] Upstream passage occurs through New York Department of Transportation Barge Lock Number 17.

[b] Upstream passage occurs through Oregon Department of Fish and Wildlife maintained fish ladder at Willamette Falls.

Table ES-2. Upstream fish passage/protection mitigation benefits. The costs are levelized annual costs (1993 dollars), over 20 years.

Project	Mitigation type	Agency objective	Mitigation benefit	Annual cost (20-year average)
Arbuckle Mountain	Denil ladder	If restoration of chinook salmon and steelhead is successful downstream, then mandated ladder will be needed; also to allow movement of resident rainbow trout around the project	No anadromous fish present, restoration hindered by drought-related low stream flows; monitoring (visual observation) indicated no obstruction of resident trout	$3,770
Brunswick	Vertical slot ladder	A sustained commercial yield of: Alewife—1 million lb/year (estimated 3.3 million fish/year) American shad—500,000 lb/year (estimated 286,000 fish/year) Present ladder capacity: Alewife—1 million fish/year American shad—85,000 fish/year	Fish moving through ladder—6-year average: Alewife—76,000/year Atlantic salmon—47/year American shad—one fish in 6 years	$342,400
Buchanan	Vertical slot ladder	Pass large numbers of migrating fish upstream for anglers	Fish moving through ladder—1992: Chinook salmon—1,856 (92% efficiency) Coho salmon—267 Steelhead—1,421 (69% efficiency)	$212,850
Conowingo	Mechanical lifts (2)	Transport maximum American eel, river herring, and striped bass upstream: present lift design; River herring—5 million/year: American shad—750,000/year	Fish moving through lift—9 year average: American shad—10,700/year (Single lift until 1991—two lifts now operating should raise this total to at least 20,000/year)	$1,538,900
Jim Boyd	V-notch weir and fish gate	Assure that no induced fish mortality results from project operation (chinook and steelhead)	No established monitoring program, visual observations	$38,290
Kern River No.3	Denil ladder	Allow upstream movement of resident rainbow trout (changing management goals may result in closing the ladder)	No established monitoring program	$8,800
Leaburg	Vertical slot ladder	"No net loss" of anadromous fish moving past the project	Fish moving through ladder—20 year average: Chinook—2,800/year (no net loss standard reportedly achieved)	$126,300

Table ES-2. (continued).

Project	Mitigation type	Agency objective	Mitigation benefit	Annual cost (20-year average)
Lowell	Vertical slot ladder and mechanical lift	Restore designated fish to the following levels: Atlantic salmon—3,000 American shad—1 million	Fish using ladder/lift—7-year average: American shad—2,200/year	$408,775
Lower Monumental	Overflow weir ladders (2)	To move anadromous fish upstream past the project	Ladder efficiency: 82%–100%, spring/ summer chinook salmon	$1,811,000
Potter Valley	Pool/weir ladder	Increase movement of chinook salmon and steelhead upstream	Fish moving through ladder—21-year average: chinook salmon—220/year Steelhead—960/year	No cost data
Wells	Pool/weir ladders (2)	"No induced mortality" standard be maintained	Fish moving through ladders—20-year average: salmon—48,000/year, steelhead—7,300/year	$2,461,000
West Enfield	Vertical slot ladder	Ladder design: Atlantic salmon—10,000/year Alewife—14 million/year American shad—1.4 million/year	Fish moving upriver—10-year average: Atlantic salmon—2,650/year	$315,000

Table ES-3. Downstream fish passage/protection mitigation benefits. The costs are levelized annual costs (1993 dollars), over 20 years.

Project	Mitigation type	Agency objective	Mitigation benefit	Annual cost (20-year average)
Arbuckle Mountain	Cylindrical, wedgewire screens	Prevent fish entrainment (chinook salmon, steelhead, rainbow trout)	No anadromous fish present. Drought restricted monitoring	$7,900
Brunswick	Steel bypass pipe	Reduce mortality for downstream migrating fish (American shad, alewife)	No established monitoring program	$46,500
Jim Boyd	Perforated steel screen	"No induced mortality" standard	Reportedly achieves agency standard. Visual observations performed	$51,000
Kern River No. 3	Fixed barrier screens	Protect "put-and-take" rainbow trout fishery	No established monitoring program	$7,700
Leaburg	"V" wire screens and bypass	"No net loss" standard	Meets agency standards	$381,200
Little Falls	Wire mesh screens and bypass	Protect downstream migrating blueback herring	Less than 1% turbine entrainment (>100,000 passed each season)	$123,400
Lowell	Bypass sluice	Pass American shad and Atlantic salmon	No established monitoring program but existing sluice is considered ineffective	$52,850
Lower Monumental	Submerged, traveling screens	Prevent turbine entrainment (salmon and steelhead)	Not yet monitored	$4,812,000
T.W. Sullivan	Eicher screen and conduit	Decrease turbine entrainment	Bypass efficiency between 77 and 95%	$713,000
Twin Falls	Inclined wedgewire screens	"No induced turbine mortality" standard	Reportedly effective	$75,850
Wadhams	Angled trash racks and bypass sluice	Protect downstream-moving Atlantic salmon from turbine mortality	1987 study: 8% entrainment	$2,420

Table ES-3. (continued).

Project	Mitigation type	Agency objective	Mitigation benefit	Annual cost (20-year average)
Wells	Hydrocombine bypass	Goal—"no induced mortality"; present agency criteria (passage efficiency): Spring—80% efficiency Summer—70% efficiency	Passage efficiency exceeds agency criteria	$1,756,000
West Enfield	Steel bypass pipe	Protect downstream migrating Atlantic salmon and alewife	Efficiency: 1990—18% 1991—62% (with attraction lighting) Mortality in bypass greater than in turbines	$61,000

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FIGURES

TABLES

ABBREVIATIONS AND ACRONYMS

cfs	cubic feet per second (volume of water)
DOE	United States Department of Energy
DWM	Downstream fish passage/protection mitigation
FERC	Federal Energy Regulatory Commission
FGE	Fish guidance efficiency
fps	feet per second (velocity of flowing water)
kW	kilowatt
kWh	kilowatt-hour
Mill	monetary value equal to 1/10 cent
MW	Megawatt
MWh	Megawatt-hour
PIT	Passive Integrated Transponder tag system
STS	Submerged traveling screen
UPM	Upstream fish passage/protection mitigation
VBS	Vertical barrier screen

CONVERSION TABLE

Multiply	By	To obtain
Gallons	0.134	Cubic feet
Cubic feet	7.481	Gallons
Cubic feet per second	448.86	Gallons per minute
Gallons per minute	0.002228	Cubic feet per second
Acre-feet	43,560	Cubic feet
Kilowatts	1,000	Megawatts
Gallons	3.785	Liters
Gallons	0.00378	Cubic meters
Cubic feet	28.316	Liters
Miles	1,609.344	Meters
Feet	0.3048	Meters
Inches	25.4	Millimeters
Millimeters	0.0394	Inches
Mills	0.1	Cents

Volume II. Benefits and Costs of Fish Passage and Protection

1. INTRODUCTION

Environmental mitigation at hydroelectric projects is being studied by the U.S. Department of Energy through its hydropower program. The mission of the hydropower program is to develop, conduct, and coordinate research and development with industry and other Federal agencies, and to improve the technical, societal and environmental benefits of hydroelectricity. The study of environmental mitigation practices is intended to provide better understanding of environmental problems and solutions that are associated with the construction and operation of hydroelectric projects. Volume I, entitled "Current Practices for Instream Flow Needs, Dissolved Oxygen, and Fish Passage" was published in December 1991. This report, Volume II, is entitled "Benefits and Costs of Fish Passage and Protection."

1.1 Hydroelectric Regulation and Mitigation

The regulatory process that controls the development of hydroelectric projects in the United States has become increasingly complex over the past decade. The most recent changes to hydroelectric regulations have come as a result of the Electric Consumers Protection Act of 1986, which significantly strengthened the role of fish and wildlife agencies and reinforced the "equal consideration" standard for evaluating nonpower values in hydroelectric development. During the public hearings on the National Energy Strategy, much industry testimony focused on the regulatory burden on hydroelectric developers. For example, the following two extremes were 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 hydroelectricity are clear: (a) hydroelectricity is by far the largest developed renewable energy resource in the United States (e.g., hydroelectricity provides 10 to 13% of the electricity in the country) and (b) its undeveloped resource potential is great (preliminary estimates by the Department of Energy indicate ~52,000 MW remains undeveloped). Renewable energy resources, including hydroelectricity, will be an important part of this nation's energy future, especially as concern for acidic and greenhouse emissions increases. If hydroelectricity's contribution to the U.S. energy portfolio is to increase, or even be maintained at its current level, electricity must be generated without unacceptable environmental effects.

The Federal Energy Regulatory Commission (FERC) is required to include mitigation of identifiable environmental impacts in the licenses it issues for non-Federal hydroelectric projects. The President's Council on Environmental Quality (49 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 hydroelectric projects, their costs can be very high, and their effectiveness is often poorly understood. These problems are the subject of this study.

1.2 Volume I Report

The Volume I Report of the Environmental Mitigation Study examined current mitigation practices for water quality (specifically, dissolved oxygen), instream flows, and upstream and downstream fish passage/protection. The report addressed the types and frequency of mitigation methods in use, their environmental benefits and effectiveness, and their costs.

Information on mitigation practices was obtained directly from three sources: (a) existing records from FERC, (b) new information provided by non-Federal hydroelectric developers, and (c) new information obtained from the state and Federal natural resource agencies involved in hydroelectric regulation. The hydroelectric 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 database. The information provided by these projects includes the specific mitigation requirements, 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. About 40% of all the projects licensed during the 1980s were identified as having 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/protection, dissolved oxygen protection, and upstream fish passage/protection facilities. The Volume I report indicated that the proportion of projects with environmental mitigation requirements has increased significantly during the past decade.

1.3 Volume II Study Objectives

The overall goal of this study of environmental mitigation practices is to provide sound experience-based information to regulatory and resource agencies and to developers. Answers are being sought for important questions that are not well understood, such as:

- How frequently is mitigation of different types required at hydroelectric 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 in terms of actual capital costs and effects on revenues?

- What are the measurable benefits of particular mitigation practices?

- What effects do the mitigation practices have on the operation and maintenance of a hydroelectric facility?

- Are current mitigation practices effective in meeting their stated objectives, or are there any specific areas where increased research and development could improve their effectiveness?

The answers to these question can provide new guidance to hydroelectric developers, regulators, and natural resource managers concerning more effective mitigation practices and regulations.

1.4 Volume II Study Information and Methods

Two basic approaches were used to examine the fish passage/protection mitigation practices: (a) A systematic review and evaluation of all hydroelectric projects to identify those with fish passage/protection mitigation requirements and to present the information, and (b) case studies of representative projects that have information for quantifying benefits and costs.

The systematic review and evaluation included the following general steps:

- Contacted FERC to identify the projects with fish passage/protection mitigation requirements. Specific contacts to each FERC regional office (Portland, San Francisco, Chicago, Atlanta, and New York) identified 1,825 hydroelectric plants with FERC licenses. These plants were screened for the fish passage/protection mitigation issues, the frequencies of the requirements, and the types of methods used (i.e., fish ladder, trap and hauling, fish elevator, bypass facility, angled bar rack, screens, light/sound, etc.).
- Reviewed the Volume I Report data to identify an initial list of fish passage/protection mitigation projects that include environmental and cost information.
- Identified the fish species present in each region to select a diversity of species affected by site mitigation practices.
- Evaluated the projects in each region and identified the potential case studies by states. The potential list of case studies was based on frequencies, types of mitigation methods, types of projects and sizes, fish species, and available data on environmental and cost information.
- Finalized the list of case study projects. Each developer was contacted to determine the willingness to participate, and to evaluate the availability of additional information on the selected case studies.
- Contacted additional developers to obtain additional cost information to expand the Volume I cost information to improve the cost analysis for the Volume II Report. About 75 project developers responded to this request. This is cost information beyond the case study projects.
- Evaluated and presented the frequencies, types of mitigation methods, benefits, and costs.

The preparation of the project case studies included the following general steps:

- Developed the case study screening criteria to identify and select the appropriate projects.
- Developed a computer database to manage and evaluate the information.
- Obtained, reviewed, and evaluated information from FERC and project developers. Coordinated with the suppliers of the information the necessary refinements and clarification of the information. Site visits were conducted at most projects. Photographs were taken and other information was collected.
- Summarized the case studies into a common outline.

Other sections of the report were prepared based on information obtained or developed as a result of the approaches described above. The report was developed by the research team with input from FERC and the project developers. Assistance from other organizations and agencies consisted of reviews and previously developed data. A formal peer review was conducted with selected representatives from the industry (public and private).

1.5 Current Hydroelectric Arena

In the current hydroelectric arena, the developer is mandated to give equal consideration to all values affecting the development. One of the most commonly used ways to evaluate the tradeoffs is through a cost-benefit analysis. This method requires that values be assigned to each element affected by the project. Trying to apply a standard method to all the various elements becomes very complex. A fish saved by a fish passage/protection facility may have several different values, depending on the final outcome. For example, a fish caught commercially will have a lower value than if caught recreationally. The location and species also changes these values. In addition to fish values, the numbers of fish must also be estimated. The other side of this equation must identify and measure the costs.

This report includes a section on estimating fish values for investments in fish passage/protection facilities. There are current limitations in estimating these benefits because the industry has not advanced to a point where guidelines and standards can be applied to the various values. The specific case studies review the various information, such as studies, fish counting surveys (pre- and post-project), monitoring methods, performance of mitigation methods, and fish populations and associated fisheries.

The cost section reviews the costs of the various mitigation methods. The costs reviewed include capital, study, annual reporting and monitoring, and operations and maintenance. The types of mitigation practices and their costs are reviewed for both upstream and downstream fish passage/protection facilities. The upstream fish passage/protection methods include trapping and hauling, ladders, elevators, and others. The downstream fish passage/protection methods include bypasses, angled bar racks, screens, light and sound, and others. The cost ranges for these types of facilities are significant and tend to be site-specific. The review of the case studies covers the physical characteristics and explains the reasons for the various cost ranges. The general use of these costs is limited because of the unique nature of each project. However, understanding the reasons for the ranges and applications may provide helpful guidelines for planning purposes.

The study focuses on projects regulated by FERC and reviews the mitigation frequencies of these hydroelectric plants. Of the 1,825 FERC licensed or exempted plants, about 9.5% and 13.0% of the plants have upstream or downstream fish passage/protection mitigation, respectively. These 1,825 plants represent about 78% of all operating plants and about 50% of the hydroelectric capacity in the United States.

The case studies were selected by reviewing the frequencies by regions and identifying other supporting information on the benefits and costs. The case studies include 16 projects. Fifteen projects are regulated by FERC and one project is owned and operated by the U.S. Army Corps of Engineers. The Federally-owned and -operated project was selected because of the variety of information that was available on this project.

The intent of this report is to present factual information. The report does not attempt to interpret or make inferences regarding the data. In some cases, data were obtained but a connection could not be made to a mitigation practice, benefit, or cost. As an example, in the case of the spill flow requirements reported by the five FERC regions, the reasons for spill flows were not reported and or not fully understood. Spill flows are sometimes used for fish passage, but often times spills are used for instream flows or dissolved oxygen requirements. Consequently, spill flows were not included in the analysis. These types of exceptions are identified and discussed but are excluded from the analysis.

1.6 Scope and Organization of Volume II

The contents of this report focus on upstream and downstream fish passage/protection mitigation practices as they have been applied to operational hydroelectric projects. The scope of this report includes:

- Obtaining additional information from FERC and project developers to expand the Volume I cost analysis and identify potential case studies.
- Selecting the case studies based on the screening criteria and information received. The screening criteria incorporated information such as: the frequency of the practice and the FERC region, the objectives of the mitigation, monitoring methods, mitigation performance, benefits, and available costs.
- Gathering, compiling, and analyzing the information and data for each case study. Sixteen projects were studied in detail.
- Obtaining additional cost information from developers to expand the cost analysis. Additional cost information was collected on about 75 projects beyond the case studies.
- Developing the benefits and cost analysis.
- Conducting an industry peer review of the report.

The report is divided into 27 sections beginning with the introduction. Temporal, regional, and national mitigation frequencies are described in Section 2, and general fish passage/protection costs at 50 hydroelectric plants are discussed in Section 3. The case studies selection process, analysis methodology, individual case studies, and the case study summary are discussed in Sections 4 through 21. Section 22 includes techniques used to determine value and benefits. The conclusions and recommendations are contained in Sections 23 and 24. A listing of fish species referenced is provided in Section 25. Color illustrations of selected fish species are presented in Section 26. References cited are listed in Section 27. Appendix A contains the raw FERC data.

This research was jointly conducted by staff from the Idaho National Engineering Laboratory and the Oak Ridge National Laboratory. Idaho National Engineering Laboratory staff acquired the expanded cost data, conducted the evaluation on frequencies and provided cost analysis for specific case studies. Oak Ridge National Laboratory staff provided the benefit analysis of specific case studies and defined values for benefits. The Bonneville Power Administration, with technical support from the Pacific Northwest Laboratory, provided case study information and data on several projects in the Pacific Northwest. Richard Hunt Associates and Northwest Water Resources Advisory Services (both under subcontract) provided information on several case studies.

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2. MITIGATION INFORMATION PROVIDED BY THE FEDERAL ENERGY REGULATORY COMMISSION

FERC directed each of its five regional offices to provide mitigation information describing practices at FERC regulated hydroelectric projects in each of the respective administrative regions (Figure 2-1). The FERC regional offices provided the following variables describing upstream and downstream fish passage/protection mitigation practices:

- Project number and name
- Upstream mitigation type: trapping and hauling, fish ladder, fish elevator, other (specified), no upstream mitigation present
- Downstream mitigation type: spill flows, bypass facility, angled bar rack, screens (type specified), light/sound guidance, other (specified), no downstream mitigation present.

The mitigation information provided by the FERC regional offices was compared to the FERC maintained Hydropower Resource Assessment database to ensure that each site was an operating and conventional hydroelectric plant. This excludes pumped storage plants, retired plants, plants under construction, and diversions and dams without a power generation plant.

Comparison of the Hydropower Resource Assessment database with the information provided by the regional offices identified some inconsistencies with the provided mitigation information. Some of the regional offices provided mitigation information of sites that only contained a dam or diversion and do not have current hydroelectric capability. These sites may be part of a larger water conveyance system and are subject to FERC regulation but are not of interest to this study as no hydroelectricity exists. Other inconsistences were the inclusion of mitigation

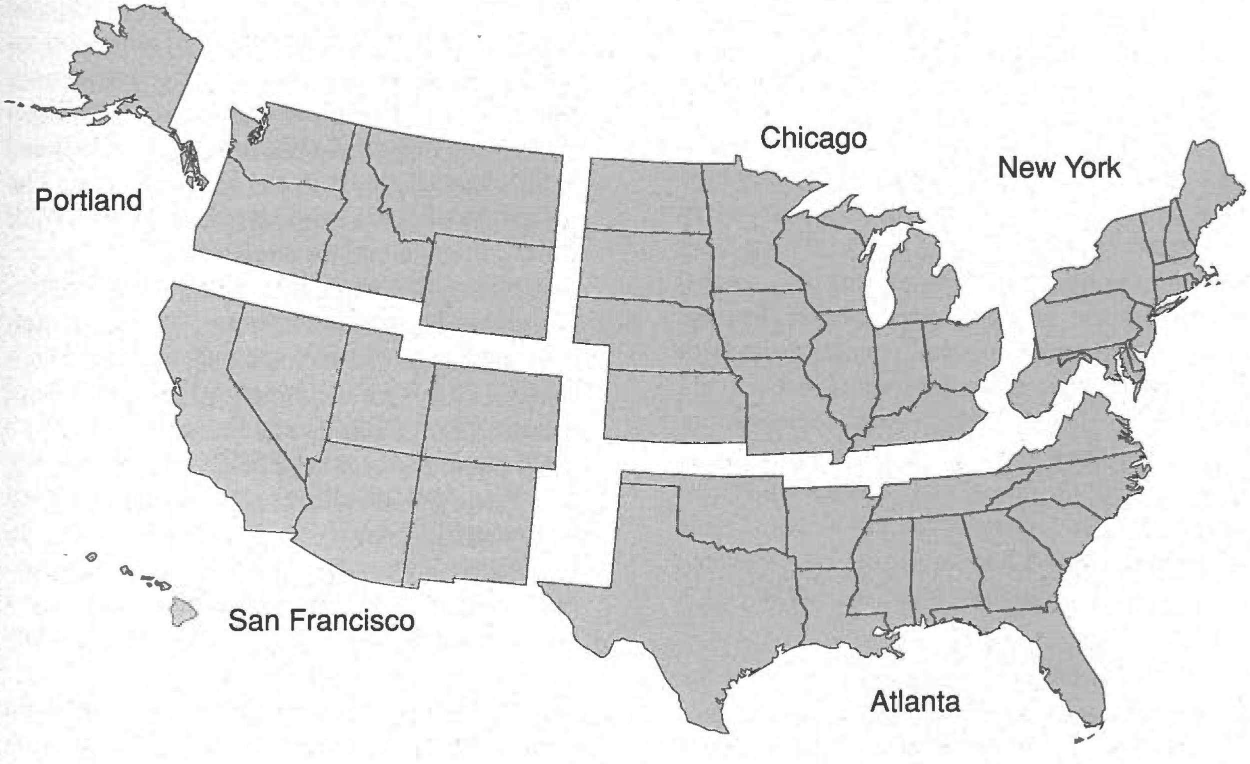


Figure 2-1. Federal Energy Regulatory Commission administrative regions.

information pertaining to hydroelectric plants that were not operating or the grouping of several hydroelectric plants into a single entry. The grouping of several plants into a single entry was not uncommon, as several plants are sometimes licensed as a single project. For instance, the Hells Canyon, Oxbow, and Brownlee power plants (Snake River hydroelectric plants) are all operated under a single license (Hells Canyon, FERC number 1971). These three plants have over 1,000 megawatts of combined power capacity, yet they were grouped and reported as a single entry. The proper reporting of mitigation frequencies requires the reporting of mitigation on a per power plant basis. Reporting information on a per license or license exemption basis is misleading, as the results could include reporting the existence of one ladder at a licensed or exempted project when in fact the project may include six hydroelectric plants at six individual locations—the difference being that the frequencies could suggest upstream mitigation at 100% of the sites (one ladder at one license) or upstream mitigation at 16.7% of the sites (one ladder at one of the six sites). Because licenses may contain more than a single hydroelectric site, it was critical to report mitigation on a per hydroelectric plant (individual site) basis to accurately report frequencies.

A second syntax definition includes the use of the word license. A FERC regulated hydroelectric plant can hold a major or minor license, or an exemption from licensing. The exemption from licensing is not, as the name implies, a total exemption from licensing requirements. Exemptions can be granted to small conduit projects or on a case-specific basis. Exempted projects are generally smaller projects. An excellent description of these three types of FERC licenses can be found in chapter one of the Bonneville Power Administration document "A Regulatory Guide to Permitting and Licensing in Idaho, Montana, Oregon, and Washington" (McCoy, 1992).

The mitigation frequencies discussed on the following pages are limited to the 1,825 plants in the United States that are either a major, minor, or exemption license. Hydroelectric plants in the United States that are not regulated by FERC also have upstream and downstream mitigation. These plants may be Federally-owned plants, such as U.S. Army Corps of Engineers plants operated on the Colombia River and Bureau of Reclamation plants operated on the Colorado River, or a small privately-owned plant whose generation is used onsite. The point of this discussion is that the use of the term licensed throughout the mitigation frequencies section refers to FERC major licensed, minor licensed, or exempted from licensing conventional and operating hydroelectric plants.

The Hydropower Resource Assessment database and the information provided by the FERC regional offices were compared to identify the previously mentioned problem of multiple plants being grouped into single licenses or exemptions. A second iteration by the regional offices was conducted. Field engineers at the regional offices were canvassed to verify the mitigation information. Additional limited iterations were used to clarify a few inconsistencies. The number of hydroelectric plants that were ultimately identified as fitting the criteria of being a conventional and operating hydroelectric plant either licensed or exempted by FERC in the United States totaled 1,825 plants and they are dispersed unevenly among the five FERC regions (Figure 2-2). There are currently about 2,350 operating conventional hydroelectric plants in the United States. The 1,825 hydroelectric plants regulated by FERC for which mitigation information was obtained represent 78% of all operating conventional hydroelectric plants in the United States. The remaining conventional hydroelectric plants are either Federally (7%) owned or privately owned and exempt from FERC licensing authority. The 1,825 plants regulated by FERC represent slightly less than 50% of all developed conventional hydroelectric capacity (~74,000 megawatts) in the United States. The remaining hydroelectric capacity is owned by nonregulated power producers or Federally owned by agencies such as the Corps of Engineers (27% of United States capacity), the Bureau of Reclamation (18% of United States capacity), and, to a significantly lesser degree, the Bureau of Indian Affairs and the National Park Service.

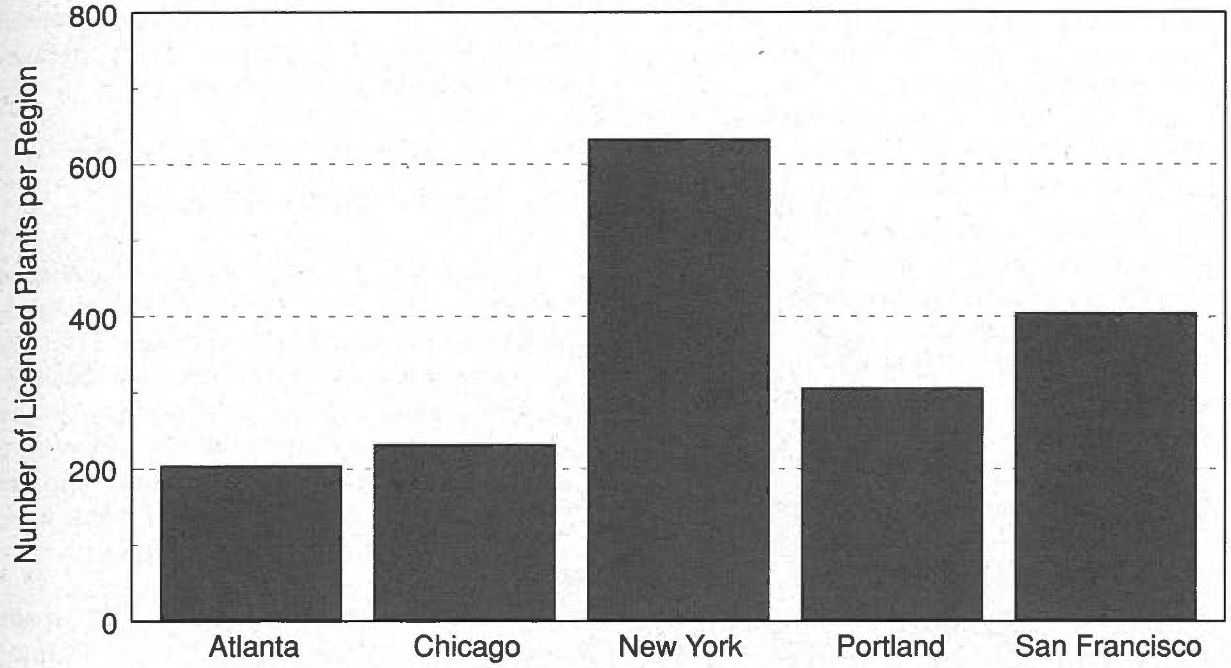


Figure 2-2. Number of conventional and operating hydroelectric plants in each of the five Federal Energy Regulatory Commission administrative regions.

The information provided by FERC regional offices was used to approximate the types and numbers of case studies required to examine the upstream and downstream fish passage/protection mitigation practices in the United States. The case study selection process is discussed in the Case Study Selection section. FERC information was used to identify national and regional mitigation frequencies and is discussed in this section.

The mitigation information excludes mitigation frequencies at Federally-owned sites. Large fish ladders at each dam and an extensive trapping and hauling system are in operation at the Federally-owned and -operated Lower Snake River and Colombia River hydroelectric plants. The mitigation frequencies discussed throughout this section do not include such mitigation practices because they are Federally-owned facilities, not subject to FERC regulation, and are not part of FERC-provided mitigation information.

Mitigation frequencies are presented in several formats: nationally, regionally, and as temporal trends. The fish passage/protection mitigation frequencies are presented graphically on the next few pages, and the raw data is presented in table format in Appendix A. The date of licensing is used to plot mitigation frequencies to examine temporal trends. The mitigation frequencies discussed in this report are based solely on FERC licensed or exempted conventional hydroelectric plants. Mitigation frequencies at Federally-operated sites are not included in this discussion. The 1,825 plants regulated by FERC are grouped into four time periods: pre-1970, 1970 through 1977, 1978 through 1985, and 1986 through 1993. The 8-year time frames are used to correlate possible legislative influences on mitigation practices. These legislative influences include the passage of the Public Utilities Regulatory Policies Act (1978) and the Electric Consumers Protection Act (1986). The mitigation frequencies are grouped to show trends, and the periods of grouping, while somewhat arbitrary, are also intended to let the reader hypothesize the mitigation implications of legislative action.

The percent of licensing actions that occurred during each of the four periods for the 1,825 plants is 24% (pre-1970), 4% (1970–1977), 54% (1978–1985), and 18% (1986–1993). It should be recognized that licensing activity continues for this last period (1986–1993), and the licensing results could shift the frequencies, but probably not significantly. In terms of megawatts of capacity licensed or exempted, the percent for each period is 63% (pre-1970), 10% (1970–1977), 22% (1978–1985), and 5% (1986–1993). The divergence and trend of the percentage of plants licensed or exempted and the percentage of megawatts of capacity licensed or exempted, especially during the pre-1970 and 1978–1985 periods, would suggest that the plants licensed earlier were of larger individual size, while more recent licensing activity is primarily concerned with small capacity plants (Figure 2-3). Possible mitigation frequency effects may result because the earlier licensed or exempted larger plants would generally have been constructed on larger rivers, possibly with anadromous fish resources. Other influences effecting temporal trends of mitigation frequencies may include development during the later periods at sites located on irrigation supply systems with fish resources previously screened at diversions and, therefore, no fish passage/protection mitigation requirements.

2.1 Upstream Fish Passage/Protection Mitigation

Upstream fish passage/protection mitigation is currently in place in 9.5% of the 1,825 hydroelectric plants regulated by FERC (Figure 2-4). The upstream mitigation frequencies vary considerably between the five FERC regions. In the Chicago region only 2.2% of the 232 plants have any type of upstream mitigation, while in the Portland region 22.5% of the 306 plants have some type of upstream mitigation in place.

Examination of upstream mitigation trends (Figure 2-5) shows a deviation in total implementation of upstream mitigation frequencies over time, from 8.6% during the pre-1970 period, to a high of 11.4% during 1970–1977, and

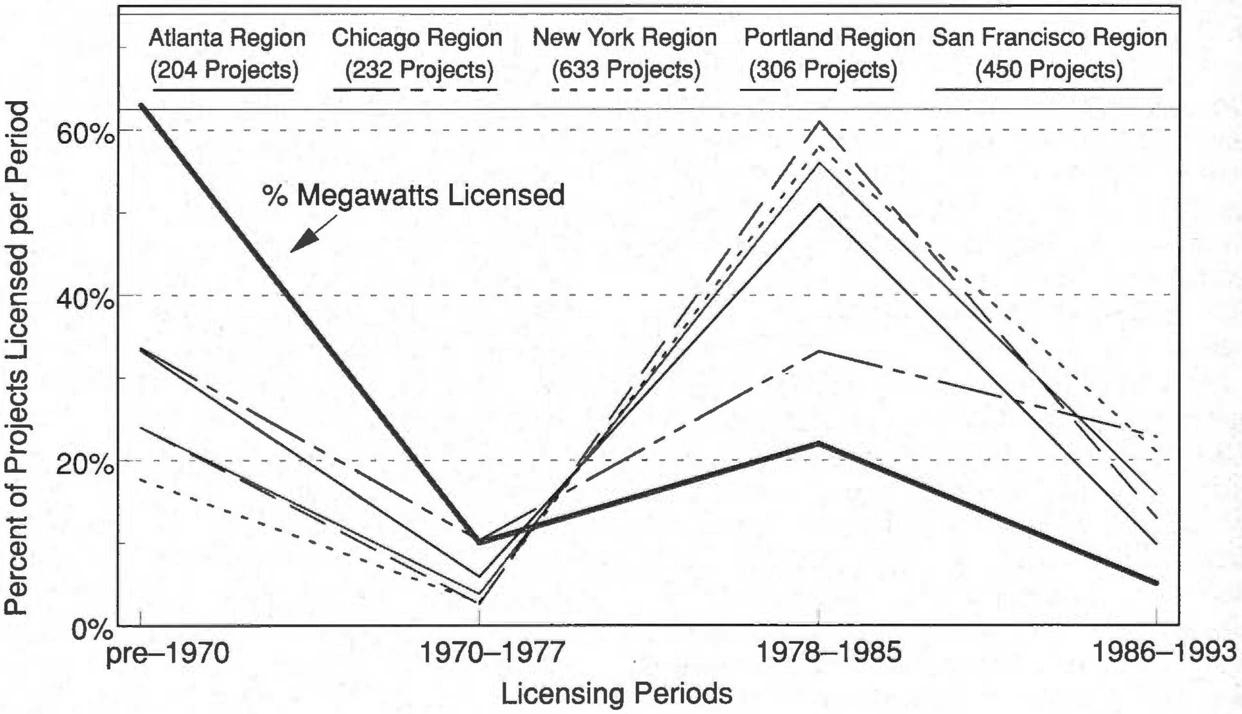


Figure 2-3. Hydroelectric licensing trends for the five FERC regions. Number of plants and the total magnitude of megawatts of capacity licensed per period. The line for each of the five regions represents the percent of plants that were licensed during each period. The % Megawatts Licensed line represents the percent of FERC regulated hydroelectric capacity licensed during each period.

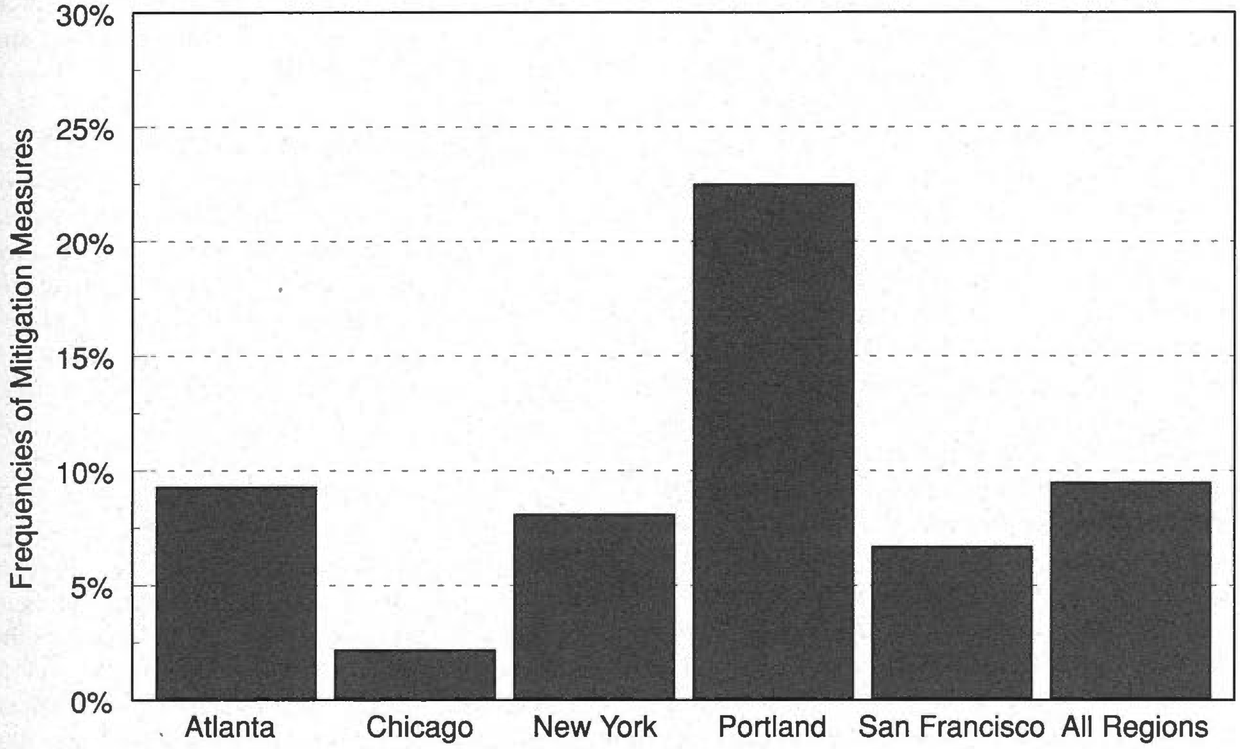


Figure 2-4. Upstream fish passage/protection mitigation frequencies. Includes national and regional frequencies based on 1,825 plants regulated by the Federal Energy Regulatory Commission.

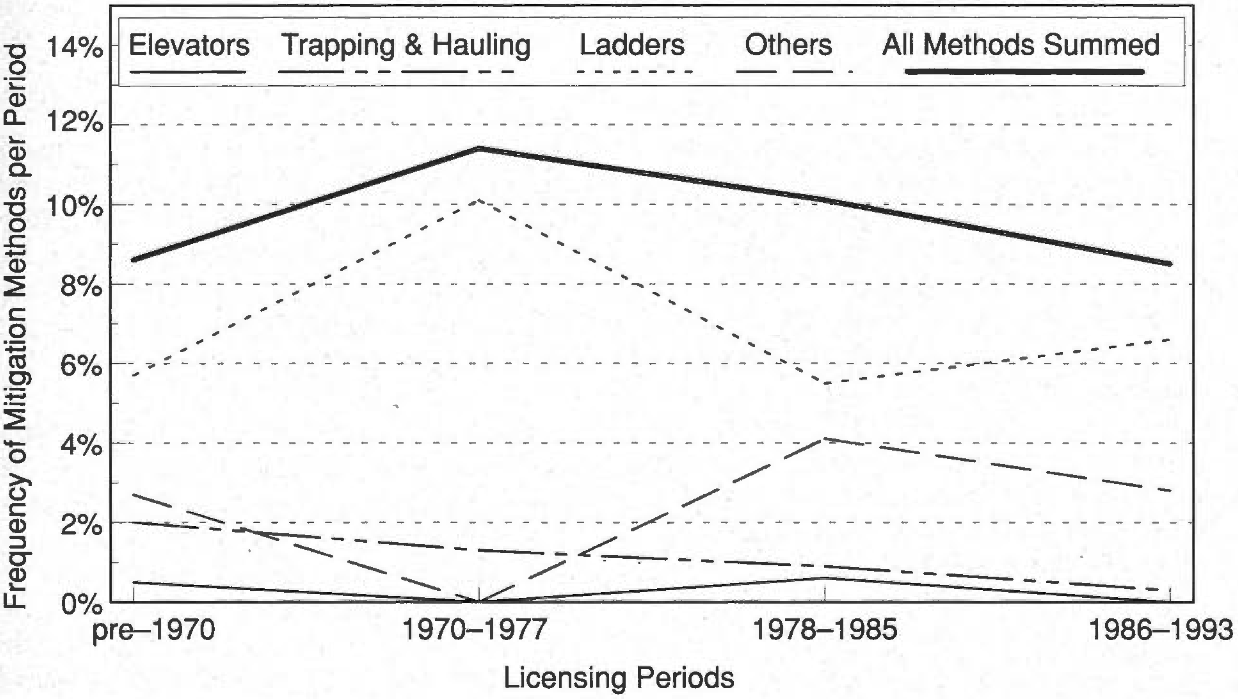


Figure 2-5. National frequencies of various upstream mitigation method usage, grouped into four licensing periods.

sloping to 8.5% during the most recent 1986–1993 period. Fish ladders for upstream passage/protection are the most frequently used of all the upstream mitigation methods. Fish ladders are used 62% of the time when some type of upstream mitigation is present. The fish ladders are used at 5.9% of the 1,825 plants. The use of ladders as an upstream mitigation method at the 1,825 plants has ranged from 10.1% during the 1970–1977 period to 5.5% during the 1978–1985 period. During the 1978–1985 period, 4.1% of the upstream mitigation methods were an assortment (Others category) of methods. Included in this group are ~20 plants that use either screens or bar racks in the tailrace to exclude fish entry, three plants that use navigation locks for upstream passage, and one plant that uses a spawning channel for upstream mitigation. During the 1986–1993 period an assortment (Others category) of methods was also used, including bypass canals, diversion facilities, and tailrace racks. Of the 1,825 plants, 1.1% use trapping and hauling, and 0.4% use fish elevators for upstream mitigation. Nationally, 174 (9.5%) of the 1,825 plants reported using 197 upstream mitigation methods, with 23 of the methods being used in conjunction with a second upstream method at the same plant. Regional upstream mitigation frequencies are discussed in the next five subsections.

2.1.1 Atlanta Region. In the Atlanta region, 9.3% of the 203 plants operate upstream mitigation. Neither trapping and hauling nor fish ladders are used in the Atlanta region. One plant uses a fish elevator, and the remaining 18 plants with upstream mitigation use an assortment of methods (Others category). Of the 19 plants with upstream mitigation, 68% use racks or screens in the tailrace to exclude entry into turbines, and 16% pass fish upstream through a navigation lock. One plant uses a barrier net and rack to ban fish from tailrace entry, and at one plant upstream migration is via a bypass that is a breach in the power canal.

Upstream mitigation is reported at one of the 68 plants licensed during the pre-1970 period, at none of the 12 plants licensed during the 1970–1977 period, at 15 of the 104 plants licensed during the 1978–1985 period, and at three of the 20 plants licensed during the 1986–1993 period (Figure 2-6).

2.1.2 Chicago Region. Upstream mitigation at the 232 plants in the Chicago region consists of five fish ladders. Of the five fish ladders installed in the Chicago region, a fish ladder was installed at one of the 24 plants licensed during the 1970–1977 period, at two of the 77 plants licensed during the 1978–1985 period, and at two of the 53 plants licensed during the 1986–1993 period (Figure 2-7).

2.1.3 New York Region. In the New York region, 51 (8.1%) of the 633 plants that have been licensed or exempted by FERC have upstream mitigation methods in place. Trapping and hauling is used at 18% of these 51 plants, ladders are used at 69%, elevators are used at 8%, and an assortment (Others category) are in use at 10% of the plants. The percentages are greater than 100% because two plants use multiple upstream mitigation methods. One of the two plants uses a fish ladder in conjunction with trapping and hauling. The other plant has a ladder at the diversion dam and a fish elevator at the powerhouse for upstream passage into the power canal.

The frequency of upstream mitigation at licensed and exempted plants has ranged from a low of 5.9% during the 1986–1993 period to a high of 11.1% during the 1970–1977 period (Figure 2-8). The use of elevators has never exceeded 1.0% during any of the periods. The use of ladders has been the most frequently used upstream mitigation method within the New York region.

The licensing and exemption activity of plants has shown significant variation between the different time periods. The occurrence of licensing and exemption activity for the 633 plants in the New York region has ranged from 17.7% of the 633 plants licensed or exempted during the pre-1970 period, to a low of 2.8% during the 1970–1977 period, to a high of 58.1% during the 1978–1985 period, and to a licensing activity frequency of 21.3% during the 1986–1993 period. The motivations or hindrances to development

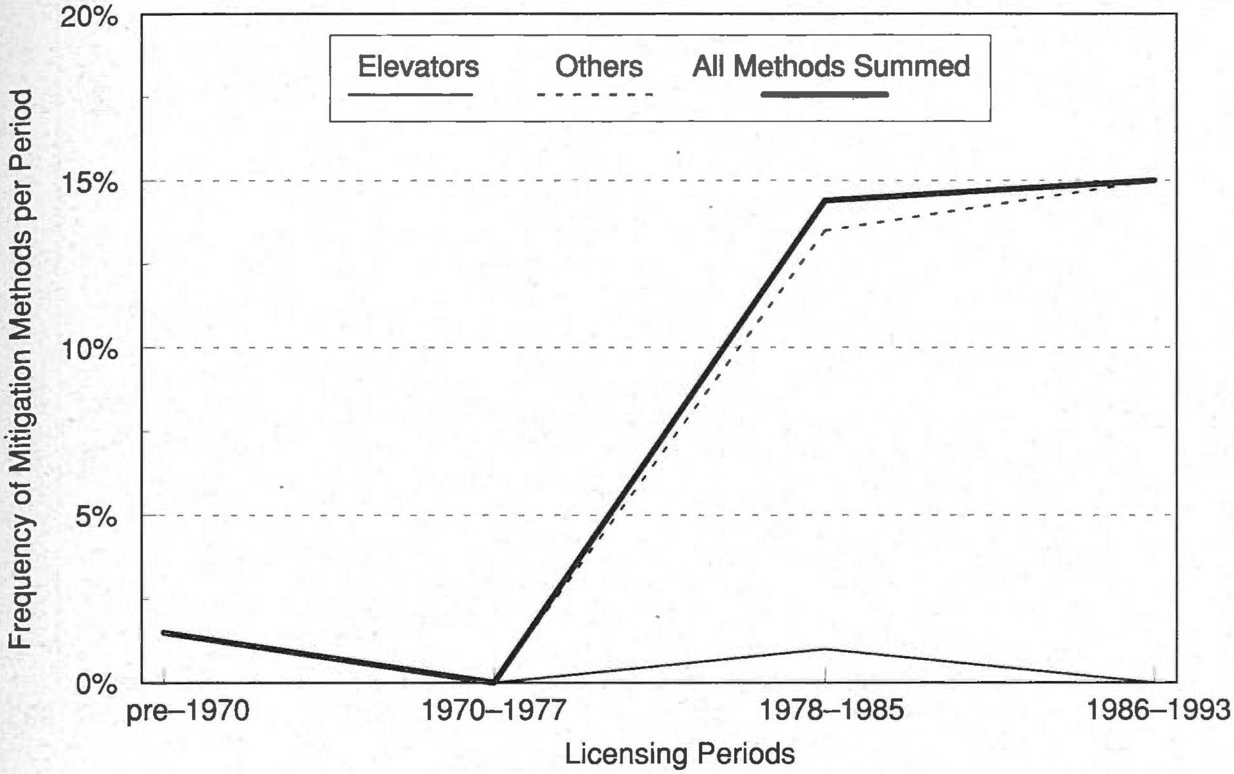


Figure 2-6. Atlanta region upstream mitigation temporal frequencies.

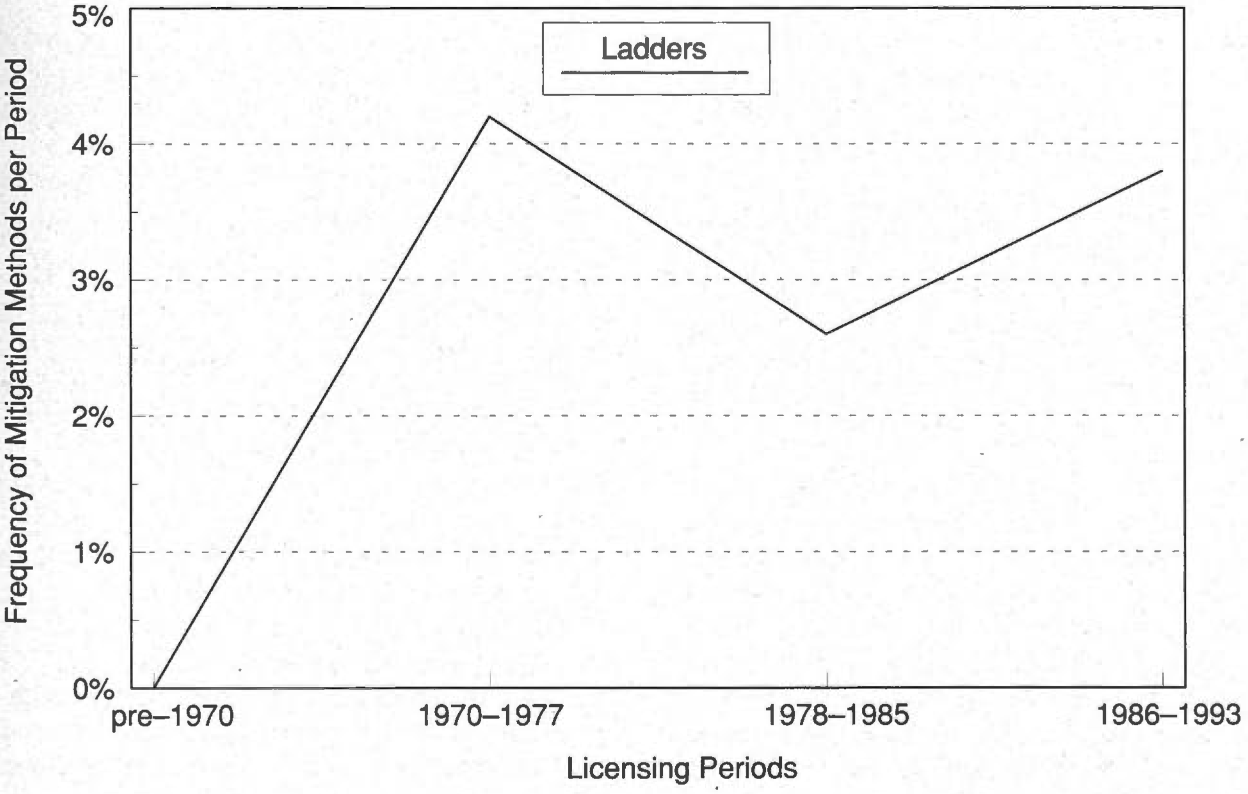


Figure 2-7. Chicago region upstream mitigation temporal frequencies.

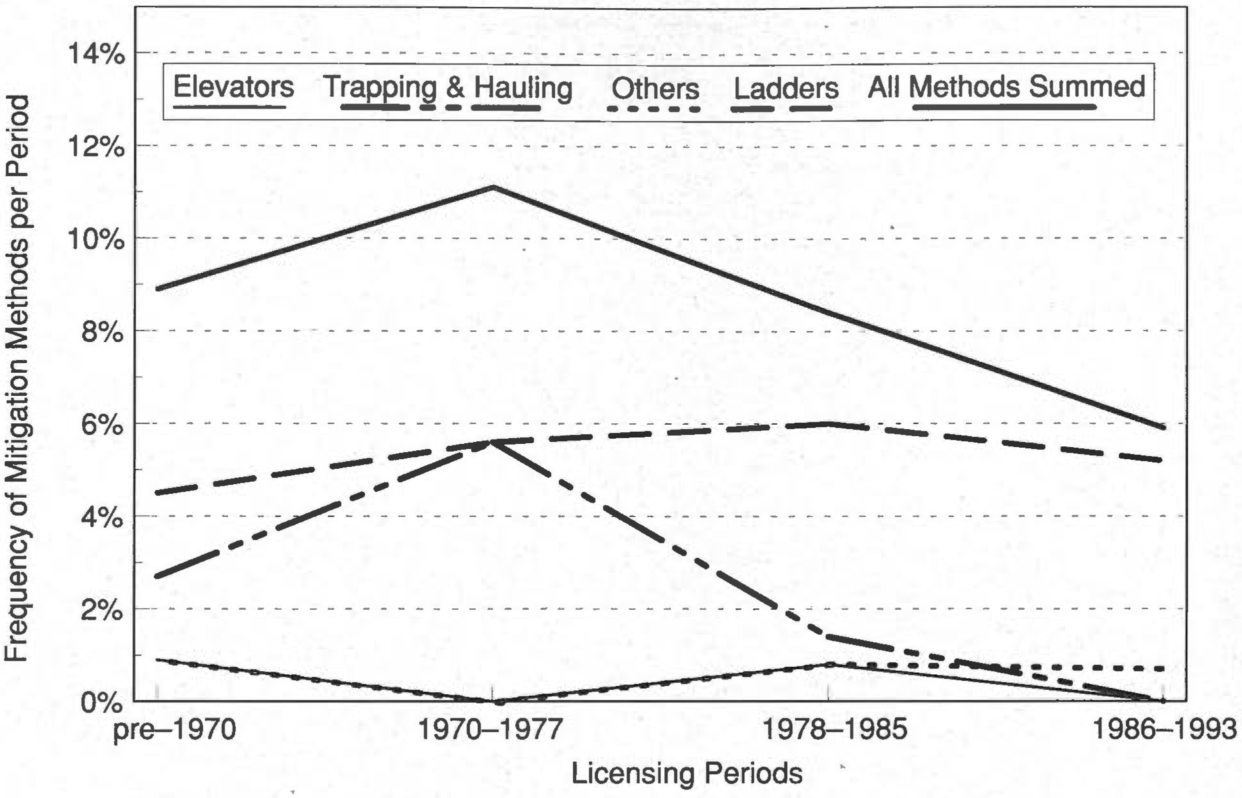


Figure 2-8. New York region upstream mitigation temporal frequencies.

are not a component of this study. However, the variation in licensing activity is interesting to note and a potential area of research to determine successful development incentives and dissuasions.

2.1.4 Portland Region. The Portland region has the highest frequency of upstream mitigation usage of the five FERC regions. Of the 306 projects in the region, 22.5% have upstream mitigation. This is almost 2.5 times the frequency of usage as the next highest region (upstream mitigation is in place at 9.3% of the Atlanta region's 204 plants).

Of the 69 plants with upstream mitigation, 63.8% have fish ladders, 15.9% have trapping and hauling, 2.9% have elevators and, 46.4% employ an assortment of methods that fit the previously discussed Others category. The total frequencies exceed 100.0% because 89 mitigation methods are used at the 69 plants. Some of the combinations of methods used at several sites include the use of trapping and hauling in combination with fish ladders at five plants, and the use of trapping and hauling, a fish ladder, and a fish elevator at one plant. The Others category for upstream mitigation in the Portland region includes five plants using fish hatcheries for upstream mitigation and 12 plants using screens to stop tailrace entrants.

Temporal trends of fish ladder usage have ranged from 24.7% during the pre-1970 period to 8.6% during the 1978–1985 period (Figure 2-9). The fish ladder usage at plants licensed or exempted during the 1986–1993 period is 22.5%. Of the 306 plants in the Portland region, 0.7% use fish elevators and 3.6% use trapping and hauling.

2.1.5 San Francisco Region. In the San Francisco region, 6.7% of the 450 plants have some type of upstream mitigation. Of the 30 plants with upstream mitigation in this region, 80.0% have fish ladders, 20% use an assortment of methods, and a single plant uses an elevator. A total of 31 mitigation methods are used at the 30 plants, with a single plant reporting the use of a fish ladder and a sluiceway for upstream mitigation.

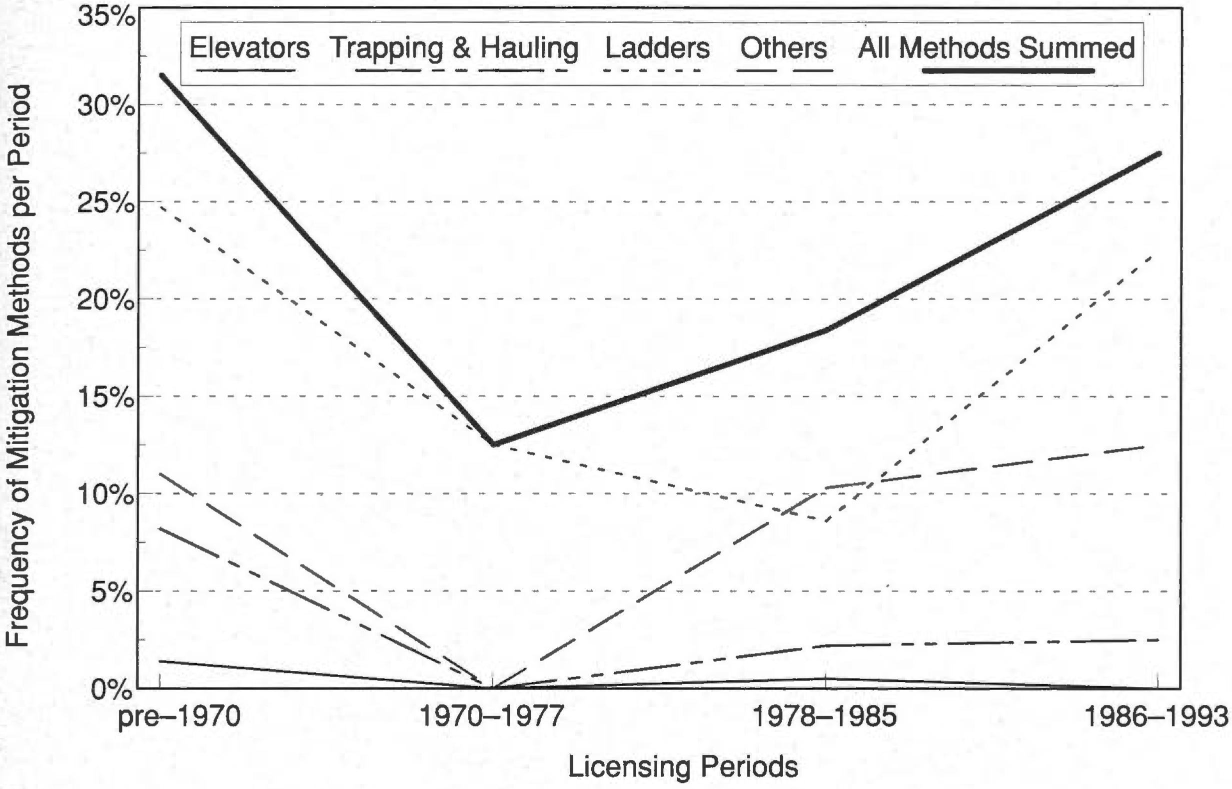


Figure 2-9. Portland region upstream mitigation temporal frequencies.

The frequencies of upstream mitigation have varied over time, from 3.6% of the plants licensed or exempted during the pre-1970 period, to 29.4% during the 1970–1977 period, 7.1% during the 1978–1985 period, and to 4.2% during the 1986–1993 period (Figure 2-10). Of the 110 plants licensed or exempted during the pre-1970 period, 1.8% have ladders; during the 1970–1977 period, 29.4% of the 17 plants have ladders; during the 1978–1985 period, 5.6% of the 252 plants have ladders; and of the 71 plants licensed or exempted during the 1986–1983 period, 4.2% have ladders.

2.2 Downstream Fish Passage/ Protection Mitigation

Downstream fish passage/protection mitigation is currently used at 13.0% of the 1,825 hydroelectric plants regulated by FERC (Figure 2-11). Of the 285 mitigation methods used, 48 are used in conjunction with other methods at the 237 plants with downstream mitigation. The frequency of downstream mitigation in each of the five FERC regions varies dramatically. In the Atlanta region 11.8% of the 204 plants have some type of downstream mitigation in place; in the Chicago region none of the 232 plants have downstream mitigation in place; in the New York region 16.3% of the 633 plants have downstream mitigation; in the Portland region 22.5% of the 306 plants have downstream mitigation; and in the San Francisco region 9.1% of the 450 plants have downstream mitigation.

The downstream mitigation requirements for all five regions over the four time periods (Figure 2-12) show an upward trend in the overall frequency of downstream mitigation usage. Of the plants licensed or exempted during the pre-1970 period 7.9% have downstream mitigation; during the 1970–1977 period the frequency slips to 5.1%; during the 1978–1985 period the frequency more than doubles to 14.4%; and during the 1986–1993 period the frequency of plants with downstream mitigation rose to 17.6%.

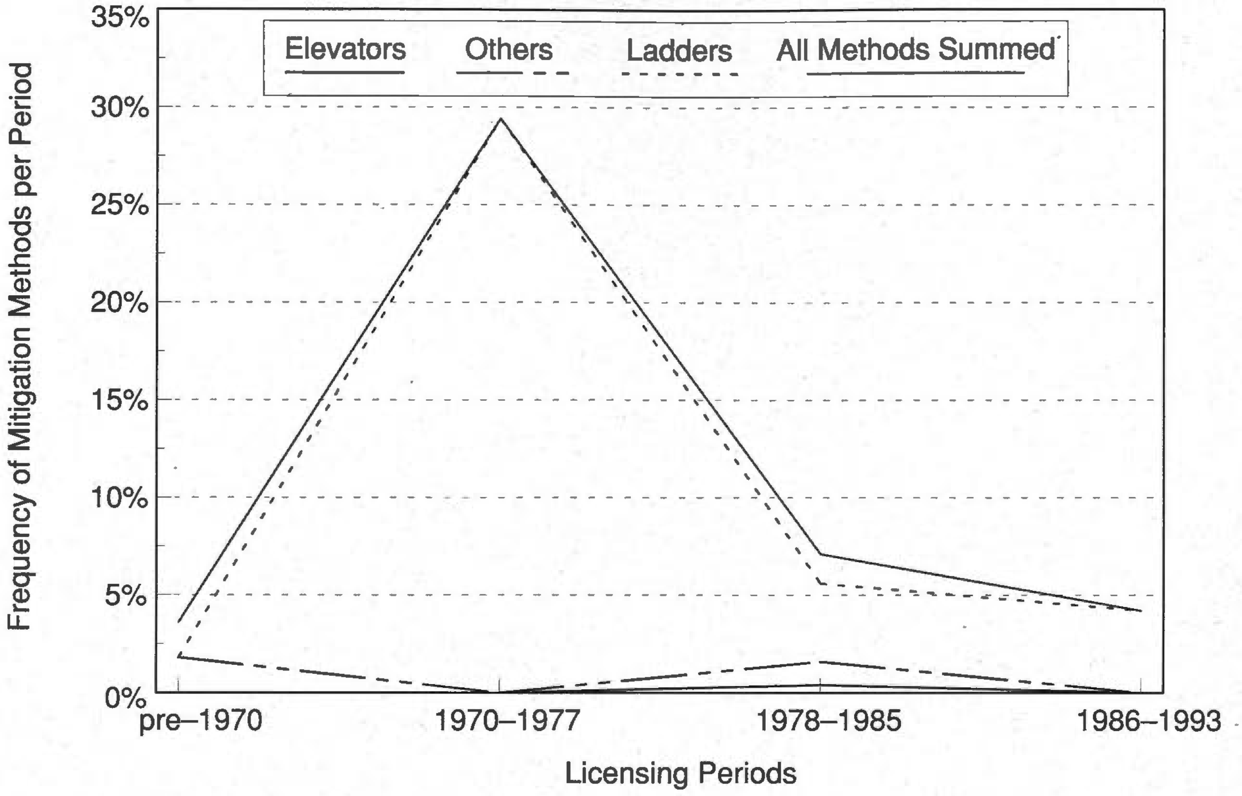


Figure 2-10. San Francisco region upstream mitigation temporal frequencies.

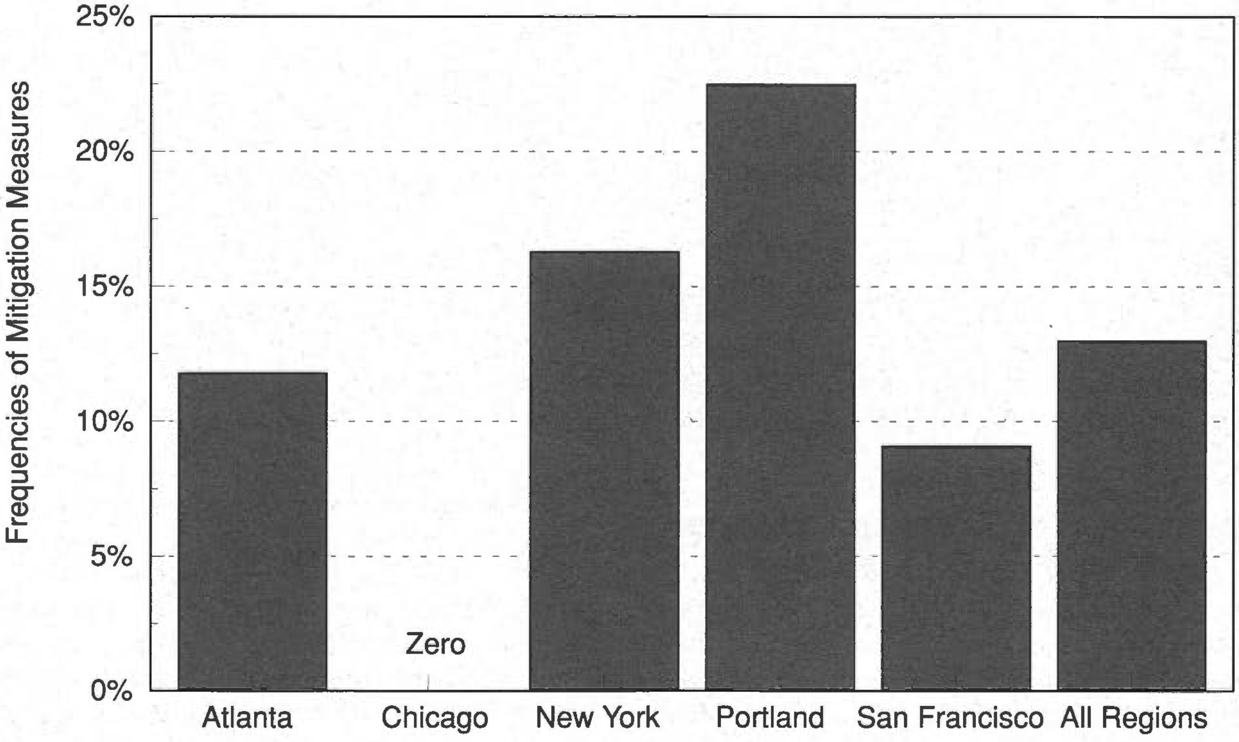


Figure 2-11. Downstream fish passage/protection mitigation frequencies. Includes national and regional frequencies based on 1,825 plants regulated by the Federal Energy Regulatory Commission.

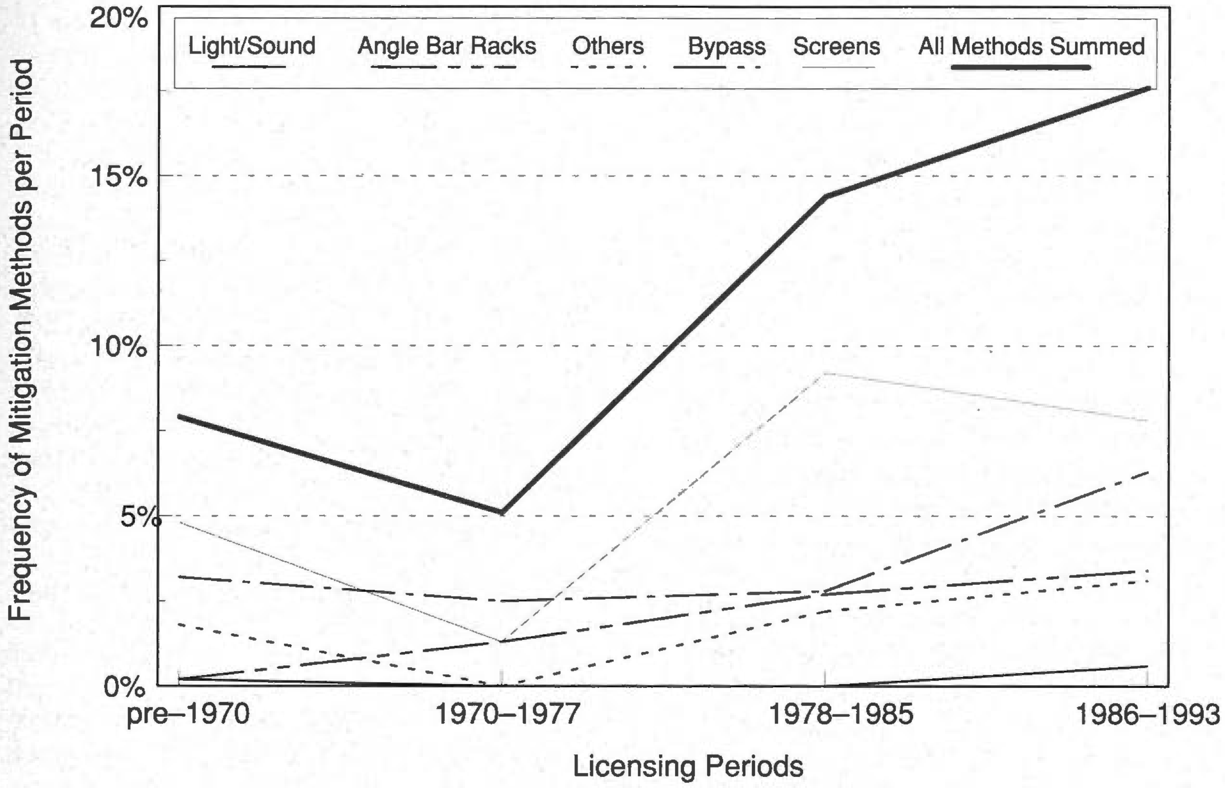


Figure 2-12. National frequencies of various downstream mitigation method usage, grouped into four licensing periods.

Of the 237 plants reported to have downstream mitigation in place, the following methods are used: screens are used at 58.2% of the plants, bypasses are used at 27.0%, angled bar racks are used at 16.7%, an assortment of methods (Others category) are used at 16.7%, and light and sound avoidance/guidance systems are used at 1.3% of the plants. The percentages total more than 100.0% because several projects use more than one mitigation method. Four plants use three downstream mitigation methods concurrently. These four plants all have downstream bypasses in place as well as angled bar racks and screens. Of the 237 plants with downstream mitigation, 36 plants have two types of downstream mitigation. Of these 36 plants 41.7% use a bypass and traveling, rotating, fixed or angled screens; 25.0% use bypasses and angled bar racks; 13.9% use angled bar racks with a screen; and 16.7% use screens and other methods such as canal improvements. Of the 137 screens used at the 237 plants, 20% are fixed screens, 6.3% are bar screens, 5.1% are traveling screens, 4.2% are punched plate screens, and 2.5% are rotating drum screens. Of the remaining screens, the descriptions reported do not appear to be completely uniform; and many are described as "standard" screens or are given some other less than descriptive name. It appears that an assortment of descriptions are used to describe a broad assortment of screens that range from powerhouse intake screens to chain link fish diversion screens in the canal head gates.

Practically all of the plants in the Atlanta region and a substantial percentage of hydroelectric plants in the remaining four FERC regions were reported to use spill flows as a downstream mitigation method. Discussions with staff at several of the FERC regional offices suggested that the application of spill flows was not limited to the enhancement of downstream migration. In fact, spill flows are often used exclusively to maintain healthy dissolved oxygen levels or minimum instream flows, or both. While the reporting of spill flow requirements by the five FERC regional offices was accurate, the reasons for spill flows was not reported the majority of the time. Because of the difficulty of determining if spill flows were used for downstream mitigation (which would involve contacting each of the 1,825 plant operators), the frequencies of spill flows was acknowledged to be inaccurate as a measure of spill flow usage for downstream mitigation. For this reason, the spill flow frequencies are not reported.

2.2.1 Atlanta Region. Of the 204 plants within the Atlanta FERC region, 24 plants (11.8%) have downstream mitigation in place. The use of 26 downstream mitigation methods was reported at the 24 plants. At the two plants with more than one downstream mitigation method, both use angled bar racks, one plant in conjunction with a bypass and the other in conjunction with a chain link fish diversion screen in front of the canal head gates.

At the 24 plants with downstream mitigation, 62.5% use angled bar racks, 12.5% use a bypass, 25.0% use various methods (Others category), and 8.3% use screens. At the six plants using one of the Others methods, five have a run-of-river requirement for downstream migrants. The sixth Others mitigation method was not specified.

Of the 204 plants in the Atlanta regions, 39.2% were licensed or exempted before 1978 (pre-1970 and 1970–1977 periods), and no downstream mitigation is in place at these plants (Figure 2-13). Of the 104 plants licensed or exempted during the 1978–1985 period, 21.2% have downstream mitigation, and of the 20 plants licensed during the 1986–1993 period, 10.0% have downstream mitigation. All 15 angled bar racks used in the Atlanta region are installed in 15 of the 104 plants licensed or exempted during the 1978–1985 period.

2.2.2 Chicago Region. None of the 232 hydroelectric plants in the Chicago FERC region are reported to have any type of downstream mitigation in place.

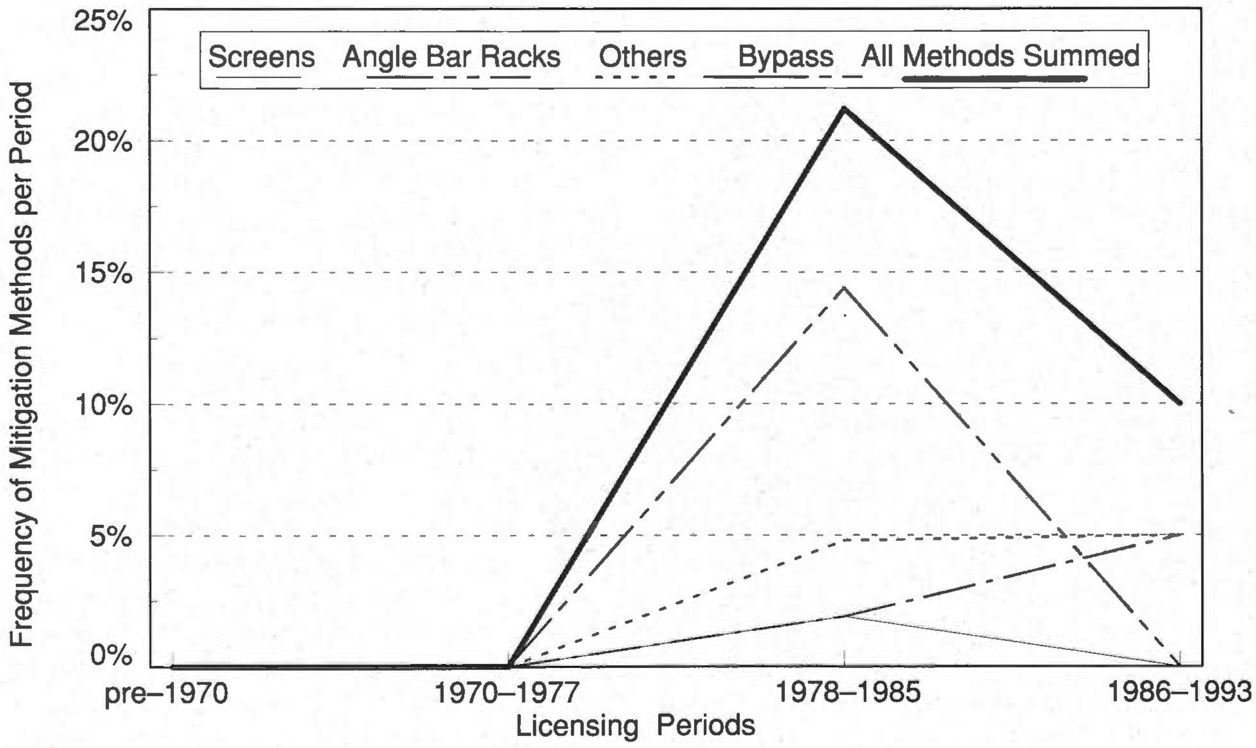


Figure 2-13. Atlanta region downstream mitigation temporal frequencies.

2.2.3 New York Region. Of the 633 plants in the New York region, 16.3% use downstream mitigation methods. At these 103 plants with downstream mitigation, 41.7% use fish screens, 36.9% use bypasses, 17.5% use one of an assortment (Others category) of methods, 15.5% use an angled bar rack, and 2.9% use a light/sound guidance system. At the 18 plants with the Others types of downstream mitigation methods, four plants located within the same state pay monetary compensation to the state resource department for their impact on fishery resources. The remaining sites in the Others category use an assortment of methods, including notched boards, pipes, flumes, sluices, and an open stop log bay.

Of the 14 plants in the New York region that use a combination of downstream mitigation methods, one plant uses an angled bar rack with a fish screen, three plants use a fish screen and a bypass facility, nine plants use a bypass facility in conjunction with an angled bar rack, and one plant uses a bypass facility, angled bar rack, and a fish screen. All of the plants with a combination of mitigation methods have been licensed or exempted since 1981.

The frequency of downstream mitigation usage has shown an upward trend over time. The frequencies have gone from 8.9% during the pre-1970 period, to 16.7% during the 1970–1977 period, lowering slightly during the 1978–1985 period to 15.8%, and increasing to 23.7% of the 135 plants licensed or exempted during the 1986–1993 period (Figure 2-14).

Angled bar racks are not used at the plants licensed or exempted during the pre-1970 or 1970–1977 periods. The 16 angled bar racks are used at 3.2% of the 503 plants licensed or exempted during the 1978–1985 and 1986–1993 periods. Bypass facilities are present at 6.2% of the plants licensed or exempted during the earlier two periods, and at 6.0% of the plants licensed or exempted during the later two periods. Screens are used at 1.5% of the plants from the earliest

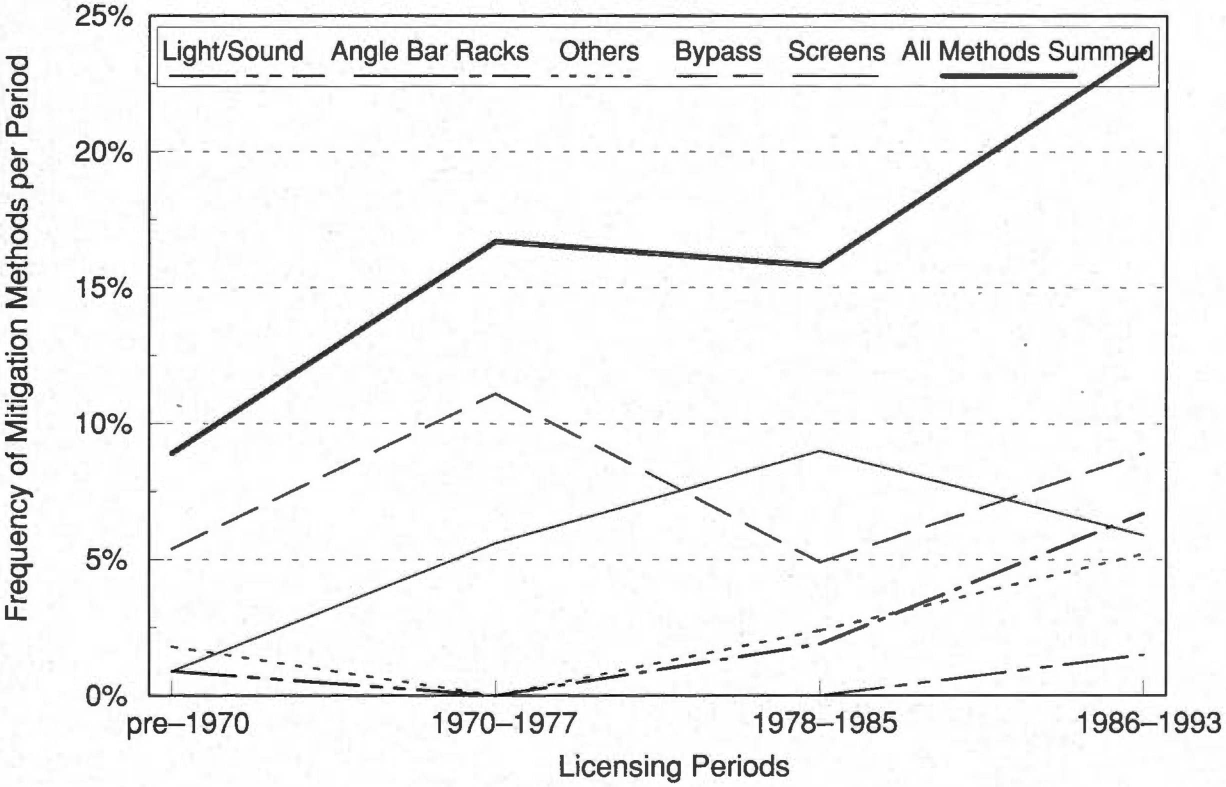


Figure 2-14. New York region downstream mitigation temporal frequencies.

two periods and at 8.2% of the plants licensed or exempted during the later two periods. The Others category experienced an increase in usage from 1.5% during the first two periods to 3.2% during the most recent two periods.

In terms of a method of choice, during the pre-1970 period bypass facilities are used at 60% of the 10 plants with mitigation; for the 1970–1977 period, bypass facilities are used at two of the three plants with mitigation; for the 1978–1985 period, screens are used at 56.9% and bypass facilities at 31.0% of the 58 plants with downstream mitigation; and for the 1986–1993 period, bypass facilities are used at 37.5%, angled bar racks at 28.1%, screens at 25.0%, and the Others methods are used at 21.9% of the 32 plants with downstream mitigation. The light/sound guidance systems are used at one plant licensed or exempted during the pre-1970 period and at two plants licensed during the 1986–1993 period.

2.2.4 Portland Region. Casual observation of downstream mitigation frequencies for plants licensed or exempted in the Portland region (Figure 2-15) would suggest large variations in temporal trends. The frequencies range from 20.2% for the pre-1970 period to 0.0% during the 1970–1977 period, rebounding to 22.7% during the 1978–1985 period. The 1986–1993 period saw a downstream mitigation frequency high for all FERC regions of 30.0%. If the 1970–1977 downstream mitigation frequencies (0.0%) for the Portland region are excluded, the remaining three periods of downstream mitigation frequencies (Figure 2-16) suggest a continuously increasing frequency of downstream mitigation usage at the licensed and exempted plants.

Figure 2-16 excludes the eight plants that were licensed or exempted during the 1970–1977 period. The eight plants comprise 2.6% of all the licensed or exempted plants in the Portland region. Based on the region's downstream mitigation frequency of 22.5%, it would be anticipated that approximately two of the eight plants would have some type of downstream mitigation. The eight plants are located in Idaho, Montana,

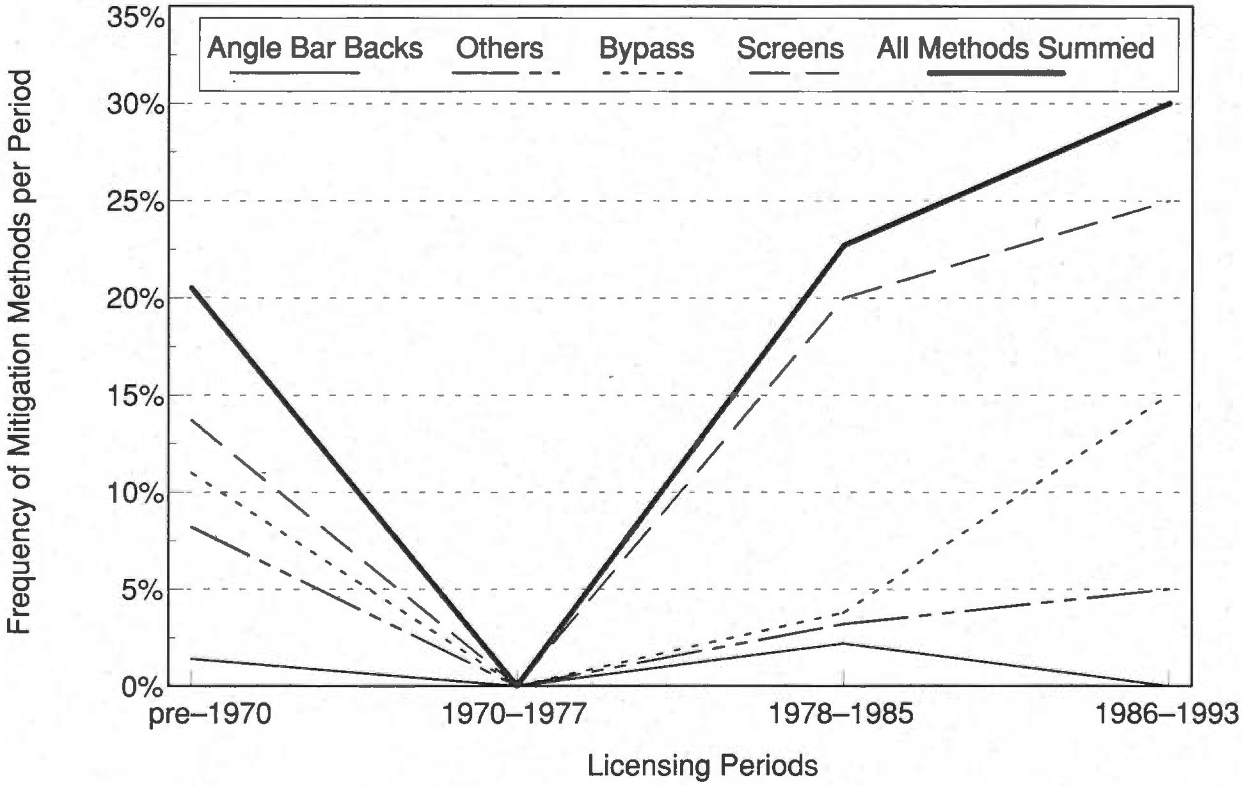


Figure 2-15. Portland region downstream mitigation temporal frequencies.

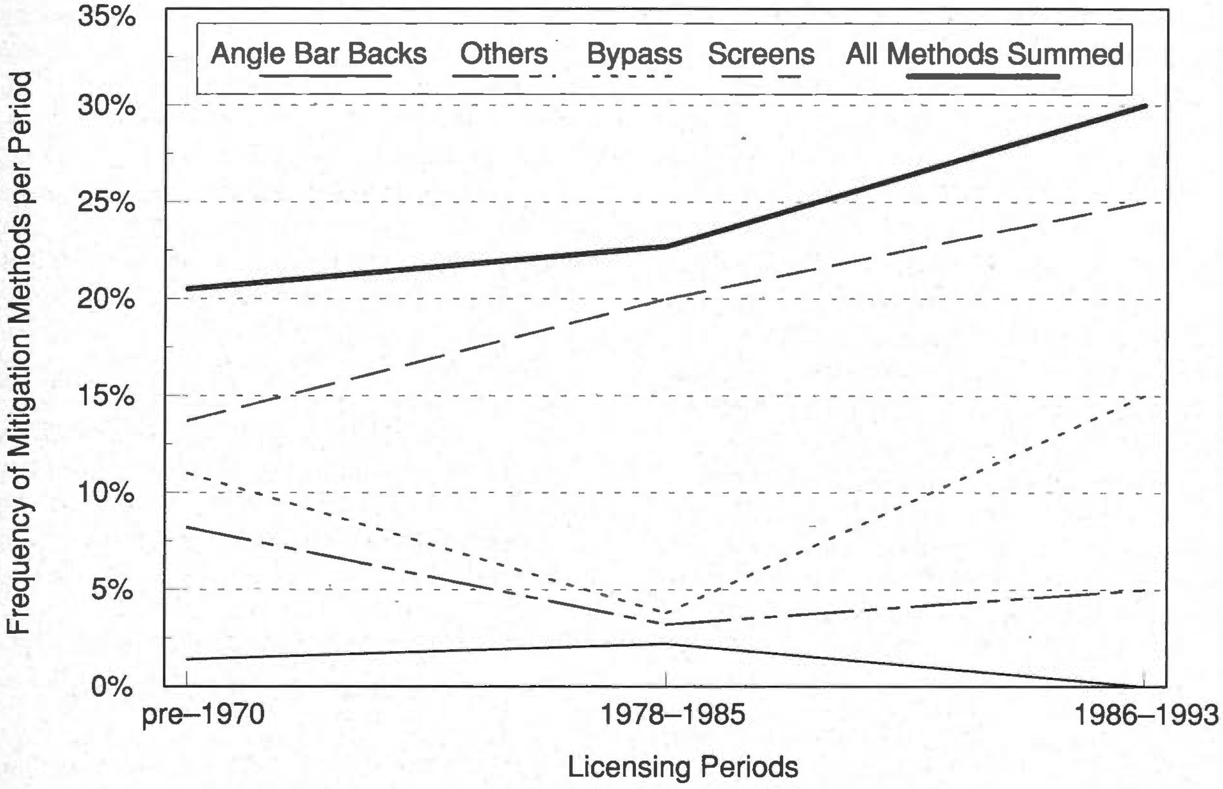


Figure 2-16. Portland region downstream mitigation temporal frequencies, excluding the 1970–1977 period licensed plants.

Oregon and Washington, and range in capacity from 1.1 megawatts to 92.3 megawatts. There is not an apparent plant characteristic that explains the absence of downstream mitigation during this licensing period (1970–1977). The eight plants are included in all of the discussions concerning the frequencies in the Portland region; it is for the sake of observing the downstream mitigation frequency trend in the Portland region that the liberty of excluding the eight plants licensed during the 1970–1977 period was exercised in Figure 2-16.

In the Portland region, 22.5% of the 306 plants have some type of downstream mitigation. Of the 69 plants with downstream mitigation, 82.6% use fish screens, 30.4% use a bypass facility, 7.2% use angled bar racks, and 20.3% report the use of an assortment (Others category) of methods. The Other methods include canal improvements and sampling facilities.

A total of 97 downstream mitigation methods are employed at the 69 plants with downstream mitigation in the Portland region. Of the 24 plants with two or more mitigation methods used, 17 report the use of a downstream bypass facility and some type of a fish screen. Angled bar racks are also used in conjunction with screens at two plants, and at another two plants each has a bypass facility, angled bar rack, and a fish screen. An assortment of methods is used at the remaining plants with multiple downstream mitigation methods.

At the 57 plants reporting the use of fish screens, 20 plants use fixed screens that are either vertical or angled; 10 plants use traveling screens; four use bar screens; four have horizontal fixed screens; and the remaining plants with fish screens use an assortment of screens such as drum, louvered, or slotted screens. It appears that the definitions for the various types of screens may not be definitive. Different terms may be used for the same type of, or similarly constructed, screens. If the use of terms to describe screen types were standardized, some of the specific numbers of screen types used at the plants might shift. The lack of standardized screen descriptions appears to be nationwide.

Of the 21 plants with downstream bypass facilities, eight are at plants licensed or exempted during the pre-1970 period, seven at 1978–1985 period plants, and six at 1986–1993 period plants. Of the five angled bar racks in use in the Portland region, one is at a plant licensed or exempted during the pre-1970 period, and four are at 1978–1985 period plants. Of the 57 screens in the Portland region, 10 are at plants licensed or exempted during the pre-1970 period, 37 at 1978–1985 period plants, and 10 at plants from the 1986–1993 period.

2.2.5 San Francisco Region. Of the 450 plants licensed or exempted in the San Francisco region, 9.3% (42 plants) have downstream mitigation in place. Of these 42 plants, 85.7% use screens, 9.5% use angled bar racks, 4.8% use a bypass facility, and 4.8% use a method from the Others category. In all, 44 downstream mitigation methods are used at the 42 plants. At the two plants with more than one type of downstream mitigation method, one plant uses an angled bar rack and a fish screen, while the other plant uses a fish screen and a bypass pipe.

At the 110 plants licensed or exempted during the pre-1970 period 9.3% have downstream mitigation, 5.9% of the 1970–1977 period's 17 plants have downstream mitigation, 8.3% of the 1978–1985 period's 252 plants and 14.1% of the 1986–1993 period's 71 plants have downstream mitigation in place (Figure 2-17).

2.3 Upstream and Downstream Mitigation at Single Sites

The 1,825 plants were examined to determine frequencies of plants that have both upstream and

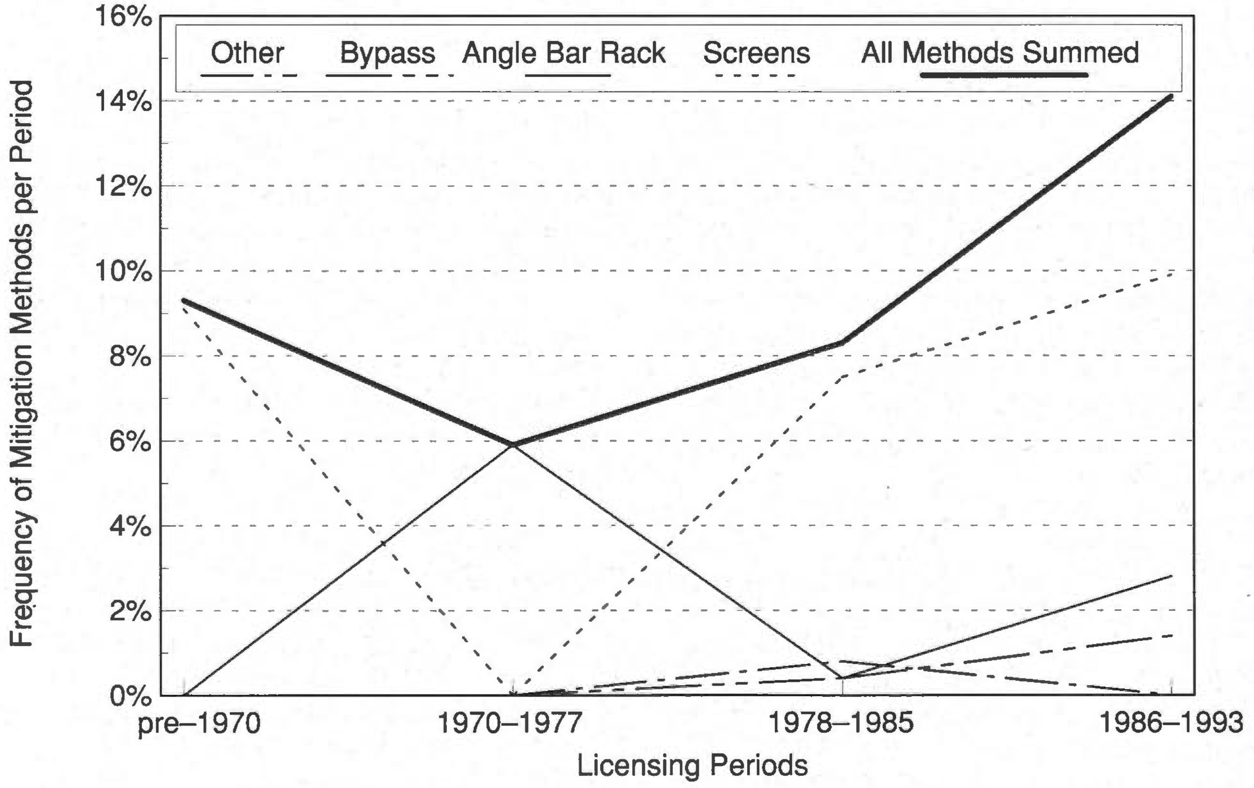


Figure 2-17. San Francisco region downstream mitigation temporal frequencies.

downstream mitigation. Of the 1,825 plants, 4.7% have both upstream and downstream mitigation methods. The frequencies vary among the five administrative regions (Figure 2-18) and over time (Figure 2-19). Regional frequencies are discussed in the next five subsections.

2.3.1 Atlanta Region. Of the 204 plants in this region 3.4 % have both upstream and downstream mitigation. Three plants were reported to use navigation locks for upstream mitigation and run-of-river requirements for downstream mitigation. It is unknown the specifics of how run-of-river is used for the downstream mitigation. The other four plants use screens, racks, and bypasses for upstream mitigation, and screens and bypasses for downstream mitigation.

2.3.2 Chicago Region. None of the 232 plants have any downstream mitigation.

2.3.3 New York Region. Of the 633 plants in this region, 3.5% have both upstream and downstream mitigation measures. For upstream mitigation, five plants use trapping and hauling along with downstream mitigation consisting of a bypass facility (three plants), a fish screen (one plant), and a pipe (one plant) for downstream mitigation. For upstream mitigation, 13 plants use a ladder in conjunction with a downstream bypass facility (six plants), a light/sound guidance system (two plants), fish screens (two plants), and flumes (two plants). Fish elevators are used at two plants, and both plants also have a downstream bypass facility. One plant uses a fish pump for upstream mitigation and a downstream bypass facility. For two other plants with upstream and downstream mitigation the mitigation methods were not specified.

2.3.4 Portland Region. Of the 306 plants in this region 15.4% use both upstream and downstream mitigation methods—more than four times the frequency for the next highest region. Seven plants use trapping and hauling along with downstream mitigation consisting of bypass facilities (four plants), an angled bar rack (one plant), fish screens (four plants), and a combination of other downstream methods. At five of the

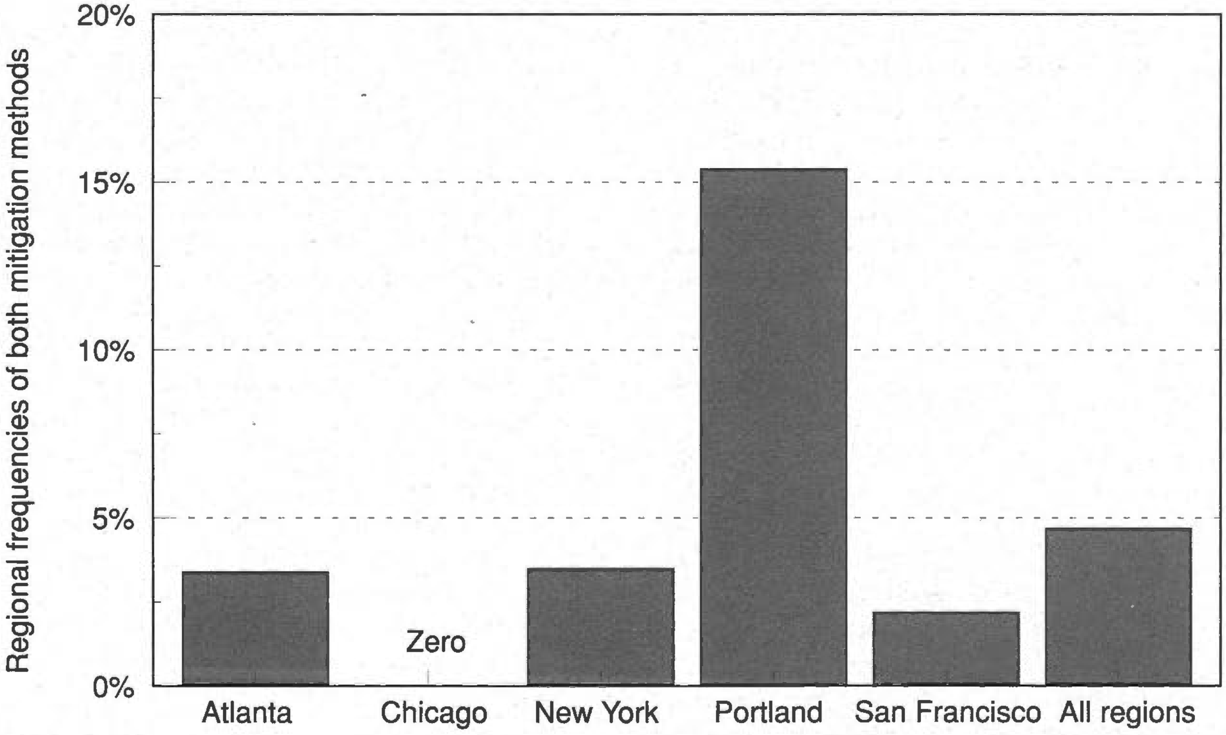


Figure 2-18. Frequency of hydroelectric plants with both upstream and downstream mitigation methods.

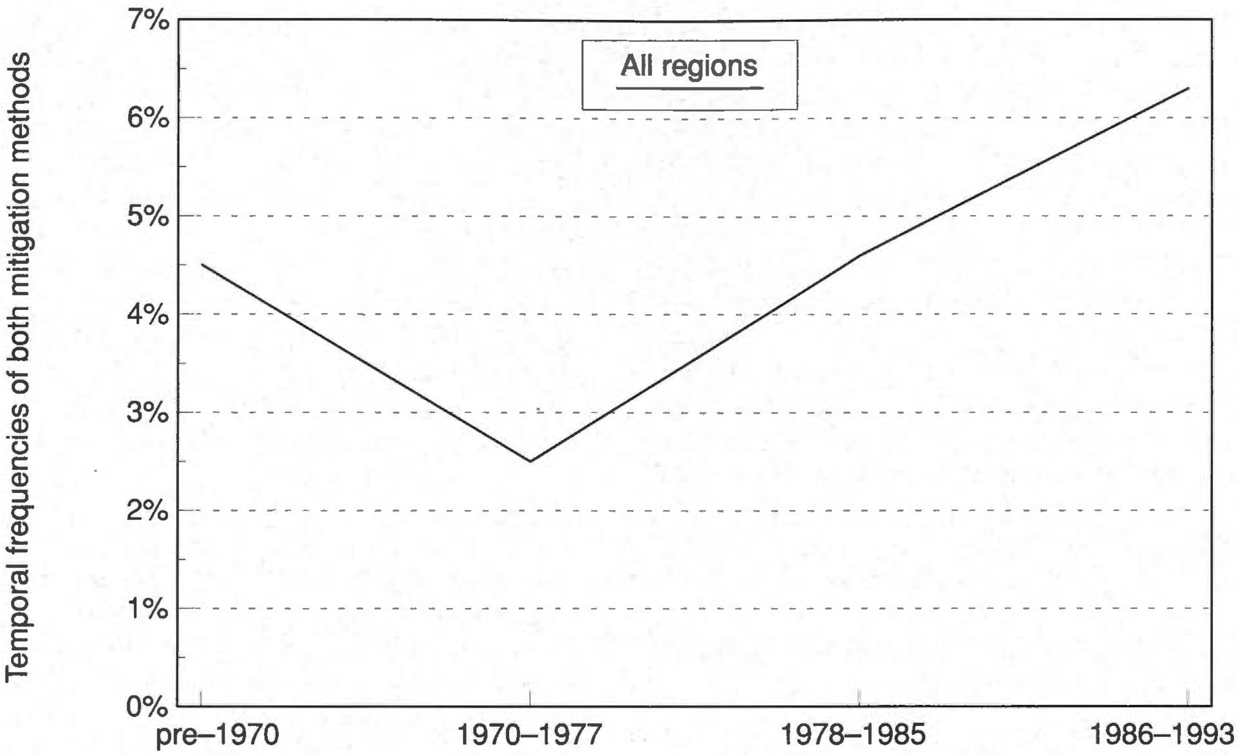


Figure 2-19. Temporal frequencies of hydroelectric plants with both upstream and downstream mitigation methods.

seven plants with trapping and hauling, ladders are also used. Thirty plants use ladders, and 22 of these also use fish screens for downstream mitigation. Two of the 30 plants with ladders also use angled bar racks, and 12 have a downstream bypass. A rather broad range of upstream and downstream mitigation combinations are used in this region, with ladders and screens being the preferred combination.

2.3.5 San Francisco Region. Of the 450 plants in this region 2.2% have both upstream and downstream mitigation methods. All 10 plants use ladders for upstream mitigation, and two of the 10 use angled bar racks and eight use fish screens for downstream mitigation. At one plant, both a fish screen and an angled bar rack are used with a ladder. At one plant a tailrace diffuser is used with the ladder.

3. GENERAL FISH PASSAGE/PROTECTION COST INFORMATION

Information request forms were sent to hydroelectric plant operators. This informal collection of mitigation costs at plants with upstream or downstream mitigation yielded information from 75 hydroelectric plants. Cost information from the Volume I report was indexed to 1993 dollar values and added to the group of 75 plants. Unfortunately, many of the 75 plants provided either incomplete cost information or were duplicates of information obtained earlier for the Volume I report. After removal of duplicates and plants that provided incomplete information, 50 plants remained. Information concerning the 16 case studies were also removed from the original group of 75 plants. This was done because if the case study cost information is compared to this general cost information section and the case studies were not excluded, comparisons would occur between the same information. The cost information presented in the general cost information section came from 50 plants that employed various and unknown assumptions when compiling their cost information. All costs have been indexed to 1993 dollars. The projects that provided useful cost information and information about these costs are discussed in the following upstream and downstream fish passage/protection general cost sections.

The four types of upstream mitigation costs (capital, study, annual reporting and monitoring, and operations and maintenance) are discussed as types of costs subsections because of the relatively high use of a single mitigation method (81% of plants use fish ladders) for upstream mitigation. Each of the four types of costs includes a discussion of fish ladder costs as well as the costs of the other two methods (one plant with trapping and hauling, two plants with fish elevators). Because of the lack of a single downstream mitigation method being used predominately, the downstream mitigation costs are discussed by the different types of methods used. The downstream mitigation methods fit into seven categories: angled bar racks (eight plants), barrier nets (one plant), bypass or sluiceways (five plants), combinations of methods (13 plants), penstock screens (seven plants), other screens (four plants), and the all Others category (three plants).

Costs are incurred at plants with upstream and downstream mitigation requirements other than just the costs discussed in the upstream and downstream fish passage/protection general cost information sections. For instance, projects with upstream mitigation incur lost generation costs when water is diverted through fish ladders or used as attraction flows instead of passing through turbines. Other downstream mitigation costs include lost generation when water is used for spill flows to pass downstream migrants. These and other costs such as indirect biological staff costs or the off-site mitigation costs of hatcheries and wildlife reserves, are not included in the general cost section. The difficulty of defining these costs and their objectives were beyond the ability of the data collection method. While not arguing for or against the appropriateness of these costs, these are real costs that are incurred, and they should be valued against the anticipated benefits from the mitigation requirements.

3.1 Upstream Fish Passage/Protection

3.1.1 Introduction. The 16 plants with upstream mitigation costs include one plant that uses trapping and hauling, two plants with fish elevators, and 13 plants with fish ladders. One plant is in the San Francisco FERC region, six are in the New York region, and nine plants are in the Portland region. The 16 plants range in size from 5 kilowatts to 1,213 megawatts. The average plant size is 239 megawatts, and seven plants are smaller than 8 megawatts.

3.1.2 Capital Costs. All 16 plants provided capital cost information for upstream mitigation methods. The one plant with trapping and hauling reported a capital cost of $168,000. It is unknown if this includes docking and fish holding facilities or trucks and barges. The two projects with fish elevators reported capital costs of $1.3 and $2.0 million each. The capital costs for these

13.9 and 19.1 megawatt capacity plants with elevators is $93 and $104 per kilowatt of installed capacity.

Four of the 11 plants with fish ladders have two ladders onsite. The respective total capital costs, for the two ladders at each of the four projects, were reported as $32.8, $38.7, $44.9, and $69.2 million. In order to show the capital cost of constructing single ladders, each of these values is halved and discussed as $16.4, $19.3, $22.5, and $34.6 million in capital costs. The reasoning behind the halving of the capital costs is that when the 13 capital costs of fish ladders are grouped and discussed, the common perception is one ladder per project. While experience says this is often not the case at large hydroelectric plants located on large rivers, such as the Colombia or Snake Rivers, the vast majority of hydroelectric plants in the United States with fish ladders will have only a single ladder per plant. The reporting and monitoring costs, and operations and maintenance costs for these four projects have not been halved as they are not of such large magnitudes (i.e., $69.2 million capital cost). In fact, one plant with a single fish ladder reports higher operating costs than a plant with two ladders. The reporting and monitoring costs and the operations and maintenance costs include a certain amount of economics of scale at the large, two-ladder plants, while the capital costs of construction do not have the same amount of economies of scale. One can not use the same brick (or other material) for two separate ladders at a single site, while many monitoring, reporting, and operations and maintenance duties can often be preformed by the same staff.

The single fish ladder capital costs range from $1,000 at the 5 kilowatt capacity plant to $34.6 million at an 881 megawatt capacity plant (Figure 3-1). The four largest plants, with an average capacity of 938 megawatts, reported an average capital cost per ladder of $23.2 million. The four smallest plants, with an average capacity of 2.1 megawatts, reported average ladder capital costs of $242,000. The two smallest plants, at 5 and 90 kilowatts each, report capital costs of $1,000 and $8,000 each. The $1,000 ladder is a rock and concrete fish ladder with a passage height of 4 feet, and it is used to pass rainbow trout. The $8,000 ladder is a multibox ladder with a passage height of 10 feet, used for trout. The 13 plants have an average fish ladder capital cost of $7.4 million. The capital costs for the fish ladders per kilowatt of installed capacity is provided in Figure 3-2.

3.1.3 Study Costs. Five of the plants reported study costs for determining upstream mitigation methods. The reported study costs range from $1,400 to $89,000. The average study cost is reported as $26,000. The plants reporting study costs ranged in size from 90 kilowatts ($1,400 study costs) to 19,060 kilowatts ($5,600 study costs).

3.1.4 Annual Reporting and Monitoring Costs. Of the 16 hydroelectric plants providing upstream mitigation related costs, 10 plants reported an average annual cost of $69,000 for the annual reporting and monitoring related to upstream fish passage/protection mitigation requirements. The annual reporting and monitoring costs ranged from $900 to $265,000 per plant. The median annual reporting and monitoring cost is $13,000 per plant. The few plants reporting the higher annual reporting and monitoring costs drove the average cost up; seven of the 10 plants reported a cost of $31,000 or less. The two plants (13.9 and 19.1 megawatt capacity each) with fish elevators reported annual reporting and monitoring costs of $12,000 and $14,000. A second 19.1 megawatt capacity plant, which uses trapping and hauling for upstream mitigation, reported a cost of $2,400 for annual reporting and monitoring requirements. The remaining seven plants with reporting and monitoring costs all have fish ladders, and the annual costs ranged from $900 to $267,000, with an average of $75,000 and a median value of $4,400 (Figure 3-3).

3.1.5 Annual Operations and Maintenance Costs. Of the 16 plants reporting costs related to upstream mitigation, 11 reported annual operations and maintenance costs. The annual operations and maintenance costs are for activities such as pumps for water attraction flows and for the

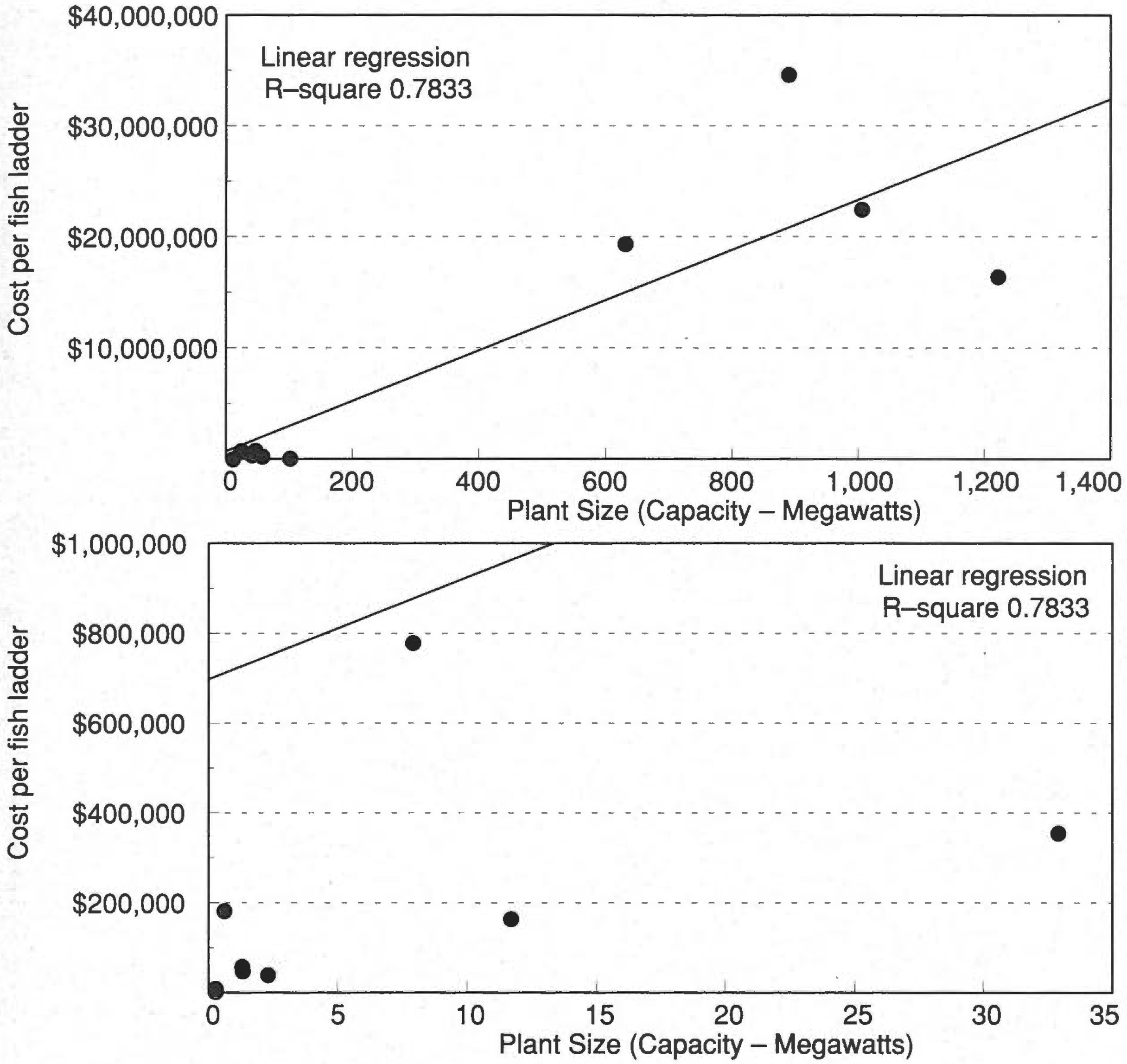
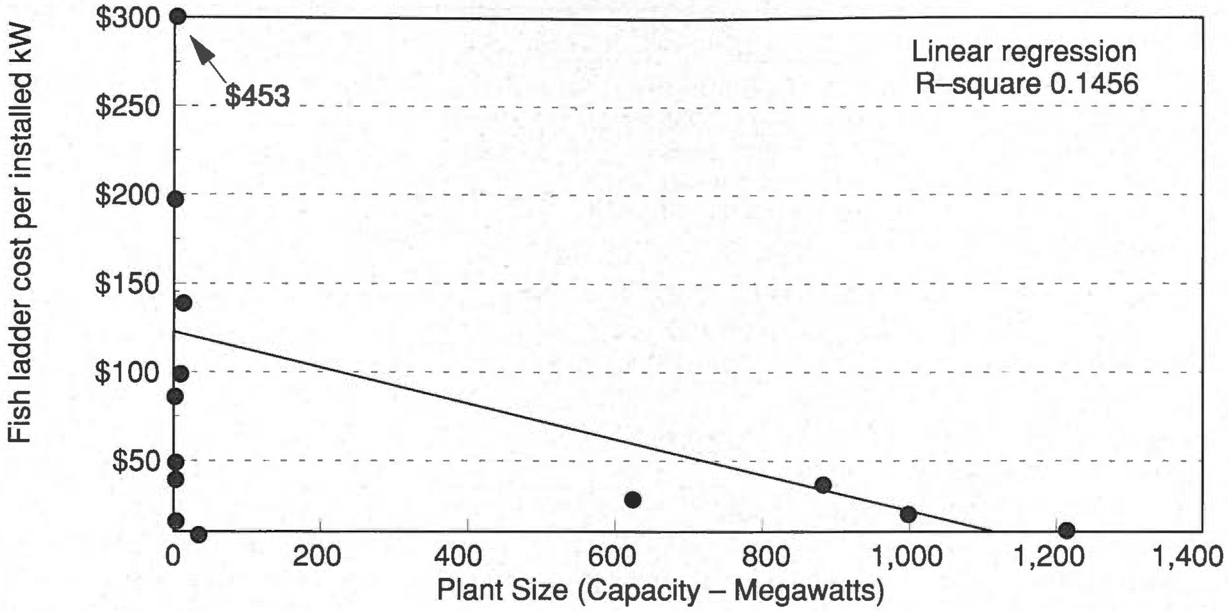


Figure 3-1. Average per project capital cost for fish ladders. The top graph includes all 13 hydroelectric plants reporting fish ladder capital costs. The bottom graph regression line includes all 13 plants but only plots the nine smallest capacity plants and their fish ladder capital costs. The regression line for both graphs includes all 13 plants.

cleaning of debris in ladders and elevators. The annual operations and maintenance cost for the plant with trapping and hauling was reported to be $24,000. The two plants with fish elevators reported costs of $6,000 for the 19.1 megawatt capacity plant and $24,000 for the 13.9 megawatt capacity plant. The eight plants with fish ladders reporting annual operations and maintenance costs reported an average annual cost of $91,000, with a range of $500 to $310,000. Four of the eight plants are large plants on the Colombia River, with two ladders at each plant. If this total of 12 ladders, four plants with one ladder each and four plants with two ladders each, is used to average the annual operations and maintenance costs per ladder the average would be $61,000. The annual costs ranged from $500 at the 90 kilowatt capacity plant to $310,000 at the 881 megawatt capacity plant with two ladders (Figure 3-4).



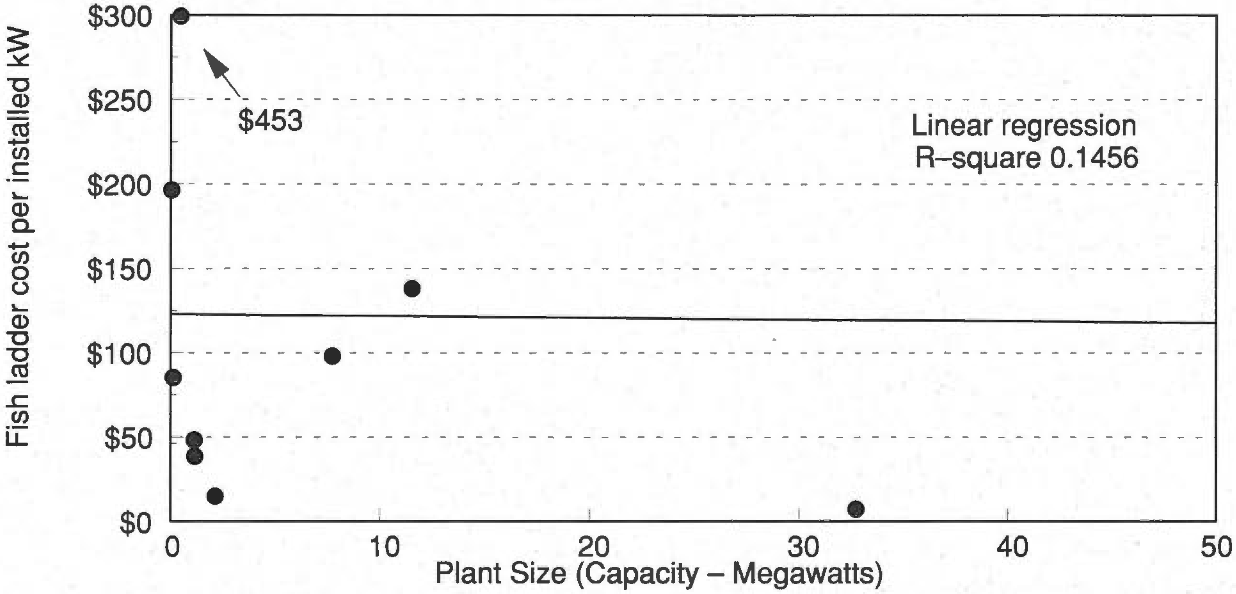


Figure 3-2. Capital costs for fish ladders per kilowatt of installed capacity. The top graph includes all 13 hydroelectric plants reporting capital costs for fish ladders. The bottom graph includes all 13 plants but only nine are displayed. The regression line for both graphs includes all 13 plants.

3.2 Downstream Fish Passage/Protection

3.2.1 Introduction. A variety of methods are used for downstream mitigation. For the downstream mitigation methods that have been used by more than a few plants, tables, along with a brief narrative, are used to present the costs. For those plants that did not indicate a particular cost (e.g., capital, study), that cost is blank in the tables. Some plants indicated that their particular mitigation method does not have a cost associated with an activity such as reporting because there is no reporting requirement. Unfortunately, the distinction between the plants with a zero cost and the plants that simply did not answer if a cost was

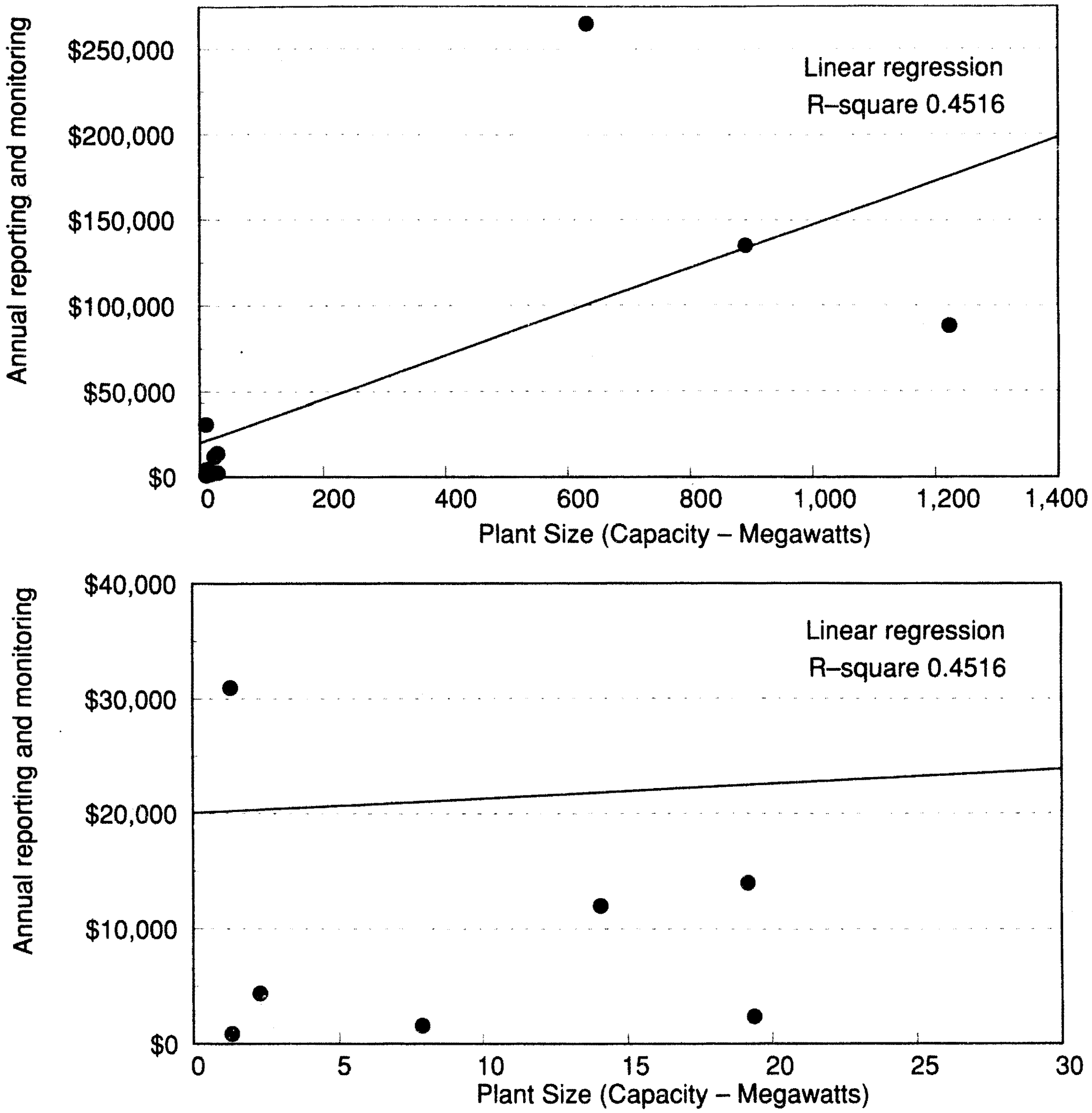
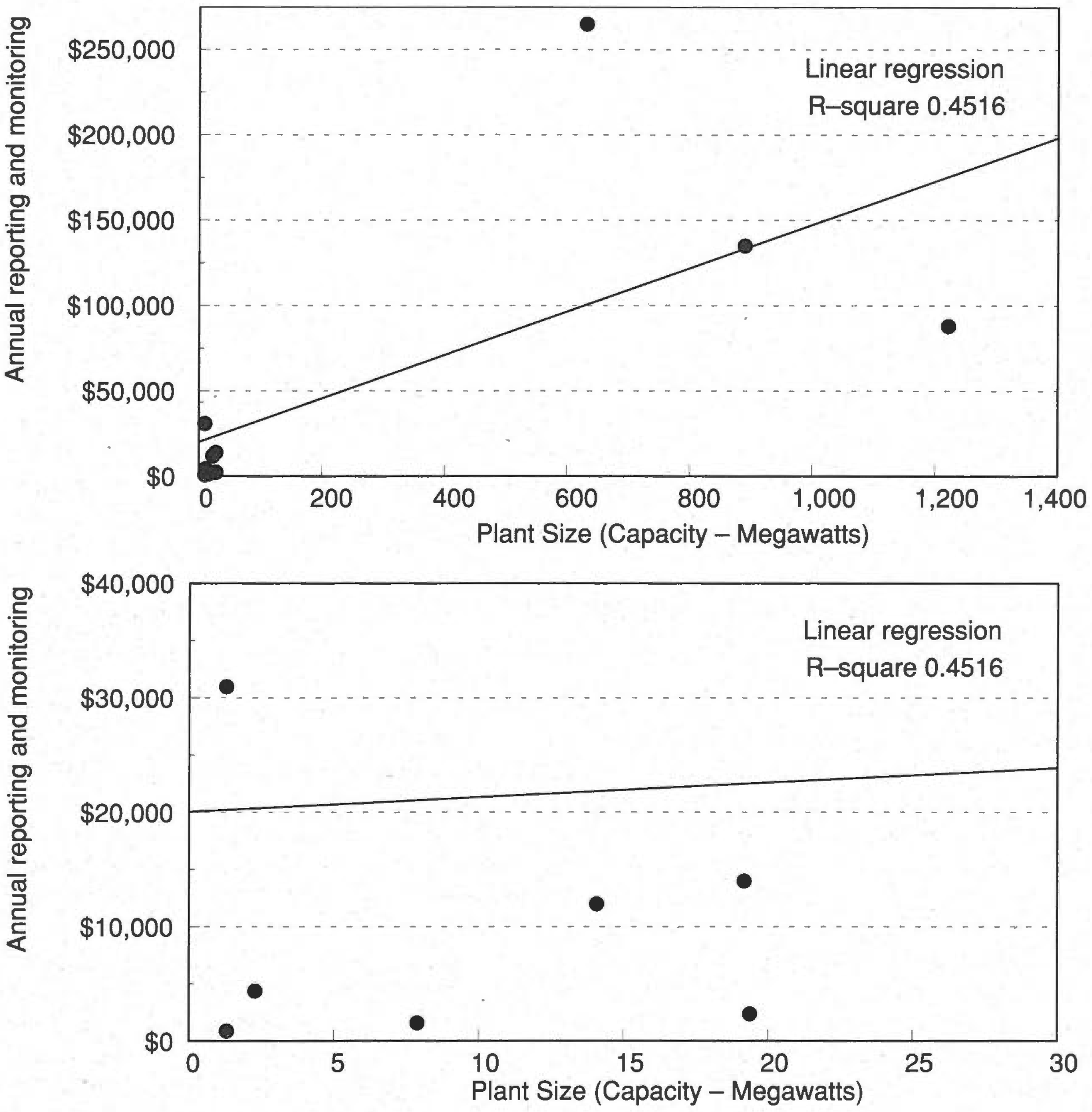


Figure 3-3. Annual reporting and monitoring costs for upstream mitigation. The top graph includes all 10 hydroelectric plants reporting annual reporting and monitoring costs. The bottom graph includes the seven smallest capacity plants (of the above 10) and their annual reporting and maintenance costs. The linear regression line in the bottom figure includes all 10 plants.

occurring is not adequately clear; if no value was reported greater than zero, the cost is left blank. The abbreviations used in the tables to designate the FERC region that a plant is located in are: A—Atlanta, C—Chicago, N—New York, P—Portland, and S—San Francisco.

3.2.2 Barrier Nets. The single 26 megawatt plant reporting the use of barrier nets in is the Portland region and reports a capital cost of $102,000 and study costs of $20,000. The annual costs of operations and maintenance duties is $26,000.



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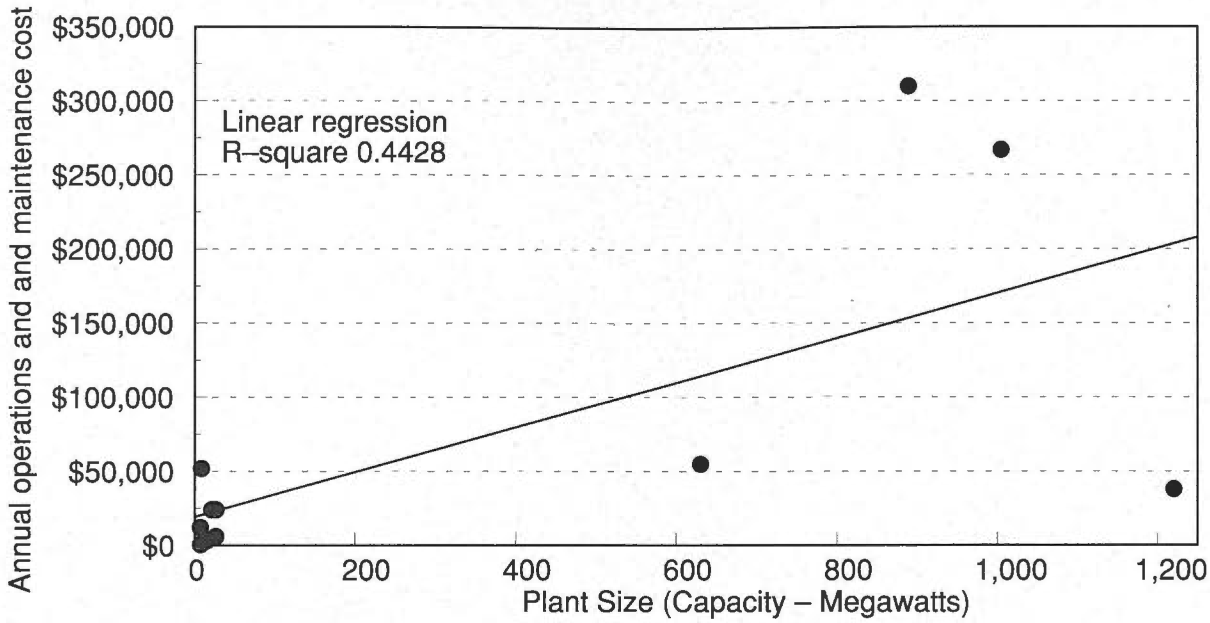

Figure 3-4. Annual operations and maintenance costs for upstream mitigation. The graph includes all 11 hydroelectric plants reporting annual reporting and monitoring costs.

3.2.3 Other Methods. The three plants in this category did not report any capital costs, only study costs for downstream mitigation were provided. The 11.6 megawatt plant in the Portland region spent $124,000 to evaluate the fish screens used in the power canal. In the New York region, a 19.6 megawatt plant spent $498,000 to study their floating raft strobe light system, which is used to direct downstream migrating juvenile shad through the sluiceway, and a 2.8 megawatt plant spent $307,000 over 5 years to study turbine fish passage/protection. The 2.8 megawatt capacity plant modifies the operation of their three turbines for optimal fish passage/protection and has been paying the state fish resource agency $6,300 each year for the value of the lost fish. The average cost for these three studies is $310,000.

3.2.4 Other Screens. Four plants reported the use of screens other then penstock or gatewell screens (Table 3-1).

The smallest plant uses a stationary screen with a wiper brush system for screen cleaning. The 2.0 and 6.89 megawatt plants both use screens described as California screen standards. The 1.1 megawatt project did not specify the type of screen used. For the four plants, the average

Table 3-1. Downstream mitigation costs for miscellaneous types of screens. All four plants are in the San Francisco region (S).

FERC region	Capacity (megawatts)	Capital cost ($)	Study cost ($)	Annual reporting cost ($)	Annual operations and maintenance cost ($)
S	0.46	53,000	24,000	6,000	22,000
S	1.10	67,000	7,000	—	4,000
S	2.00	160,000	—	—	12,000
S	6.89	160,000	—	—	12,000

screen capital cost is $110,000 per plant and $42 per installed kilowatt of capacity. The operations and maintenance costs per plant average $12,500 annually.

3.2.5 Sluiceway and Bypasses. Five plants provided costs associated with the use of sluiceways or bypasses as a downstream mitigation method (Table 3-2).

The smallest plant did not describe the type of bypass used. The 3.5 megawatt plant uses a collection box and a pipe for bypass. The 6.4 and 8.4 megawatt plants both use sluiceways from April 1 through June 30 and from October 1 through November 3 to pass Atlantic salmon smolts. Both of these plants are on the same river. The average bypass and sluiceway capital cost for the five plants is $224,000 per plant and $30 per installed kilowatt of capacity. The average cost of studies at the four plants that reported study costs is $71,000. The two highest cost studies were radio telemetry studies.

3.2.6 Penstock Screens. Seven plants provided the costs of using penstock screens as a downstream mitigation method (Table 3-3 and Figure 3-5). One of the seven plants did not provide a capital cost as the penstock cost was part of the entire plant cost, and the operator could not accurately segregate the penstock capital cost. The average plant size is 3.5 megawatts.

The average capital cost for penstock screens is $177,000 per plant and $43 per installed kilowatt

Table 3-2. Downstream mitigation costs for sluiceway and bypasses. All five plants are in the New York region (N).

FERC region	Capacity (megawatts)	Capital cost ($)	Study cost ($)	Annual reporting cost ($)	Annual operations and maintenance cost ($)
N	0.40	60,000	12,000	1,000	5,000
N	3.50	210,000	47,000	—	5,000
N	6.40	143,000	112,000	1,000	5,000
N	8.40	472,000	112,000	1,000	5,000
N	19.06	236,000	—	—	3,000

Table 3-3. Downstream mitigation costs for penstock screens. Six of the plants are in the San Francisco region (S) and one is in the Portland region (P).

FERC region	Capacity (megawatts)	Capital cost ($)	Study cost ($)	Annual reporting cost ($)	Annual operations and maintenance cost ($)
P	0.16	81,000	—	—	500
S	0.90	9,000	5,000	—	1,000
S	1.10	149,000	156,000	31,000	21,000
S	1.10	228,000	57,000	52,000	105,000
S	3.00	228,000	60,000	31,000	84,000
S	5.00	—	36,000	31,000	21,000
S	13.30	366,000	—	5,000	5,000

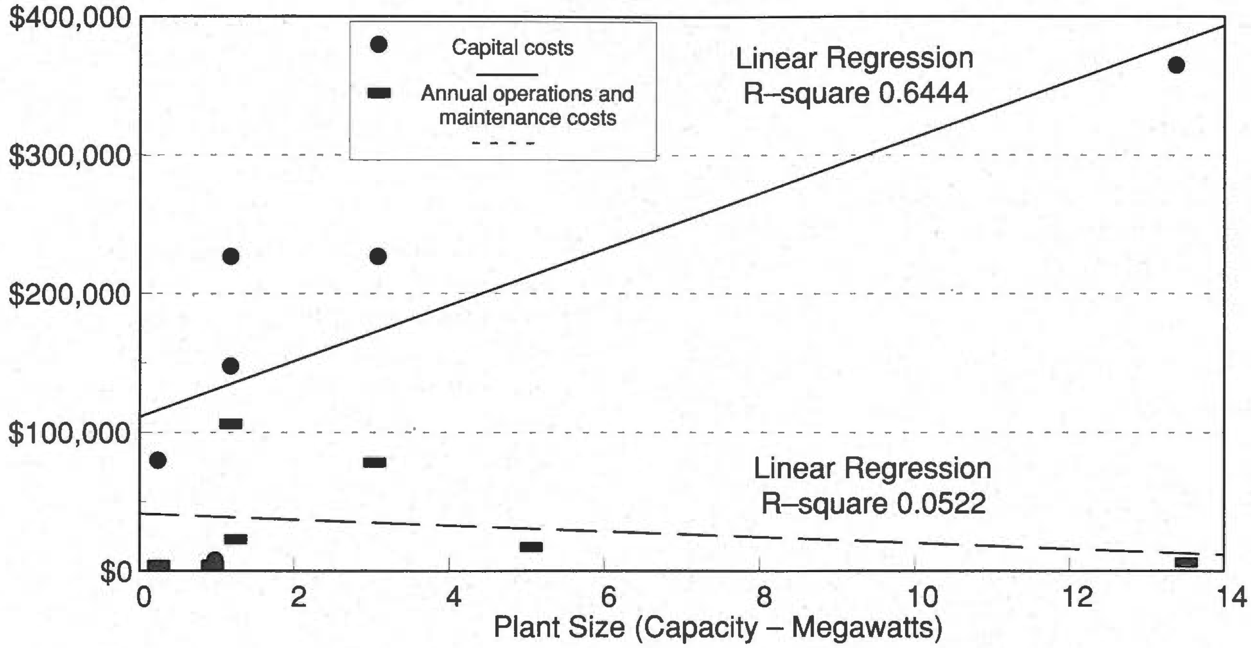

Figure 3-5. Capital, and operations and maintenance costs for penstock screens.

of plant capacity. The average study cost is $63,000, and the average annual reporting cost is $30,000. The average annual operations and maintenance cost is $34,000.

3.2.7 Angled Bar Racks. Eight plants, with an average capacity of 2.5 megawatts, provided angled bar rack cost information (Table 3-4 and Figure 3-6).

The angled bar rack capital costs averaged $363,000 per plant and $144 per kilowatt of installed capacity. The average capital cost for angled bar racks at the six smallest plants is $2,750 per plant and $12 per kilowatt of installed capacity. The high capital cost for the 4.9 megawatt plant seems out of line with the other costs, but this is the amount reported.

Table 3-4. Downstream mitigation costs for angled bar racks. The abbreviations for the regions are N—New York, S—San Francisco, and P—Portland.

FERC region	Capacity (megawatts)	Capital cost ($)	Study cost ($)	Annual reporting cost ($)	Annual operations and maintenance cost ($)
N	0.03	1,000	—	—	1,000
N	0.04	500	—	—	500
N	0.06	2,000	—	—	—
N	0.06	1,000	—	—	1,000
S	0.13	3,000	—	1,000	3,000
P	1.12	9,000	—	—	—
P	4.90	2,593,000	55,000	—	—
N	13.88	295,000	—	6,000	12,000

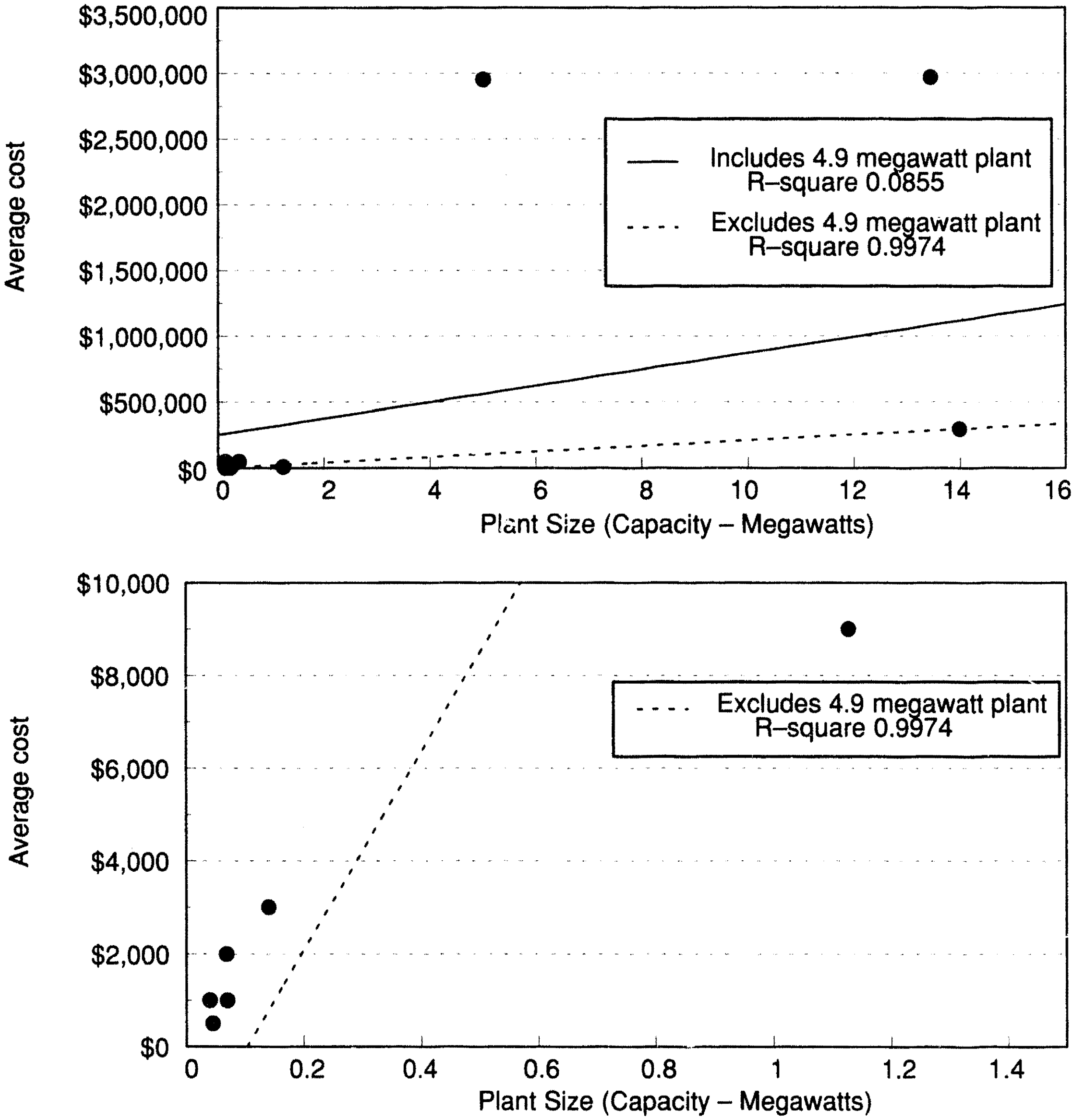

Figure 3-6. Angled bar rack capital costs. The solid line in the top graph includes the angled bar rack capital cost of the 4.9 megawatt plant. The dotted line in the top graph excludes the 4.9 megawatt plant angled bar rack capital cost. The bottom graph shows average costs for the six smallest capacity plants.

3.2.8 Combination of Methods. Thirteen plants reported using a combination of methods for downstream mitigation (Table 3-5). The average plant capacity at the 13 plants is 4.6 megawatts.

The downstream mitigation capital costs ranged from $500 to $1.05 million (Figure 3-7). The plant with the $500 capital cost has a 50 kilowatt capacity and uses a bypass and an angled bar rack. The plant with the $1.05 million downstream mitigation capital cost has a 29.9 megawatt capacity and it uses a bypass and an angled bar rack also. Other combinations of methods include penstock screens and bypasses, trash racks and bypasses, and several plants with angled bar racks and bypasses. The average downstream mitigation capital cost of these 13 plants is $168,000 per plant and $36 per kilowatt of installed capacity. Six plants reported study costs at an average of $23,000 per plant. Nine plants reported an average annual operations and maintenance cost of $12,000.

Table 3-5. Downstream mitigation costs for plants with a combination of methods. The abbreviations for the regions are A—Atlanta, C—Chicago, N—New York, P—Portland, and S—San Francisco.

FERC region	Capacity (megawatts)	Capital cost ($)	Study cost ($)	Annual reporting cost ($)	Annual operations and maintenance cost ($)
C	0.05	500	—	—	—
A	0.17	8,000	—	—	3,000
N	0.30	26,000	5,500	—	—
P	0.60	487,000	85,000	1,000	7,000
A	0.64	68,000	—	—	5,000
N	0.70	59,000	4,000	—	6,000
S	0.99	133,000	—	—	9,000
N	1.71	31,000	19,000	2,000	6,000
N	2.05	4,000	6,000	—	—
N	2.10	78,000	20,000	—	—
P	2.10	96,000	—	300	4,000
N	19.13	142,000	—	2,000	10,000
S	29.90	1,050,000	—	—	56,000

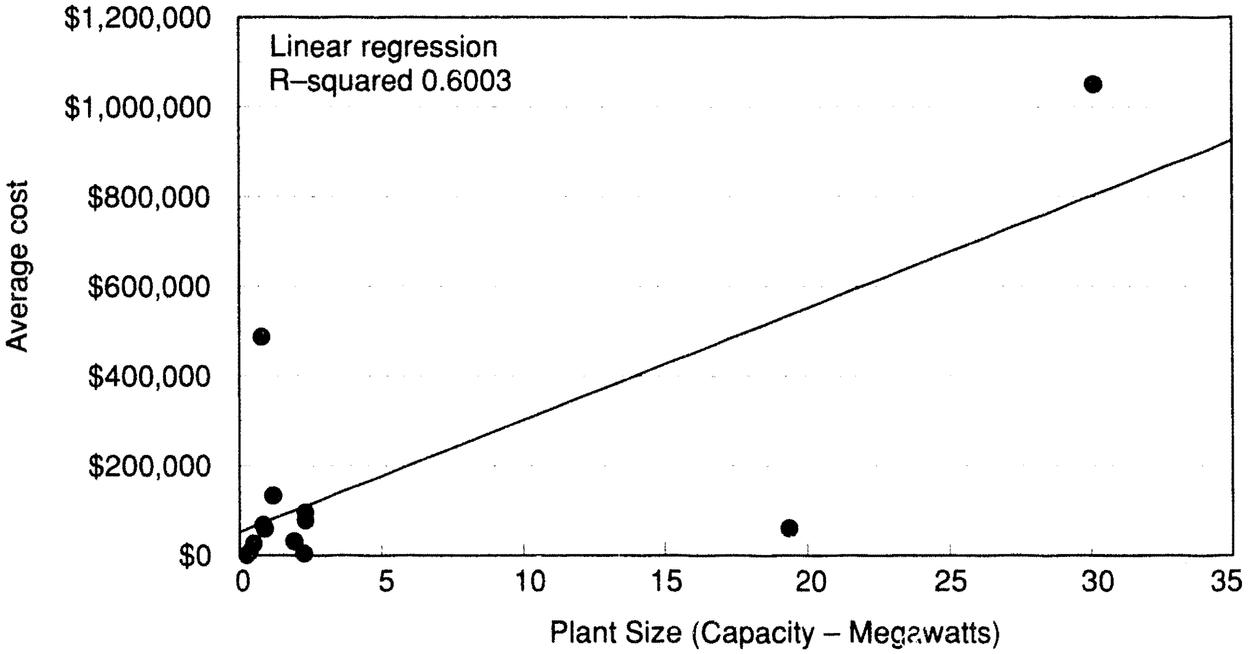

Figure 3-7. Capital costs for projects reporting more than one type of downstream mitigation method.

4. CASE STUDIES INTRODUCTION

In order to identify case study candidates that are representative of general upstream and downstream fish passage/protection mitigation practices in the United States, some understanding of the current mitigation methods and frequencies is required. Possible fish passage/protection technologies include fish ladders and fish elevators for upstream mitigation, and bypasses, angled trash racks, and penstock screens for downstream mitigation. Of course, a myriad of other practices and technology combinations are possible. A difficulty faced when identifying the case study candidates was to select cases representative of national practices when the mitigation practices are often extremely site specific and unique. Criteria for case study selection included a geographical sample based on FERC regions and the types of technologies employed. Other additional case study candidate selection criteria included the fish resource present (e.g., herring, shad, salmon, steelhead, trout, bass) and the type of developer (e.g. municipality, Federal, private). The size of the hydroelectric plant was another consideration, as the case studies were intended to identify mitigation practices, benefits, and costs that were applicable to other hydroelectric sites. Unfortunately, a list did not exist that contains all of the hydroelectric projects in the United States and the type of mitigation used, or even if a mitigation practice is present. To identify the mitigation frequencies and specific practices, FERC was contacted and their cooperation was solicited.

4.1 Methodology

Benefits are encountered every time a smolt or adult is safely passed, time after time, year after year. Additional benefits would include the future generations that are successfully spawned. While it may be possible to quantify the costs per kilowatt-hour of mitigation methods or, for example, the cost per upstream fish trip via a ladder, it is difficult to quantify all present and future benefits derived from that cost. It would be imprudent to assume that the capital cost of a fish bypass system will only benefit the migrating fish that year. Costs are estimated for upstream and downstream mitigation by combining the capital costs and annual costs over the 20 year analysis and computing levelized annual costs and costs per kilowatt-hour of generation. The levelized annual cost is not a discounted or net present value cost, it is the simple yearly cost (in 1993 dollars) which is used to represent the costs over a period of time.

The outlying cost years have the potential to be the most inaccurate because uncertainties tend to be compounded over time when estimating future costs, and the loss of historical data may hinder the accuracy of cost data associated with past events. Every effort has been made to accurately obtain and present the cost data in a relevant manner with the intention of allowing the reader to understand the types and economic magnitudes of mitigation decisions. In spite of any acknowledged uncertainties, it is important to represent costs as they occur, over time. The goal of the mitigation efforts is to provide a positive benefit to a species or a number of species over an entire life-cycle and to ensure continuous generations. Both upstream and downstream mitigation is intended to ensure safe passage at some point during the migration of anadromous species, or to ensure passage/protection to resident fish. Unfortunately, providing mitigation at a single site to ensure that site has no impact on a species does not ensure proliferation of that species. Other factors, ocean fishing or the loss of spawning habit for instance, can impact species regardless of mitigation at a single site or at a single point in the species life-cycle.

4.1.1 Case Studies Selection Process. The initial collection of mitigation information from the FERC five regional offices was recognized as incomplete. However, waiting for the subsequent data collection iterations before identifying case study candidates was unacceptable because of scheduling constraints. The initial information was acceptable as a tool for determining general regional and national upstream and downstream mitigation practices and frequencies.

Approximately 300 plants were initially identified by FERC regional offices as having upstream or downstream mitigation. These plants were plotted in each of the five FERC regions. Scheduling and resource constraints suggested that a total of approximately 15 case studies would be appropriate. It was anticipated that an unknown percentage of the identified case study candidates would decline to participate, so the initial target of case studies was set at 20 plants. Based on the regional distribution of mitigation methods and the requirement to identify 20 plants, the number of cases desired per region were Atlanta—2, Chicago—1, New York—9, Portland—5, San Francisco—3. This was based on the total number of plants with mitigation in each region.

The next step was to determine the number of case studies required for each mitigation method. For instance, it was initially thought that 149 of the 300 plants had upstream mitigation methods. The breakdown for each method was trapping and hauling at 20 plants, fish ladders at 98 plants, fish elevators at nine plants, and other methods at 32 plants. To determine how many of each of the upstream methods should be included in the 20 case studies, these were applied to the 20 cases. For instance, the fish ladders were present in 98 (66%) of the 149 plants, so applying this ratio to the 20 cases suggested that 13 (66%) of the 20 study cases should have ladders. The final iteration of obtaining national frequencies from the FERC regional offices indicated the presence of 108 plants (62%) with fish ladders out of the 174 plants with upstream mitigation. While not exactly the same frequency as the first iteration suggested, a variation of this magnitude (62%–66%) is acceptable for the process of case selection.

The case studies that were selected dealt with relatively conventional mitigation technologies (i.e., ladders or lifts for upstream passage/protection and some form of physical screen to exclude or guide downstream migrants). However, the hydroelectric industry continues to experiment with alternative mitigation technologies, particularly to protect fish from turbine intakes. Refinements in behavioral exclusion measures (e.g., electrical barriers, lights, sound systems) have been tested at a number of hydroelectric sites (EPRI, 1986, In Press). A number of tests of behavioral screening measures have yielded encouraging results, but full-scale installations are rare. Results of testing programs to date indicate that behavioral screens will need to be tailored to the specific characteristics of the site and the size and species of fish, and thus effectiveness is not yet generalizable or predictable. It is likely that considerable testing of novel screening approaches will need to be conducted in a variety of environments before these measures will gain wide acceptance by the regulatory and resource agencies. Nationally, light and sound avoidance/guidance systems are used at 1.3% of the 237 plants with downstream mitigation in place. Applying the 1.3% to the 20 case studies does not suggest that a project with a light and sound avoidance/guidance system be used as a case study.

The next step in the case study selection process was the identification of plants that also provided mitigation information for the original *Volume I Environmental Mitigation At Hydroelectric Projects* report. This effort produced a list of 25 plants that had previously provided, for the *Volume I* report, some type of information describing costs, biological studies, and descriptions. This list was expanded to include 10 additional plants that the authors were personally familiar with and believed to be good case study candidates. Based on the criteria of biological information being available from previous studies, the likelihood of obtaining cost data, the fish resource, the FERC region, generating capacity, water flow size, the type of plant operation (e.g., run-of-river, store and release), the type of owner (e.g., municipality, entrepreneur), and the need to represent the various states within a single FERC region, 18 plants were selected as case study candidates. The case study selection process was not a pure statistical process; engineering and biological judgment was exercised in the case selection process. However, at no time was the success or failure of a particular mitigation method a criterion. It was hoped to examine both the successes and the failures of various mitigation methods.

The final step of the case study selection process was a "self selection" process including the 18 plants selected by the authors and the desire to select two additional hydroelectric plants, one located in Idaho with a fish ladder and a second plant located in the FERC Atlanta region that has an angled bar rack. Unfortunately, a plant was not found either in Idaho or in the Atlanta region that had the desired biological information and was willing to be a case study participant. The Corps of Engineers was also contacted to determine their willingness to provide a plant to serve as a Federally owned case study. The Corps of Engineers agreed to participate and designated the Lower Monumental plant on the lower Snake River as a case study. Of the 19 plants identified by the authors, two declined to participate. Of the remaining 17 plants, one subsequently declined to participate after the tragic death of a member of the company. This is mentioned only to highlight how the best made plans can change based on a totally unanticipated and unfortunate event. The remaining 16 plants formed the case studies (Figure 4-1). Unfortunately, cost information at one of the 16 case studies (Potter Valley) was unavailable. The case studies included 16 cases with biological information and 15 with cost information.

4.1.2 Mitigation Costs, Inflation Index. All of the mitigation costs are adjusted to 1993 dollars and discussed as such. This adjustment of all mitigation costs allows an analysis of the magnitudes of costs as if they occurred today, minimizing any inflationary effects. Ignoring inflationary effects on costs can distort the relative magnitudes of costs that occur in different years. For instance, discussing a $25,000 house purchased in 1963 and $25,000 house purchased in 1993 at first glance could imply similar houses are purchased. In reality, significantly different levels of quality, size, or location would be present in spite of the fact that the same amount ($25,000) is spent on both houses. That 1963, $25,000 house, is worth ~$94,000 in 1993 dollars (4.5% annual index). To compare similar houses would require comparing the 1963 house and its 1993 dollar value of $94,000 and a 1993 $94,000 house (in 1993 dollars).

Figure 4-1. Location of 16 case studies.

No attempt is made to value competing mitigation options, nor is the space available to examine and discuss the principles and effects of discount or risk factors. A simple handling of costs has been chosen to best estimate yearly costs. If a comparison is done as to which of two options to choose, then a net present value or present value analysis would be appropriate to understand the forces of the time value of money and risk. However, the mitigation cost analysis is not considering competing options, it is presented to understand economic consequences in terms of current dollars.

The choice of an inflation index is not a clear-cut scientific decision. Inflation rates vary over time and usually between consecutive years. The consumer price index is used to define the rate for indexing all costs to 1993 dollars. The consumer price index has shown an inflation rate of 4.3% during the last 5 years, a 3.8% rate during the last 10 years, and a 5.8% rate during the last 15 years. The inflation rate during the 1980–1992 period averaged 4.53%. Because the majority of costs were incurred during this last period, 4.5% is used to approximate the yearly inflationary effects on mitigation costs.

While the current inflation rate is lower than 4.5%, it is certain that the rate will also be higher than 4.5% some time in the near future. Therefore, all cost values have been indexed to 1993 dollars (at 4.5%) to best help the developer, regulator, resource agencies, or other interested parties to gain an appreciation of the costs and resource requirements of mitigation methods in terms of today's dollar values.

4.1.3 Twenty-year Analysis Period. The benefits of mitigation should be cumulative over many years and many aquatic generations, and the costs of mitigation are also cumulative over many years and generations. A 20-year cost analysis is used to estimate mitigation costs as they occur over a period of time. It would be a misrepresentation to only examine a single year's costs. For example, capital costs may be incurred during a single year and this may skew, unfairly, an analysis of that year's costs in relation to that year's benefits while ignoring any future benefits.

A 20-year cost analysis period is used to level the large, up-front capital costs that are usually associated with mitigation. The benefits of mitigation, be it to current or future generations of fish using ladders or downstream migrants using bypasses, will be enjoyed for many years, provided that other influences on the life-cycle do not interfere with passage and reproduction. A difficulty in obtaining the mitigation costs is memory length, record retention, and the ability to find individuals that can provide input about fish mitigation events that occurred 5, 10, or 20 years ago. Additional difficulties arise when discussing costs with a financial person that has no understanding of the operations or equipment that a specific cost is associated with. The opposite side of this is the biological staff that understands the requirements of the passage/protection mitigation method but has no association with the economic requirements. Hours were sometimes spent learning from both types of individuals before accurate costs were compiled. Obtaining the mitigation cost information in this manner was not the norm, as most of the case study sites was able to access cost information after a not always brief search. The actual years that some costs occurred were often difficult to determine. Expending beyond a 20-year analysis would have greatly compounded the difficulty of obtaining accurate cost information.

Some readers of this report may suggest that the cost analysis should be either of a shorter or longer duration than the chosen 20-year period. In reply, 20 years is the optimal period for this exercise for several reasons. A shorter duration would tend to heavily load capital costs into a shorter period, raising the cost per kilowatt-hour. Also, with benefits enjoyed over many years, this would tend to overestimate the associated costs. A longer period might more accurately reflect the operations length of a capital structure such as a ladder. However, several factors argued for avoiding a longer analysis period. Using a longer time frame, say 30 years, requires obtaining even greater information from humans associated with a mitigation method. The practical reality is that few humans can plan or remember information for that long a period of time, not to mention the difficulty of finding a nonretired employee with that long of a tenure. If a 30-year analysis was used, the identified capital costs would be lowered when viewed as annual and per kilowatt-hour costs. However, it is unknown if additional capital structures or studies would be required during the extended 10 years and to what degree this would raise costs. Additional annual costs would also be included in a longer analysis, minimizing the impact of leveling the capital costs over a longer period of time. A longer period of analysis would also increase the possibility of increased mitigation requirements. This increase would most likely be accompanied by increased mitigation-related costs.

Using the 20-year analysis allows for variations in yearly cost requirements, such as studies conducted for only a few years, or the costs of lost generation when spill flows are required for a few years while screens are installed. The 20-year leveling of costs provides a true picture of long-term costs while avoiding the influences that a single or few years of extraordinary low or high costs would have on the cost analysis.

4.1.4 Total Costs, Levelized Annual Costs, and Costs per Kilowatt-hour. The mitigation costs are provided to the reader as total 20-year costs to reflect the total expenditures often required to install and operate mitigation methods. The annual costs are provided to highlight the magnitude of annual budgetary requirements. All of the mitigation costs are also provided as a function of historical generation levels. These per kilowatt-hour values allow for an understanding of economic resource requirements in terms of costs as a function of revenue (i.e., the ability to pay). Electric plant costs are tracked on a per kilowatt-hour basis, usually in terms of mills per kilowatt-hour. These power production expenses, such as operation supervision and engineering, maintenance of equipment and facilities, and rent, are all tracked on a per kilowatt-hour cost basis. The mitigation costs are provided as per kilowatt-hour costs to allow the reader to understand the economic consequences of mitigation decisions. This is not an argument that the costs are too high, too low, or proper; it is an argument that the economic ramifications of resource decisions must be considered in the realm of the ability to pay for mitigation requirements or another choice should be made. These other choices may include the abandonment of a developed site or not constructing a new site, and the environmental and economic consequences of using an alternative power source.

4.1.5 Mitigation Costs Defined. The only costs considered in the case study analyses are the costs directly related to the upstream or downstream passage/protection of fish. These costs do not include offsite costs such as hatchery and stocking costs, and lost generation resulting from instream flow release requirements. While some portion of hatchery requirements may be to mitigate for the impacts on fish passage caused by a hydroelectric plant, the hatchery requirements may also be for the negative impact on preproject spawning beds when impoundments are created. The hatchery may also be required to supplement the loss of spawning habitat because of upstream regional degradation of habitat and other factors. To include hatchery costs as a fish passage/protection cost would inaccurately portray fish passage/protection costs.

Other costs such as lost generation resulting from flows to facilitate adult movement in a spawning channel of a hatchery are not included as a fish passage/protection cost. Unless specifically required for fish passage/protection, lost generation costs resulting from instream flow releases are excluded. Instream flow releases are generally driven by other requirements such as habitat, recreation, dissolved oxygen, or aesthetics.

4.2 Organization of the Case Studies

The case studies section of this report contains descriptions of the methods, benefits, and costs of upstream and downstream mitigation at 16 hydroelectric plants. The only exception to this is the Potter Valley case study; the mitigation costs were not obtainable for this case. Numerous figures, diagrams, tables and photographs are provided to further the readers' understanding of the types of mitigation methods used at the case study projects and the associated benefits and costs. A summary of general information about the 16 case studies is presented in Table 4-1.

4.2.1 Benefits. At the beginning of each case study discussion, the physical plant is described in general terms and the mitigation methods are discussed in detail. The resource management objectives and monitoring methods are discussed, as is the performance of the various mitigation methods. The mitigation benefits are also examined. However, not all of the cases have defined objectives and monitoring methods, nor have benefits been identified for all of the case studies. The amount of information provided for each case study is dependent on the type of mitigation employed, whether or not monitoring has occurred, and if information was available describing the identified benefits.

Assessment of benefits of a fish passage/protection measure hinges on its short-term effectiveness (i.e., how many or what proportion of fish are transported around the obstruction) and what effect this mitigation subsequently has on the fish population. Simple fishway counts are of limited value for judging the effectiveness of an upstream fish passage design. For example, the upstream transport of 1000 spawners may seem to be an indication of a successful fish ladder, unless associated studies indicate that another 10,000 were unable to find the entrance to the fishway and became stalled at the base of the dam. Thus, whenever possible the effectiveness of a case study measure was expressed as the percent of the available population that used the mitigation. Adults that have been successfully transported above the hydroelectric dam must encounter suitable water quality and upstream spawning habitat in order for the mitigative measure ultimately to have a beneficial effect on the fish population. Similarly, if downstream-migrating juveniles experience excessive predation, adverse water quality, or are overfished at a later stage in the life cycle, the benefits of a turbine intake screen may be obscured or lost. Whenever possible the fish population level benefits of case study measures are reported, although in most cases this important criterion for determining success is beyond the control of the hydroelectric operator.

Conceptually, the alternatives for upstream passage/protection of fish are straightforward; fish can be either transported above the hydroelectric dam or blocked from further upstream movements. It is almost always desirable to transport as many anadromous fish upstream as possible, although some adults blocked from further upstream movements may still spawn at the base of the dam or in nearby tributaries.

Downstream mitigation presents additional alternatives; fish may be simply excluded from downstream movement by intake screens, or may be passed downstream via turbines, spills, or a bypass system associated with the downstream mitigation measure. The most effective mitigation for downstream passage/protection is to transport as many fish as possible using the route that results in the least mortality. Mortality associated with spill passage is often very low, but it may not be possible to pass a sufficiently large proportion of the migrants via that route. Further, spill can be a costly measure in terms of lost electrical generation. Although turbine-passage mortality may be very high, recent improvements in techniques for estimating this factor indicate that under some circumstances (e.g., large turbines with sufficient clearance and operating under optimal conditions), the survival of turbine-passed fish may be quite high. Heisey et al. (1992) estimated short-term survivals of 94 percent or greater among turbine-passed juvenile American shad at one hydroelectric plant; this level of protection could be difficult to achieve with a turbine-intake screen and bypass system. Recent studies at the second powerhouse at the Bonneville Dam on the Columbia River indicate that subyearling chinook salmon suffered 2.5 to 13.6 percent greater short-term mortality in the screen and bypass system than when passed through the turbines. Data from subsequent adult returns showed no significant differences between the long-term survivals of bypassed and turbine-passed salmon. Ferguson (1991) suggested that the greater mortality among bypassed juvenile salmon may have been due to the

Table 4-1. Case studies general information. Costs are in 1993 dollars, per kilowatt-hour of generation, based on 20-year averages. The costs includes all upstream and downstream mitigation-related costs.

Project name	Capacity (MW)	Annual energy production (MWh)	Diversion height (ft.)	Average site flow (cfs)	State	Upstream mitigation	Downstream mitigation	Mitigation cost (mills/kWh)
Arbuckle Mountain	0.4	904	12	50	California	Y	Y	12.9
Brunswick	19.7	105,200	34	6,480	Maine	Y	Y	3.7
Buchanan	4.1	21,270	15	3,636	Michigan	Y	N	10.6
Conowingo	512	1,738,000	105	45,000	Maryland	Y	N	0.9
Jim Boyd	1.2	4,230	3.5	556	Oregon	Y	Y	21.1
Kern River No. 3	36.8	188,922	20	357	California	Y	Y	0.09
Leaburg	15	97,300	20	4,780	Oregon	Y	Y	5.2
Little Falls	13.6	49,400	6	n/a	New York	N[a]	Y	2.8
Lowell	15	84,500	15	6,450	Massachusetts	Y	Y	5.5
Lower Monumental	810	2,856,000	100	48,950	Washington	Y	Y	2.3
Potter Valley	9.2	57,700	63	331	California	Y	Y	n/a
T.W. Sullivan	16.6	122,832	45	23,810	Oregon	N[b]	Y	5.8
Twin Falls	24	80,000	10	325	Oregon	N	Y	0.9
Wadhams	0.56	2,000	7	214	New York	N	Y	1.2
Wells	840	4,097,851	185	80,000	Washington	Y	Y	1.0
West Enfield	13	96,000	45	12,000	Maine	Y	Y	3.9

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n/a—not available.

[a] Upstream passage occurs through New York Department of Transportation Barge Lock Number 17.

[b] Upstream passage occurs through Oregon Department of Fish and Wildlife maintained fish ladder at Willamette Falls.

concentration of predators near the single point outfall of the bypass system. While these results are unlikely to represent the situation at most small-scale hydroelectric plants, they underscore the need for carefully designed and executed studies in order to determine both the need for turbine-passage exclusion measures and, if so, the best means for safely bypassing screened migrants.

4.2.2 Costs. The case study cost sections vary in the approach taken to present the cost information. The 20-year total costs range from $48,000 at one plant (560 kilowatt capacity) to $132 million at another plant (810 megawatt capacity). Because of this range in cost magnitudes (and mitigation methods and plant sizes) no single method is appropriate to present the costs. In spite of the different types of costs and methods, when reading the cost sections of the case studies the reader can find summary cost information at the front of each case study cost section and detailed information towards the end of each cost section. Of the 15 case studies with cost information, spreadsheets are used to analyze and present the costs at 13 cases. A cost descriptions and a tions section describes the assumptions u these 13 cases. The costs at the two cases without spreadsheets (Kern River No. 3 and Wadhams) have costs that are displayed and totaled in tables. The cost sections contain tables and figures so the reader can view the costs in summary detail and note cost percentages and trends.

The costs sections were not written with the intent to proclaim that other hydroelectric sites would encounter identical costs. Rather, the cost sections are intended to help developers, regulatory agencies, and resource agencies understand the economic consequences of different mitigation methods. The magnitude of mitigation costs at any given hydroelectric plant can depend on the particular fish species present, the size of the plant, including water flows and diversion heights, and perhaps the region or state the plant is located in.

The costs are presented in the greatest detail possible so the reader will understand the assumptions and computations used to total the costs. The cost totals include 20-year totals, levelized annual costs, and costs per kilowatt-hour of generation. Summary discussions of the benefits and costs can be found in the case study summary section.

5. ARBUCKLE MOUNTAIN CASE STUDY

5.1 Description

The Arbuckle Mountain project (FERC number 07178) is a 0.4-MW, run-of-river project on the Middle Fork Cottonwood Creek, a tributary of the Sacramento River, in northwestern California (Figure 5-1). The project began operation in December 1986.

The project incorporates a Denil fish ladder for upstream fish passage/protection at the 12-foot-high diversion dam (Figure 5-2). The ladder is intended to facilitate upstream movements of salmon, resident rainbow trout, and steelhead trout (i.e., anadromous rainbow trout). Instream flow releases up to 5 cfs are released through the ladder. At a flow of 5 cfs, the water depth in the ladder is 1.6 feet and maximum velocity is 3.4 fps (Ott, 1986). The ladder consists of 22-inch by 36-inch baffled sections on 10-inch centers (Ott Water Engineers, Inc., 1988). The lower section is 40 feet long and leads to a 4-foot-square resting pool. A 20-foot section of ladder leads from the resting pool to the diversion pond (Figure 5-3).

Fish entrainment is prevented by eight cylindrical wedge-wire fish screens mounted directly on a concrete manifold (Figure 5-4). The screens are 33 inches in diameter and 66 inches high. The slot-width is 0.094 inches and the approach velocity is 0.33 fps (Ott 1986). A maximum of 115 cfs of water can be diverted through the screens. Debris is back-flushed from the screens by means of a compressed air system. The screens are intended to operate as an exclusion device; downstream passage is through the fish ladder, which stays in constant operation under normal stream flows.

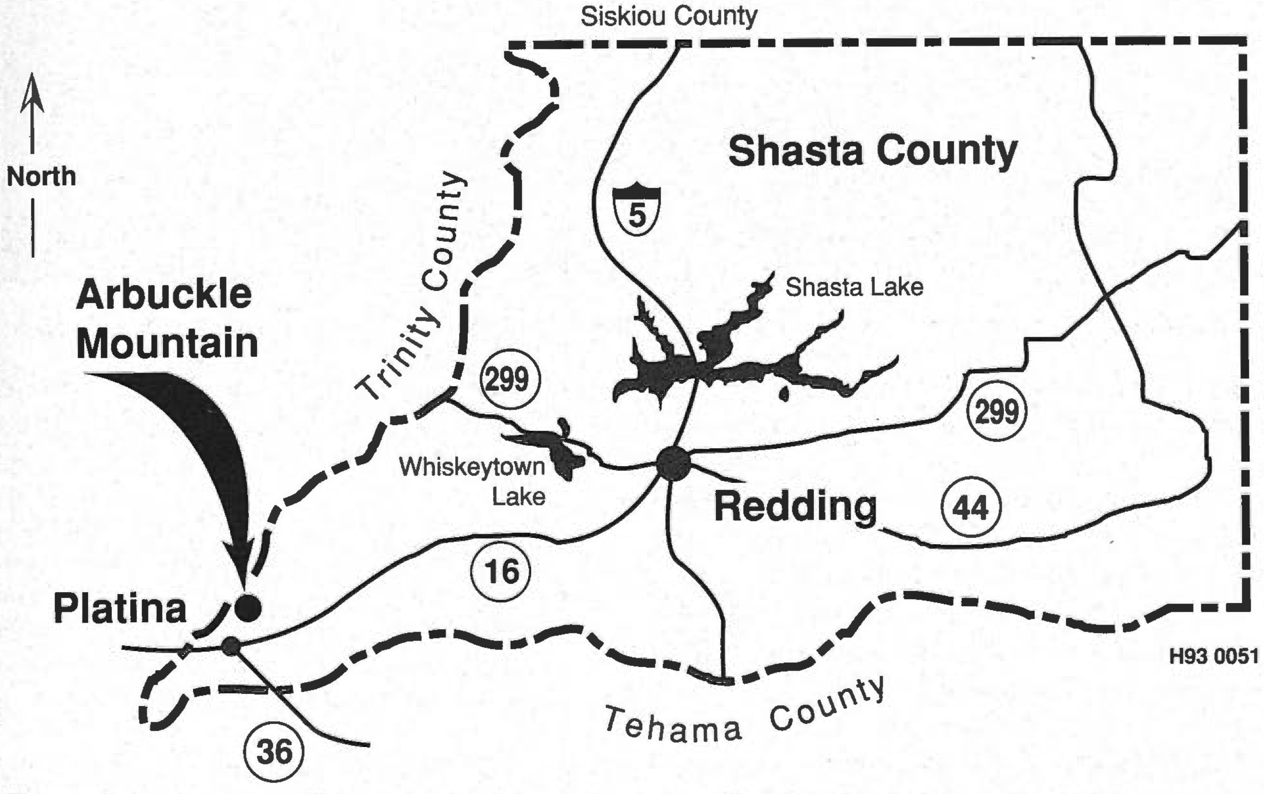


Figure 5-1. Location of the Arbuckle Mountain project. Numbers in circles are local highway route numbers.

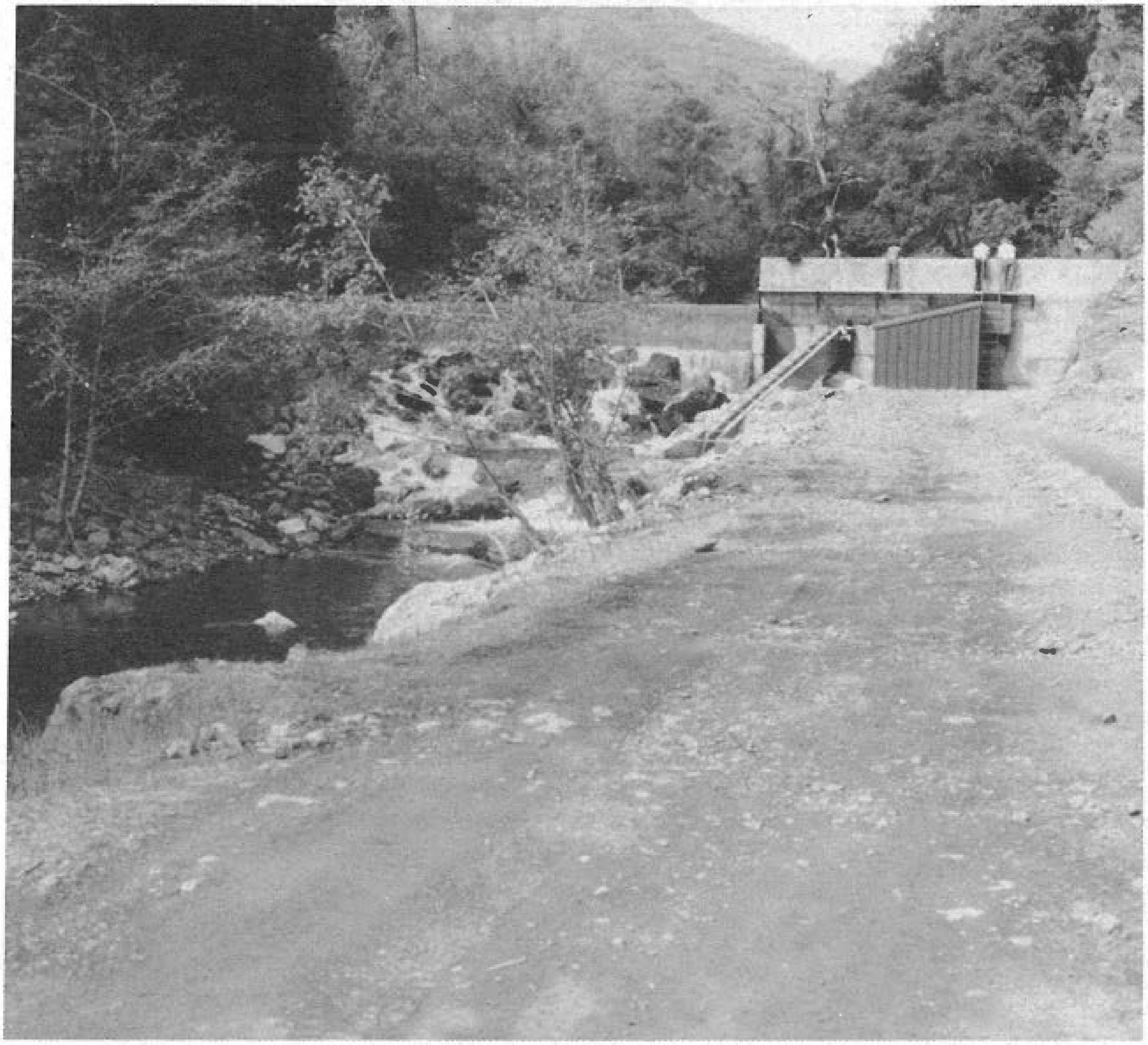


Figure 5-2. Diversion dam and fish ladder at Arbuckle Mountain. Penstock is partially buried to right.

5.1.1 Fish Resource Management Objectives of Mitigation. The Middle Fork Cottonwood Creek historically supported runs of Chinook salmon and steelhead trout, but no anadromous fish have been observed near the site in over 20 years (Hunn 1985). Annual surveys conducted by the licensee since 1984 also failed to detect salmon or steelhead at the site (Ott, 1990). However, because there are no barriers to anadromous fish migration between the Sacramento River and the site, the fish ladder and screens were installed primarily to protect anadromous salmon and steelhead trout in the event that restoration efforts for these species in the Sacramento River are successful.

Rainbow trout, Sacramento suckers, Sacramento squawfish, speckled dace, hardhead, and sculpin are present in the project area. The fish passage/protection measures are also intended to protect the resident rainbow trout population in Middle Fork Cottonwood Creek.

5.1.2 Monitoring Methods. The licensee was required to monitor both the Denil fish ladder and

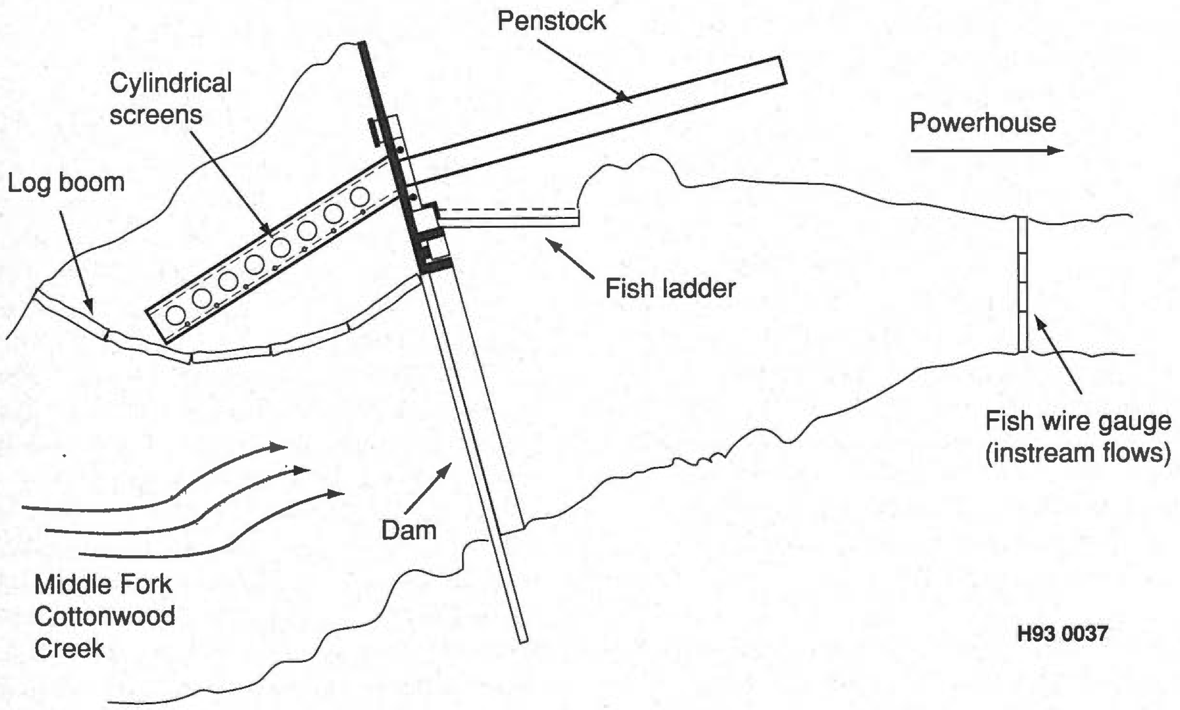


Figure 5-3. Overhead of fish ladder, screens, and diversion at Arbuckle Mountain. The cylindrical screens sit on a concrete intake manifold, the penstock leads to the downstream powerhouse, and the dotted line by the fish ladder is a pipe used for attraction flows.

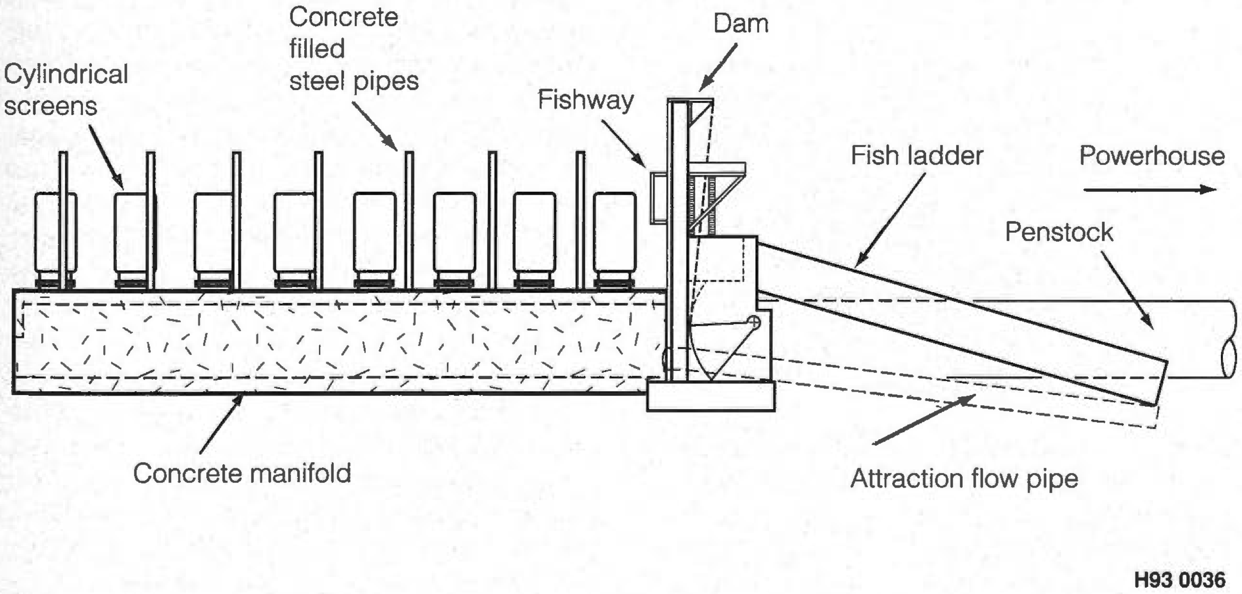


Figure 5-4. Cylindrical, wedgewire intake screens and manifold at Arbuckle Mountain. The concrete-filled steel pipes keep large debris away from the cylindrical screens.

the intake screens each year for 3 years and perform a preconstruction underwater survey. Fish usage of the ladder was to be observed by the plant operator between January 1 and April 30 of each year. In addition, an underwater (snorkeling) survey of both the ladder and the intake screens was required in the license. This 3-year monitoring effort was conducted between 1987 and 1989.

5.1.3 Performance of Mitigation. Over the 3-year monitoring period, only six resident rainbow trout were observed to use the fish ladder in both the upstream and downstream directions. No fish have been observed congregating either above or below the diversion dam, indicating no passage problems in either the upstream or downstream direction (Ott, 1990).

No salmon or steelhead trout were observed at the site during monitoring. In its comments on the monitoring report, the California Department of Fish and Game attributed the absence of anadromous fish to the series of low-precipitation years during this time; the creek has dried up between July and October every year between 1986 and 1989 (Ott, 1990). In addition, low population levels of anadromous salmonids in the Sacramento River, the source of spawners for Middle Fork Cottonwood Creek, are believed to contribute to the lack of use of the project area.

The only impingement observed on the intake screens occurred in 1989, when 12 decomposed 5- to 6-inch-long lampreys were found on the sides of the screen after a major flow event caused debris buildup (Ott, 1990). Excessive debris buildup could increase fish impingement by increasing both approach and through-screen velocities at the remaining filtering surface of the screen. The air-burst screen cleaning system was subsequently modified to increase the air pressure and debris removal capabilities. Because screen monitoring has not been conducted since then, it is not known whether this modification will prevent further impingement. Improved screen cleaning, such that through-screen velocities are uniformly low, should help minimize future impingement.

5.2 Mitigation Benefits

5.2.1 Benefits to Fish Populations. Because no anadromous fish were observed near the project during the 3-year monitoring period and the preconstruction survey, there are no data to assess the adequacy of fish passage/protection facilities for anadromous species at the Arbuckle Mountain project. In the event that restoration of anadromous fish populations in the Sacramento River basin results in upstream migrants into Cottonwood Creek, FERC has reserved the right to require future monitoring of the fish passage/protection facilities at this project.

The ladder has been used by resident rainbow trout for both upstream and downstream passage. The cylindrical wedge-wire screens prevent entrainment of juvenile rainbow trout, and no impingement of trout on the screens has been observed. Because resident rainbow trout can complete their entire life cycle (i.e., grow and reproduce) within short stream reaches, it is not known whether passage around the Arbuckle Mountain diversion structure is needed to maintain the resident rainbow trout population in Middle Fork Cottonwood Creek. In any case the project does not appear to constitute a barrier to movement of this species. Although Cottonwood Creek appears to provide excellent adult trout habitat for much of the year, the scarcity of adult fish in preproject surveys indicates that other factors (e.g., high water temperatures, low stream flows during the summer) may be limiting resident trout populations (Payne, 1984).

5.2.2 Benefits to Fisheries. There are presently no benefits to anadromous fish from fish passage/protection facilities at the Arbuckle Mountain project as anadromous fish are not present to use the facilities. The passage/protection facilities may help maintain recreational fishing for resident rainbow trout, although only small numbers of adult trout were observed in preproject surveys. It is not known whether the upstream movement of adult trout is needed to maintain the population or the fishery, but limited observations of use of the fish ladder indicate that the diversion does not constitute a barrier to trout movements.

5.3 Mitigation Costs

5.3.1 Introduction. The mitigation cost analysis for the Arbuckle Mountain hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; an upstream fish passage/protection system section, discussing the upstream mitigation costs; a downstream fish passage/protection system section, discussing the downstream mitigation costs; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal correspondence and reports (Ott Water Engineers, Inc., 1988).

5.3.2 Cost Summary. The upstream and downstream mitigation costs for fish passage/protection at the Arbuckle Mountain hydroelectric plant include the costs of the fish ladder system used for upstream fish passage/protection and the eight cylindrical screens that provide downstream mitigation and protect fish from entering the penstock and turbines. Future mitigation activities are estimated to be limited to operations and maintenance functions, and it has been assumed that no significant variations in duties (or costs) will occur. The startup costs (capital and study) comprise the largest component of the mitigation costs at Arbuckle (Figure 5-5), and they will not be replicated in future years (Figure 5-6).

The total cost for upstream and downstream mitigation at Arbuckle Mountain is estimated at $233,300. Levelizing this cost over 20 years produces a levelized annual cost of $11,670. To show the mitigation costs as a function of plant size, the mitigation costs are computed against the annual generation. Arbuckle Mountain has been operated for a relatively short period of time in terms of hydroelectric plant-life, and the geographic area where the plant is located has been in a drought. The past few years of historical generation may provide a misleading long-term picture of mitigation costs in terms of costs per kilowatt-hour. For this reason (and because the data is available) the best estimate of probable long-term yearly average generation is to simulate yearly generation production based on the historical daily flow records from 1957 through 1980. The simulated yearly generation is estimated to be 904,000 kilowatt-hours. Based on this estimated generation of 904,000 kilowatt-hours and the levelized annual cost of $11,670, the cost for upstream and downstream mitigation is 12.9 mills per kilowatt-hour (Table 5-1). This is about 1.3 cents for every kilowatt-hour generated over 20 years at the Arbuckle Mountain plant.

5.3.3 Upstream Fish Passage/Protection. The largest cost component of the upstream mitigation costs is the Denil fish ladder system. Comprising the ladder, resting pools, attraction pipe, and the trash rack at the head of the ladder, the ladder system cost $34,000. The capital costs, together with the study and design costs for the ladder, comprised 83% of the upstream mitigation costs (Figure 5-7). The annual costs include 4 years of underwater fish surveys (preconstruction survey and 3 years of monitoring), performed from 1984 through 1990, and operations and maintenance duties (Figure 5-8).

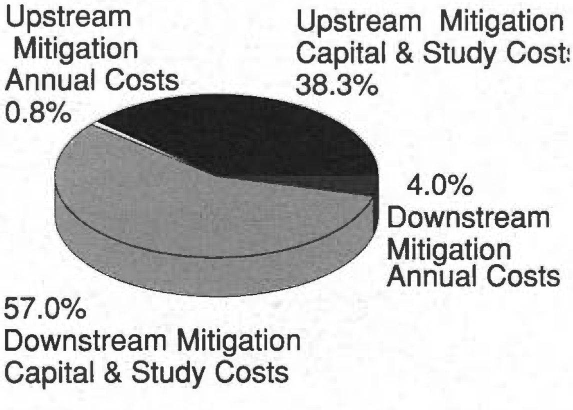


Figure 5-5. Total upstream and downstream mitigation costs at the Arbuckle Mountain project.

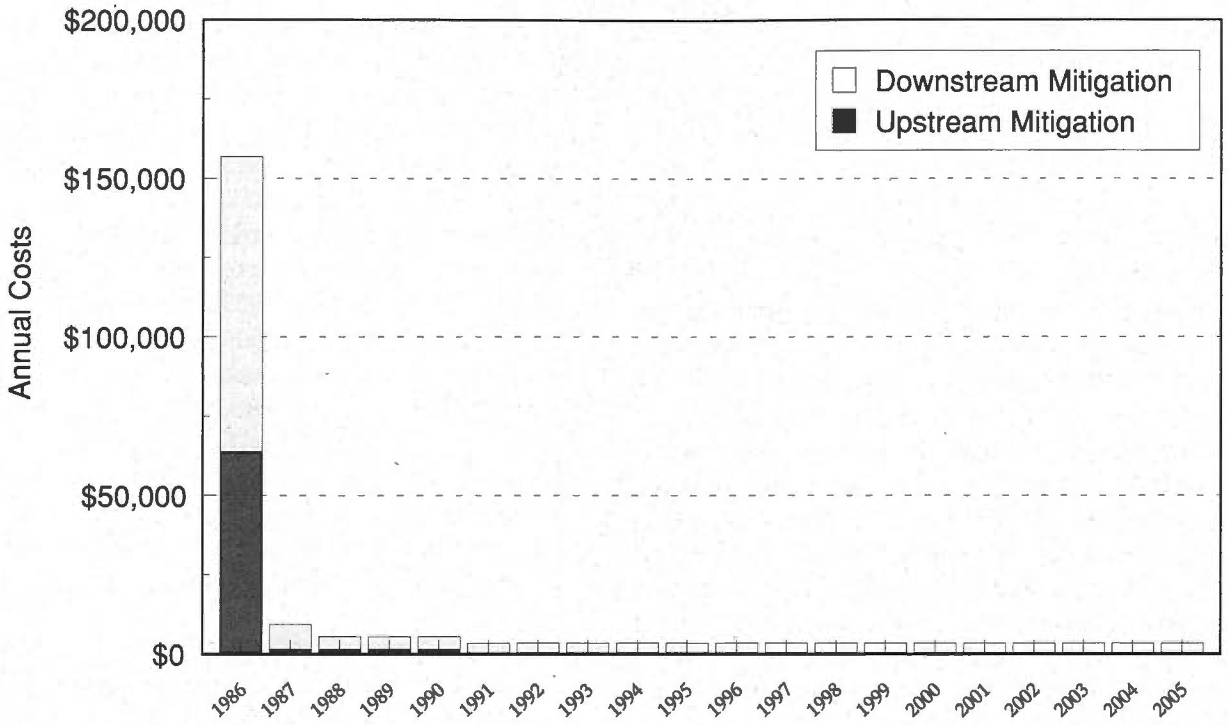


Figure 5-6. Yearly upstream and downstream mitigation costs at Arbuckle Mountain. Includes upstream and downstream mitigation.

Table 5-1. Twenty years of mitigation costs at Arbuckle Mountain for upstream and downstream mitigation.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Upstream	75,400	3,770	4.2
Downstream	157,900	7,900	8.7
Total costs	233,300	11,670	12.9

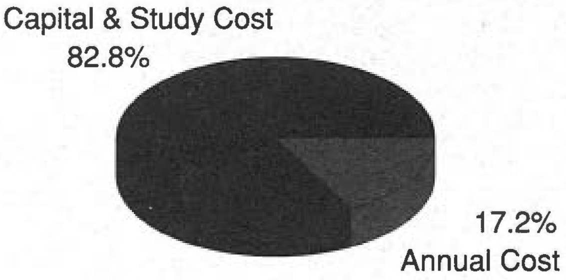


Figure 5-7. Arbuckle Mountain capital, study, and annual costs for upstream mitigation.

The upstream mitigation capital and study costs totaled $62,400 (Table 5-2). Levelizing this cost over 20 years results in a levelized annual cost of $3,120, and, based on the estimated annual average generation of 904,000 kilowatt-hours, the capital and study costs for upstream mitigation is 3.5 mills per kilowatt-hour.

The upstream mitigation related annual costs total $13,000. Levelizing this cost over 20 years suggests a levelized annual cost of $650, and, based on the estimated annual average generation

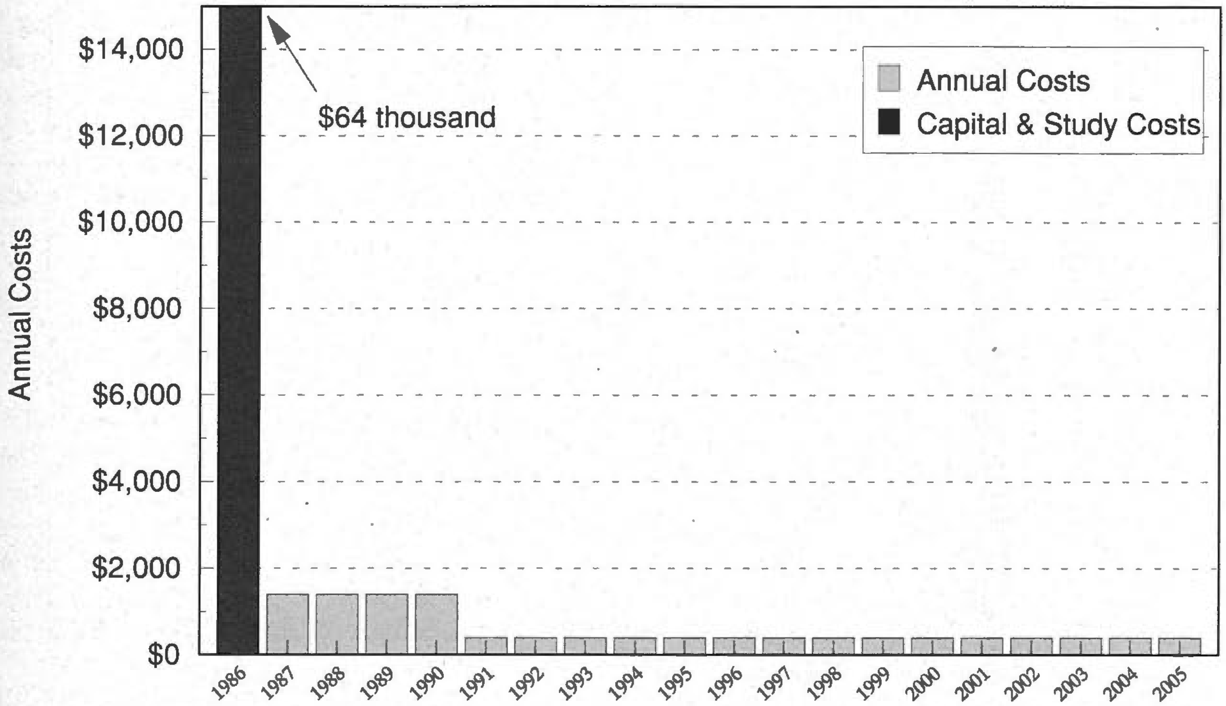


Figure 5-8. Yearly costs of upstream mitigation at Arbuckle Mountain. Includes capital, study, and annual costs.

Table 5-2. Arbuckle Mountain upstream mitigation total capital and annual costs.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital and study	62,400	3,120	3.5
Annual costs	13,000	650	0.7
Total upstream costs	75,400	3,770	4.2

of 904,000 kilowatt-hours, the annual cost of upstream mitigation is 0.7 mills per kilowatt-hour.

5.3.4 Downstream Fish Passage/Protection. The single largest cost component of downstream mitigation costs is the fish screen system capital cost. The studies associated with the design of the screen system and the capital cost to construct the screen system comprise 58.8% of all the downstream mitigation costs (Figure 5-9). This is reflected in the magnitude of startup costs (59%) as is seen in Figure 5-10.

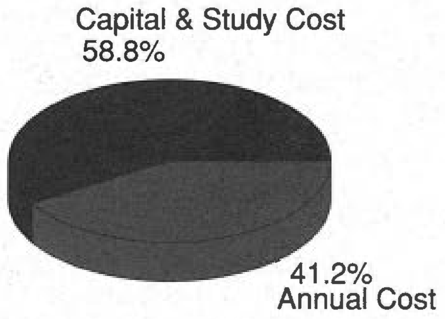


Figure 5-9. Downstream mitigation costs at Arbuckle Mountain. Includes capital, study, and annual costs.

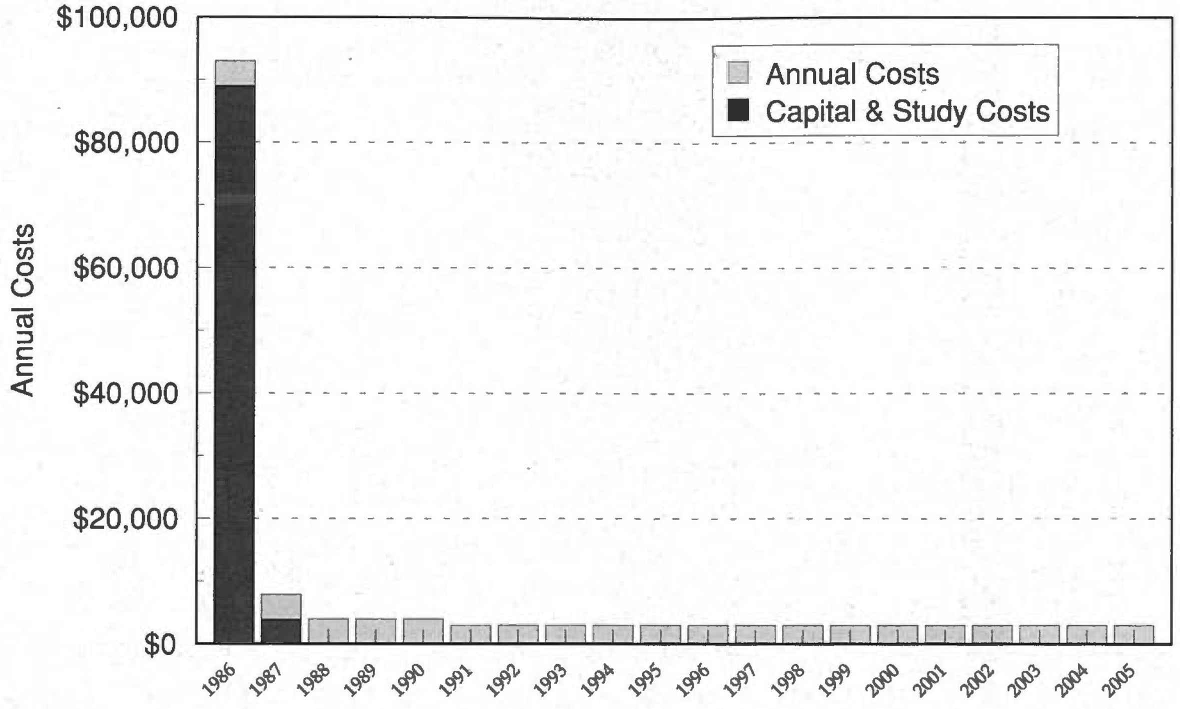


Figure 5-10. Yearly costs of downstream mitigation at Arbuckle Mountain. Includes capital, study, and annual costs.

The capital and study costs contribute 5.1 mills to the cost per kilowatt-hour for the mitigation costs at Arbuckle Mountain. The downstream mitigation annual operations and maintenance, and annual monitoring costs contribute an additional 3.6 mills to the mitigation costs per kilowatt-hour (Table 5-3).

The total downstream mitigation costs are primarily driven by the capital cost of the cylindrical screen system. The total cost for the eight screens, airburst cleaning system, and screen manifold is $78,700. The screen system encompasses 50% of the total 20-years of downstream mitigation costs. Including the licensing and design costs for the screen system, the nonannual costs of mitigation totaled 59% of the total downstream mitigation costs. The 20-year downstream mitigation capital and study costs totaled $92,900. The levelized annual cost is $4,650. With an estimated annual energy generation of 904,000 kilowatt-hours per year, the capital and study cost for downstream mitigation is 5.1 mills per generated kilowatt-hour of electricity.

The annual costs of downstream mitigation totaled $65,000. This includes the cost for 4 years of underwater surveys conducted by a fisheries biologist, and for 20 years of operations and

Table 5-3. Total Arbuckle Mountain downstream mitigation costs (cost totals for capital, study, and annual costs).

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital and study	92,900	4,650	5.1
Annual costs	65,000	3,250	3.6
Total downstream costs	157,900	7,900	8.7

maintenance costs for activities such as screen cleaning and maintenance of the airburst cleaning system. The 20 year total cost of $65,000 equates to a levelized annual cost of $3,250. Based on the estimated annual average energy production of 904,000 kilowatt-hours, the downstream mitigation annual costs total 3.6 mills.

5.4 Cost Descriptions and Assumptions

This section provides an explanation of the individual cost items and the assumptions and estimates required to quantify the cost items and derive cost totals. The item numbers correspond to the 20-year spreadsheet (Table 5-4) used to determine cost dimensions. All costs have been converted to 1993 dollars.

5.4.1 Capital Costs.

1. **UPM—Ladder, Resting Pools, Attraction Pipe & Trash Rack** (Upstream Mitigation—Fish Ladder, Resting Pools, Fish Ladder Attraction Pipe. and Draft Tube Trash Rack). A Denil type fish ladder (also called an Alaskan steeppass ladder) on a one-on-four slope is used. The ladder consists of 22- by 36-inch baffled sections on 10-inch centers. As the fish enter the ladder from the downstream end, the first section is 40 feet long and it leads to a four- by four-foot resting pond. From this resting pond. the fish travel upstream through a 20-foot section of the ladder and exit into the pool through a trash rack with bars set on six-inch centers. The ladder's operating range is from 3 to 7 cfs. The site has a minimum instream flow requirement of 5 cfs, which is normally maintained via the ladder. An attraction flow pipe was also constructed. The total height of the passage structure is 12 feet. The total cost of this facility was $34,000.

2. **DWM—Screens & Cleaning Equipment** (Downstream mitigation—Vertical Axis Cylindrical Wedge Wire Screens and Airburst Cleaning System). These cylindrical wedge wire screens (Figures 5-11 and 5-12) have approach velocities of 0.33 fps, with 0.094-inch openings and a wire width of 0.071-inch. They are 66-inches high by 33-inches in diameter. Each of the eight screens has an internal flow modulator consisting of a deflection cone cylinder within the screen cylinder to facilitate uniform velocities over the screen and to assist forcing the airburst to uniformly exit through the screen.

   The cleaning system uses compressed air to actuate the controls for the depth-sensing pressure transducers and to actuate the automatic shutoff valve in the penstock. A compressed air system for controls was used because electricity was not available at the headwords. The compressed air system proved more cost effective than electrical equipment, since the air system is easier to protect from floods than an electrical system. A 7.5 horsepower air compressor and storage tank is located in the powerhouse and a 150-gallon accumulator tank is located at the headwords to provide air to the pneumatically operated programmable controller. The airburst backwash system ensures less than a 0.2 foot of head loss across the screens, or the airburst system can be set to cycle continuously while under maximum operation and debris load, at varying airburst pressures. The airburst cycle commences with the most upstream screen, farthest from the diversion, and then sequentially cycles until it cleans the screen closest to the diversion. The accumulated debris on the screens is flushed off and moved downstream. The total installed cost for the screens and cleaning equipment was $34,000.

3. **DWM—Air Line.** This powerhouse-to-headwords airline for the airburst cleaning system was originally constructed of a PVC type material. Air leaks made it necessary to replace the line with a steel pipe. The original PVC airline cost is included as part of item number 2 above. The total cost to install the replacement steel airline pipe was $3,900.

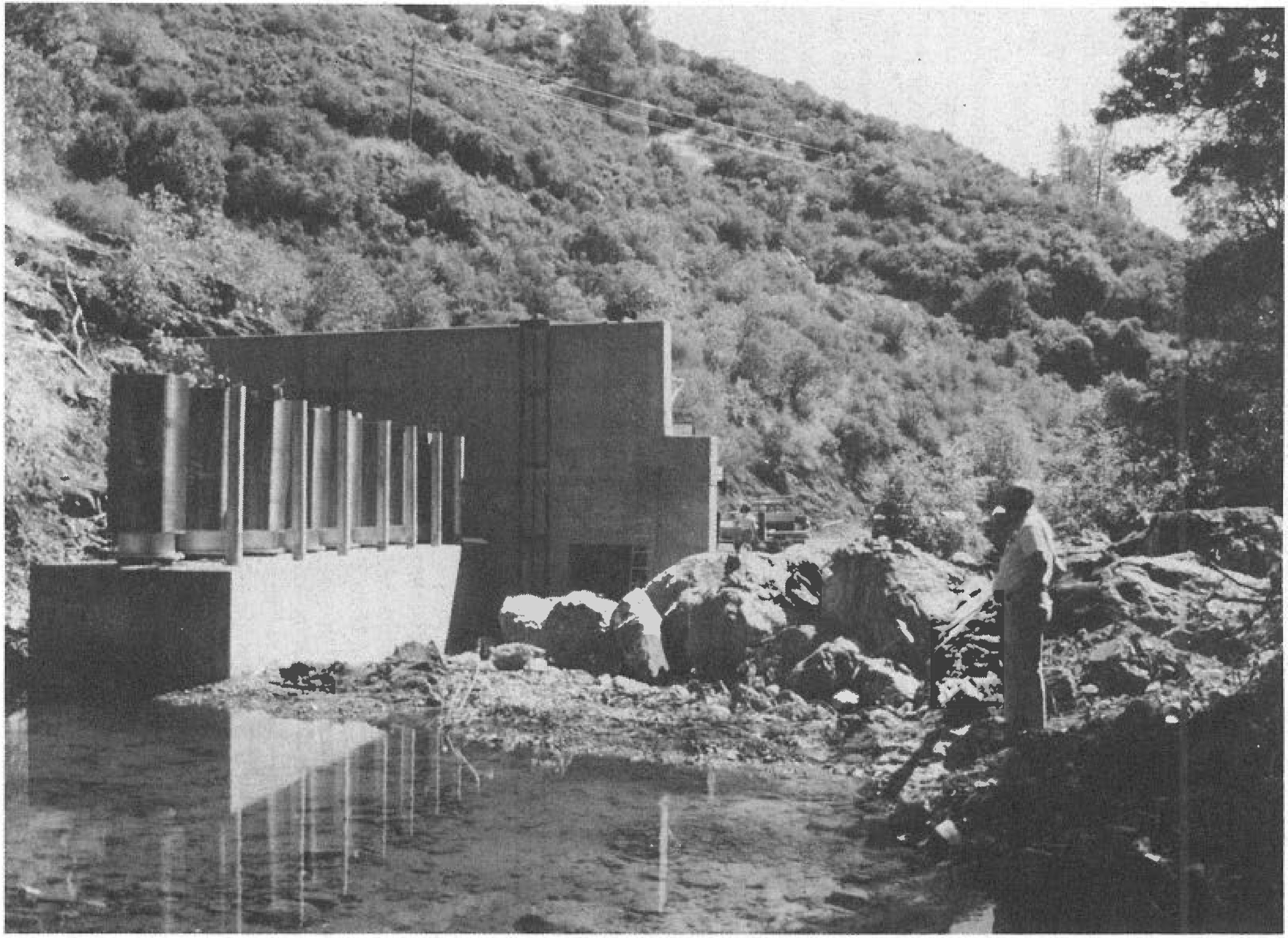


Figure 5-11. Arbuckle Mountain cylindrical wedge wire screens and screen manifold under construction.

Figure 5-12. Arbuckle Mountain cylindrical wedge wire screens under water.

4. **DWM—Screen Manifold.** This $40,800 cost is for the reinforced concrete manifold that supports the eight cylindrical wedge-wire screens. The concrete manifold box is 4-feet by 5-feet and 48-feet long. The box exits into a smooth transition that follows into the 60-inch penstock.

5.4.2 Study Costs.

5. **UPM—Licensing/Design ('85).** This $28,400 cost includes the fisheries surveys and studies required for the fish ladder. The cost includes additional activities such as agency meetings and approval of the fish ladder design. The resource agencies involved included the California Department of Fish and Game, United States Fish and Wildlife Service, National Marine Fisheries Service, the United States Bureau of Land Management, and several others.

6. **DWM—Licensing/Design ('85).** The $14,200 cost includes the fisheries surveys and studies, and agencies' approval (agencies mentioned in above Item 5) of the screen system plans.

5.4.3 Annual Costs.

7. **UPM—Monitoring & Reporting.** The licensee reports an annual cost of $1,000 for a fisheries biologist to perform monthly observations (January–April) by swimming the project reach, conducting an underwater survey, and documenting the observations. This activity was a licensing condition and was performed, as required, through 1990.

8. **UPM—Operations & Maintenance.** The estimated annual cost of $400 includes the cleaning of the trash rack at the head of the fish ladder, the adjustment of the outlet weir boards, any adjustment of the attraction flows, and the cleaning and painting of the ladder.

9. **DWM—Monitoring & Reporting.** The licensee reports an annual cost of $1,000 for a fisheries biologist to annually swim the project reach, conduct an underwater survey, and document the observations. Underwater surveys included observations of the fish screens for fish impingement. The screens were also inspected by the plant operator. This activity was a licensing condition and was performed, as required, through 1990.

10. **DWM—Operations & Maintenance.** The estimated annual cost of $3,000 includes the cost of the plant operator manually cleaning the cylindrical screens, the electrical cost of running the air compressor, and the maintenance of the airburst system.

5.4.4 Other Revenue Losses. This project has a minimum instream flow requirement of 5 cfs in the bypass reach and it is spilled via the fish ladder. Because this ladder spill is a minimum instream flow requirement it has not been included as a lost generation cost of fish passage/protection. The energy equivalent formula is:

5 (cfs) × 3 (kw/cfs) × 30 (days/month)

× 24 (hours/day) × 6 (months)

= 64,800 kWh.

This equates to a lost generation value of $5,000 a year. Again, this cost is considered as an instream flow cost and is not included as a cost of mitigation at this project.

Table 5-4. Arbuckle Mountain mitigation costs.

Arbuckle Mountain Project—Mitigation Cost Analysis—All Values in 1993 Dollars

12/20	–7	–6	–5	–4	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	10	11	12	
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	TOTALS
Capital Costs																					
1) UPM—Ladder, Resting Pools, Attraction Pipe & Trash Rack	$34,000																				$34,000
2) DWM—Screens & Cleaning Equipment	$34,000																				$34,000
3) DWM—Air Line		$3,900																			$3,900
4) DWM—Screen Manifold	$40,800																				$40,800
Study Costs																					
5) UPM—Licensing/Design ('85)	$28,400																				$28,400
6) DWM—Licensing/Design ('85)	$14,200																				$14,200
Annual Costs																					
7) UPM—Monitoring & Reporting	$1,000	$1,000	$1,000	$1,000	$1,000																$5,000
8) UPM—Operations & Maintenance	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$8,000
9) DWM—Monitoring & Reporting	$1,000	$1,000	$1,000	$1,000	$1,000																$5,000
10) DWM—Operations & Maintenance	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$60,000
Subtotal UPM Capital & Study Costs	$62,400	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$62,400
Subtotal UPM Annual Costs	$1,400	$1,400	$1,400	$1,400	$1,400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$13,000
Subtotal UPM—All Costs	$63,800	$1,400	$1,400	$1,400	$1,400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$400	$75,400
Subtotal DWM Capital & Study Costs	$89,000	$3,900	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$92,900
Subtotal DWM Annual Costs	$4,000	$4,000	$4,000	$4,000	$4,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$65,000
Subtotal DWM—All Costs	$93,000	$7,900	$4,000	$4,000	$4,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$157,900
Total Expenses—1993 Dollars	$156,800	$9,300	$5,400	$5,400	$5,400	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400	$3,400	$233,300

Notes: 4.5% Index rate used to present values as 1993 dollars
UPM = Upstream Mitigation
DWM = Downstream Mitigation
Subtotal UPM Capital & Study Costs includes items: 1 & 5
Subtotal UPM Annual Costs includes items: 7 & 8
Subtotal DWM Capital & Study Costs includes items: 2, 3, 4 & 6
Subtotal DWM Annual Costs includes items: 9 & 10

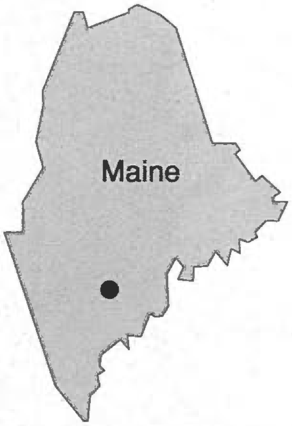
6. BRUNSWICK CASE STUDY

6.1 Description

Brunswick, a run-of-river project with a 39-foot head, is the first of a series of 40 dams on the Androscoggin River in Maine and New Hampshire (Figure 6-1). The Brunswick site (FERC number 02284) was initially developed by the Androscoggin Pulp Company in 1895. It was acquired by the Brunswick Light and Power Company in 1908, and three generating units were installed; a fourth was installed in 1911. A new dam and powerhouse (Figure 6-2) was approved at relicensing in 1979 and completed in 1982, having a three-unit combined capacity of 19.7 megawatts. The project has a total discharge capacity of 9,880 cfs, an average powerhouse flow of 4,000 cfs, and generates 105,200 megawatt-hours per year.

6.1.1 Fish Resource Management Objectives of Mitigation. Upstream and downstream fish passage/protection measures were incorporated into redevelopment when the project was relicensed in 1979. Upstream fish passage/protection is accomplished by a 500-foot-long, 42-step, vertical slot fish ladder, with a fish counting window and fish trap on the south abutment adjacent to the powerhouse (Figure 6-3). Each pool is 10 feet long by 8.5 feet wide, having a floor slope of 6 degrees, a slot width of 11 inches, and a drop per pool of 12 inches. Attraction flow is 100 cfs (30-cfs fishway plus a 70-cfs supplement), and entrance jet velocity is 4 to 6 fps. After traversing the fishway, the fish enter a 50-foot-long by 8-foot-deep holding area where they are crowded into a hopper, and species targeted for upstream transport are netted and placed in truck-mounted tanks. Fish are transported upstream May through November for placement in the river below Lewiston Falls. Design capacity is to assist 1,000,000 alewife and 85,000 American shad per year.

Downstream fish passage/protection is facilitated by a steel pipe through the dam between Units 1 and 2. Initially operated in 1983, the 18-inch-diameter pipe flows 50 cfs during the migration season between June 15 and the end of November. Species assisted are alewife, American shad, and Atlantic salmon.



The present program (Maine Department of Marine Resources 1983) for the lower Androscoggin River emphasizes the reestablishment of American shad and alewife anadromous fish runs upstream to their historic spawning habitat in the watershed below Lewiston Falls. Fish are stocked in upriver areas depending on the numbers and species entering the fishway and trap at Brunswick. Maximum use is to be made of remnant stocks of fish in the river before fish from other rivers are introduced. The program calls for stocking from other rivers if less than 10,000 alewives or 100 shad are available from the Androscoggin River for upriver stocking. The program sets stocking rates in the lower Androscoggin River and its tributaries at 58,800 alewife maximum and 85,000 American shad maximum, with a minimum of 150 American shad. The following paragraphs detail the objectives of the fisheries management program for each fish species.

6.1.2 Alewife. When the initial details of the program were established in 1983, the Maine Department of Marine Resources estimated that the long-term annual alewife yield from the Androscoggin River watershed could be 100 to 200 pounds per acre. Based on the alewife habitat surveyed by the Maine Department of Marine Resources, the long-term yield was estimated to range from 700,000 to 1,400,000 pounds annually.

In 1992, the Maine Department of Marine Resources' refined and updated plan stated that

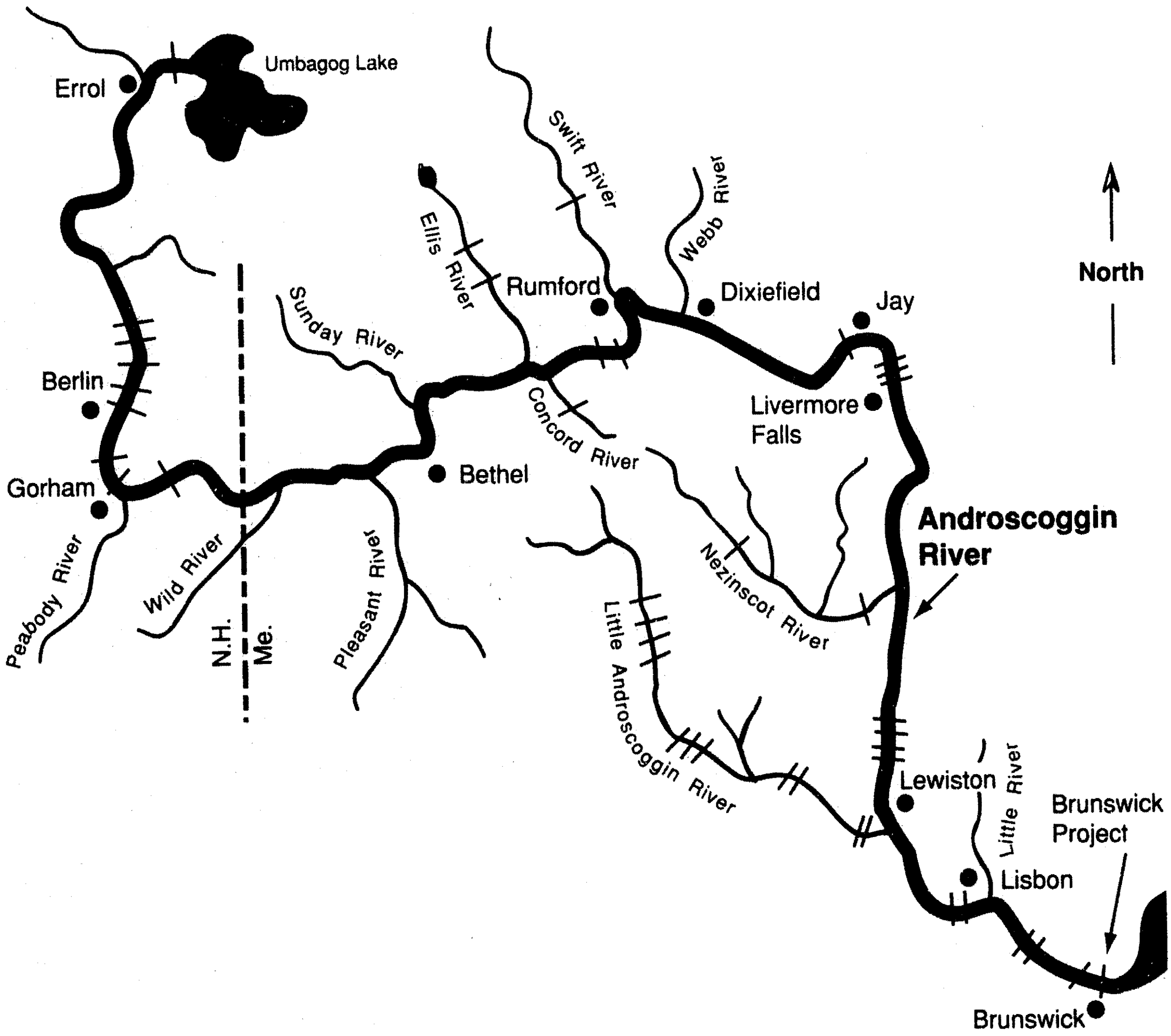


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Figure 6-1. Androscoggin River basin and location of the Brunswick project. The Brunswick project is located on the main stem of the Androscoggin River, at the bottom right corner. The small dashes perpendicular to the rivers are dam sites.

the results expected from the program were to develop a sustained commercial yield of 1,000,000 pounds of alewife annually (Table 6-1).

6.1.3 American Shad. In the initial restoration plan (1983), the Maine Department of Marine Resources estimated the long-term commercial yield of American shad could be 350,000 pounds annually. This projection was based on the following assumptions: (a) production of 2.3 adult fish per 100 square yards of suitable riverine surface water, (b) approximately 8,700,000 square yards of suitable riverine surface water habitat available for adult shad production, (c) an average weight of 3.5 pounds per fish, and (d) a 50% exploitation rate. It was also surmised that a sport fishery for shad could provide thousands of additional hours of recreational fishing to the area, with its attendant spinoff revenue. The Maine Department of Marine Resources' refined and updated plan of 1992

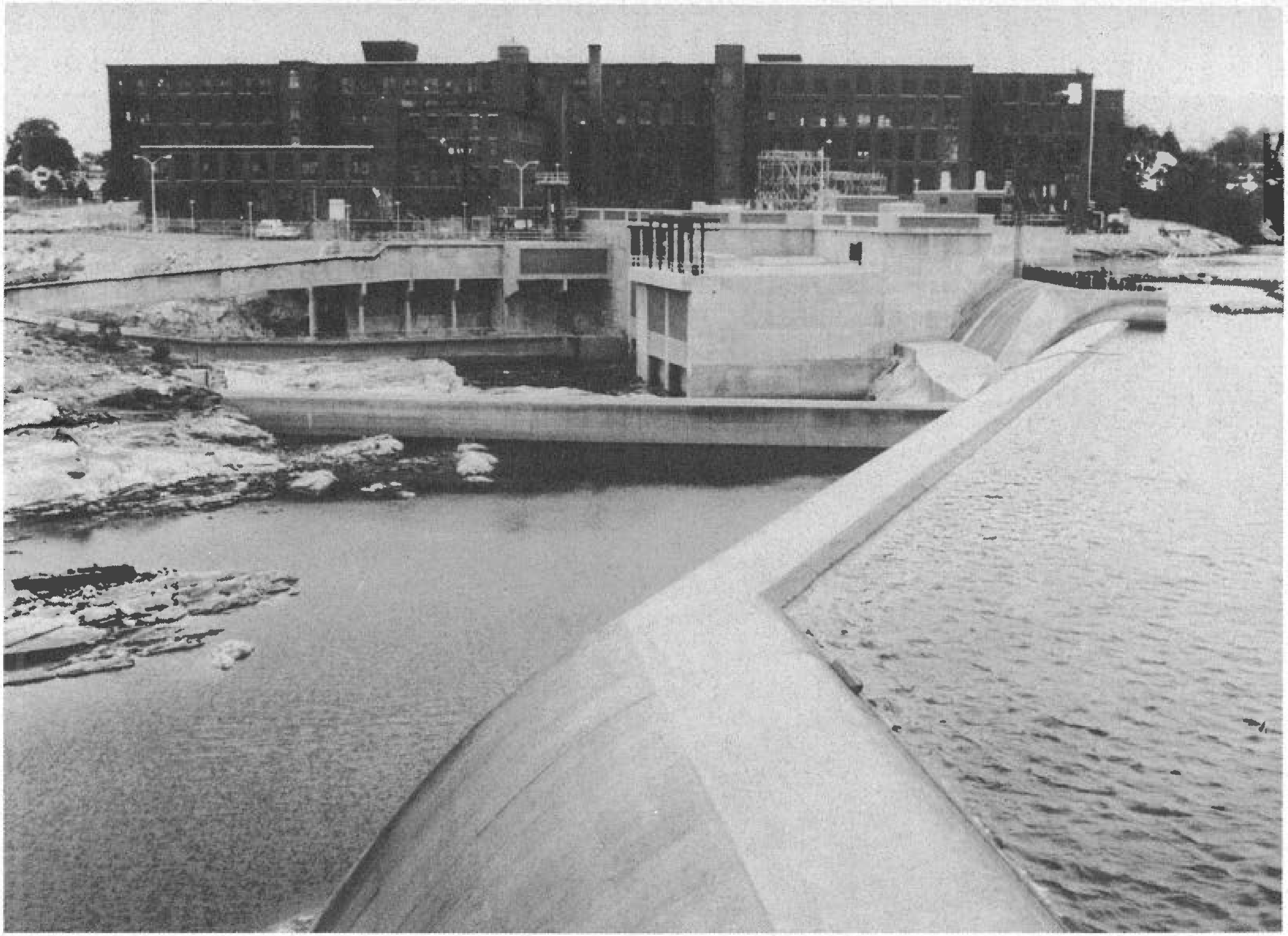

Figure 6-2. Side view of Brunswick fish ladder with dam in foreground, powerhouse, and fish ladder. Older industrial building is in the background.

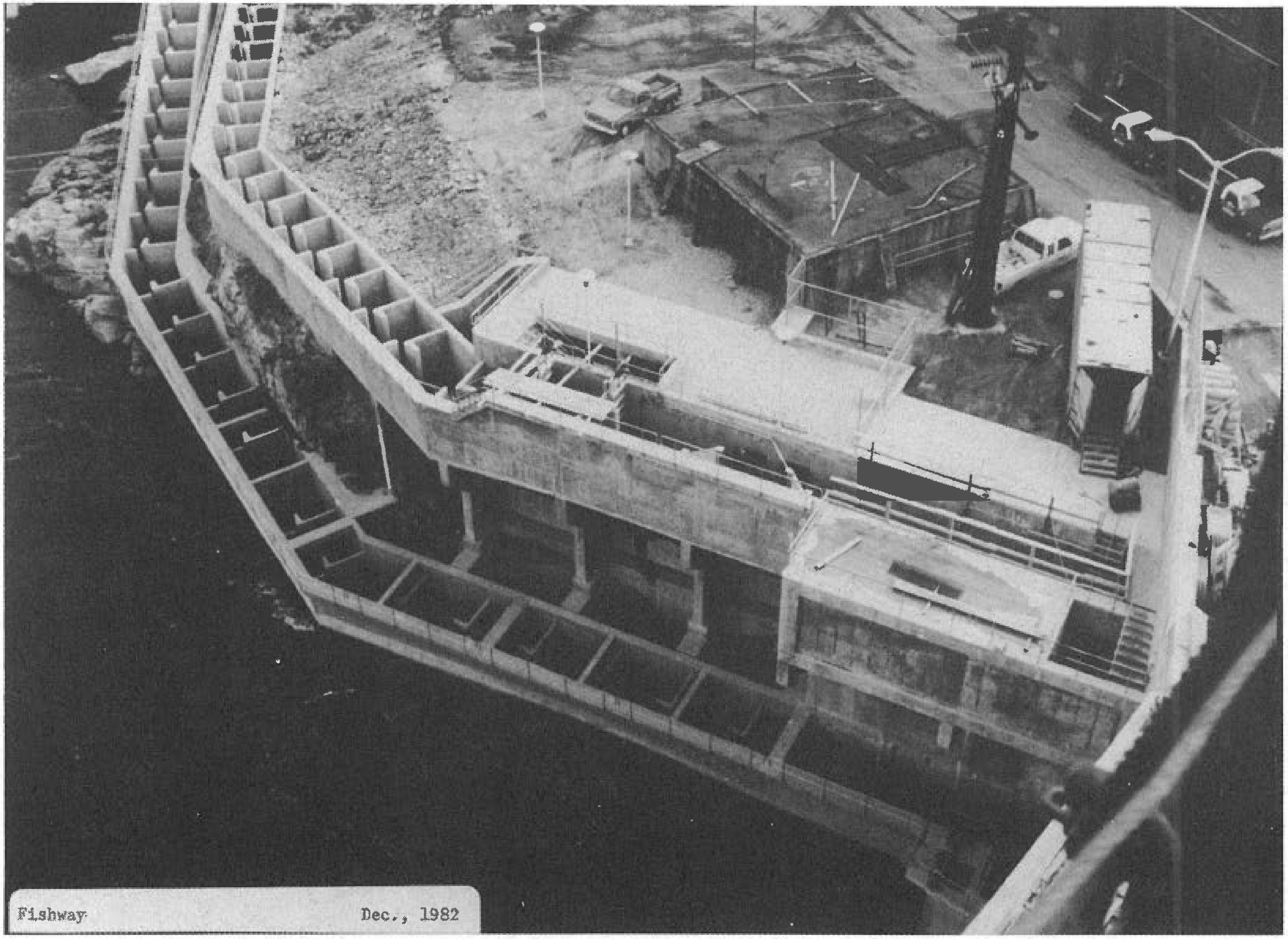

Figure 6-3. Overview of Brunswick fish ladder under construction. Ladder entrance is at the bottom right.

Table 6-1. Objectives of the Androscoggin River anadromous fish restoration program. The objectives of this program are to restore American shad and alewife run to historical spawning areas of the river.

Species	Sustained commercial yield
Alewife	1,000,000 lb/year
American shad	500,000 lb/year
Atlantic salmon[a]	1,000 salmon/year

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a. The program objectives did not provide detailed goals for restoration of Atlanta salmon. To compute the benefits of the fishway for Atlantic salmon, an analysis was conducted using Maine Department of Inland Fisheries and Game assumptions to estimate the theoretical maximum number of salmon that could be produced and returned to Brunswick each year under the most favorable conditions. The Department of Inland Fisheries and Game estimated this number to be about 1,000 per year. The value is based on the following assumptions:

- All 18,100,000 square yards of nursery habitat in the basin is available to the salmon and is used to its full potential to produce two salmon/ per square yard
- Low water pollution exists throughout the river basin
- Fishways are constructed at all 22 main stem dams on the Androscoggin River
- There is a 10% average loss of fish moving through each of the 22 main river dams
- There is a 5% average loss at each of the 18 remaining dams in the river basin
- There is a 2% ocean survival rate.

states that the results expected from the program are to develop a sustained annual commercial yield of 500,000 pounds of American shad (Table 6-1).

6.1.4 Salmonid and Incidental Species. The plan states that the salmonid species of Atlantic salmon and brook trout taken in the trap were to be used in accordance with the joint management recommendations of the Atlantic Sea Run Salmon Commission, the Department of Inland Fisheries and Wildlife, and the Maine Department of Marine Resources. No specific management objectives for these species are stated. However, in order to valuate maximum projected program benefits, the maximum theoretical number of salmon that could return to Brunswick each year was estimated. This maximum value, estimated to be 1,000 salmon per year, was computed using published Maine Department of Marine Resources assumptions and analyses performed in the past (Table 6-1).

Incidental species that occur in the lower Androscoggin River include Atlantic sturgeon, shortnose sturgeon, and blueback herring. It was anticipated that neither sturgeon species would use the fish ladder. However, any fish of either of these species that did enter the trap at Brunswick were to be stocked upriver in the main river stem below Lewiston Falls. Blueback herring would be allowed to pass through the ladder directly into the Brunswick headpond unless large numbers entered the trap. In the event that large numbers moved through the project, distribution of this species to suitable river habitats would be initiated.

6.1.5 Undesirable Species. The plan also recognized that carp and sea lamprey are present in the tidal portion of the Androscoggin River and that both of these species are known to cause adverse effects to freshwater and anadromous fish populations. Any fish of these two species entering the trap are to be removed, killed, and disposed of through local commercial fishermen or other commercial outlets, and a plan to generate a larger commercial demand for these species will be initiated in the event that large numbers are present.

6.1.6 Commercial Regulation. The plan states that the commercial fish catch is to be regulated as necessary based on the annual data obtained from the Brunswick fishway and trap. This task will help prevent overfishing and aid in the establishing the sustained yields targeted in the plan.

6.1.7 Monitoring Methods. The monitoring program provided by the plan is to determine (a) the timing, magnitude, and year-class strength of alewife and shad ascending the Androscoggin river, and (b) the mean size of juvenile emigrant, alewife and reproductive success of shad in selected waters of the Androscoggin River above tidewater.

The monitoring program comprises the following steps. American shad and alewife are identified by species and counted as they pass through the Brunswick fish counting station during the migration season (the count is recorded daily). As they ascend the fishway, the fish are then trapped. Fifty shad and alewives per week (as available) are killed to determine weight, length, sex, and age data. Water temperature and river flow conditions are recorded daily for later correlation with fish migration behavior.

Samples of juvenile shad are obtained monthly in the summer and fall from nursery areas. A shad index based on catch per unit effort is then developed to determine relative abundance of the year-class produced. American shad collected at the Brunswick fishway are trucked upstream to suitable spawning areas. The restoration program calls for a minimum of 500 adult shad to be stocked upriver in an attempt to rebuild the depleted stocks in the Androscoggin River. When collections at Brunswick are less than 500, prespawner adult shad collected at the Holyoke fishway on the Connecticut River will be transported to the Androscoggin River for stocking above Brunswick. Collection of prespawner adult shad from other suitable river habitat sites within Maine for transport to the lower Androscoggin River will also be attempted.

Samples of juvenile alewife are collected at selected lake outlets in the summer and fall. These specimens are then measured to determine mean size. Adult alewives are collected and truck-stocked into lake spawning areas below Lewiston Falls. A minimum stocking density of six fish per acre for the 9,000+ surface acres of lakes and ponds in the lower Androscoggin requires 54,000 adult alewives. If insufficient alewife stocks are available at Brunswick, additional fish will be transported from the Royal River in Yarmouth.

6.1.8 Performance of Mitigation. Normally, the performance or effectiveness of the fishway would be assessed by comparing the numbers of fish passing through the fishway with the total numbers of fish that have moved upstream into the project tailrace during migration periods. Since no studies have been completed or are contemplated to determine the total number of fish moving upstream into the tailrace, the percentage of fish in the tailrace that are using the fishway each year (i.e., the effectiveness of the fishway) cannot be determined. Therefore, reports prepared by the Maine Department of Marine Resources (operator of the fishway) are the only evidence of operating efficiency.

Annual reports prepared by Maine Department of Marine Resources concerning the operation of the Brunswick fishway indicate that the operation of the fishway in each year since 1983 has been nearly trouble-free. Constant removing of debris during operation (for both upstream and downstream facilities) is the primary complaint. Maintenance and replacement of mechanical parts is an ongoing task. Minor modifications and adjustments have been made a number of times in the past 9 years to improve operations, but no major breakdowns or malfunctions are reported.

6.2 Mitigation Benefits

6.2.1 Benefits to Fish Populations. A number of factors were reviewed, assessed, and compared in order to evaluate the benefits of the program to date in meeting the stated program objectives. For each year from 1987 through 1992, the actual numbers of fish returning to Brunswick and passing through the project fish ladder, and the number of fish trapped/trucked and stocked upriver, were documented (Tables 6-2 and 6-3); thus, the numbers of fish returning to Brunswick each year can easily be compared with the numbers returning from each previous year to determine if the actual return numbers are increasing, both annually and over the long term (Table 6-2).

Table 6-2. Number of alewife and American shad trucked and stocked above Brunswick (1987–1992).[a,b,c]

Species	1987	1988	1989	1990	1991	1992
Alewife	25,772	34,945	42,165	55,357	24,051	20,339
American shad	92	513	414	354	357	566

a. These values were obtained from various Maine Department of Marine Resources publications and supplemented with preliminary 1992 data from the Department of Marine Resources. (Maine Department of Marine Resources 1992, 1990, January 1992 (a,b).

b. All alewife trucked and stocked upriver were taken at the Brunswick fishway.

c. In 1987, all shad trucked and stocked upriver were taken from the Merrimack River. In 1988–1992, all shad trucked and stocked upriver were obtained from the Connecticut River (except the lone shad that returned to Brunswick in 1990—see Table 6-3).

Table 6-3. Number of alewife, American shad, and Atlantic salmon passed upstream through the Brunswick fishway (1987–1992).[a]

Species	1987	1988	1989	1990	1991	1992	Average
Alewife	63,523	74,341	100,895	95,574	77,511	47,000	76,500
American shad	—	—	—	1	—	—	—
Atlantic salmon	27	14	19	185	21	17	50

a. These values were obtained from a number of Maine Department of Marine Resources publications and supplemented with preliminary 1992 data from the Department of Marine Resources. [Maine Department of Marine Resources 1984, 1991, 1992, 1990, January 1992 (a,b)].

The results of the program are summarized to date. At least 10,000 alewife were available at the Brunswick fishway each year from 1987 through 1992 for trapping and trucking upriver. Therefore, the minimum number of remnant stock were available from Brunswick to meet the program requirements without stocking from other rivers (Table 6-2).

Only one shad passed through the Brunswick fishway during the past 6 years. Thus, all shad trucked and stocked into the lower Androscoggin River over these 6 years, except one (in 1990), were taken from either the Merrimack or Connecticut Rivers (Table 6-2).

Comparing 1987 data with 1989 data, the number of alewife passing through the Brunswick fishway increased by almost 60%. Comparing 1989 data with 1992 data, the total number of alewife passing through the fishway declined by almost 50%. Alewife passing through the Brunswick fishway in 1992 numbered 25% less than those passing in 1987 (Table 6-3).

In 1987, 1988, 1989, 1991, and 1992, the number of Atlantic salmon passing through the fishway varied between 17 and 27 annually. In 1990, 185 salmon passed through Brunswick (Table 6-3).

In addition to the analysis of fish returns, the fishway design population was documented (Table 6-4); the annual runs of each species necessary to sustain the targeted commercial yields of the restoration program were estimated

Table 6-4. Estimated annual returns to the Brunswick fishway necessary to sustain targeted commercial yields.[a,b,c,d]

Species	Estimated annual runs necessary to sustain targeted commercial yields	Fishway design population (annual run)
Alewife	3,300,000	1,000,000
American shad	286,000	85,000
Atlantic salmon	1,000	—

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a. Alewife—based on an exploitation rate of 50% (the rate the Department of Marine Resources assumed for American shad) and a program goal of 1,000,000 lbs/year sustained commercial yield, the total weight of alewife returning to the river each year must be 2,000,000 lbs. Assuming that returning alewife were adults weighing 0.6 lbs per fish, then 3,300,000 fish would be required to return annually (Maine Department of Marine Fisheries 1984, 1992).

b. American shad—the Department of Marine Resources has assumed an average wight of 3.5 lbs/fish for American shad and a 50% annual exploitation rate in recent analyses. Therefore, 1,000,000 lbs of American shad (or 2 × 500,000 lb) need to return annually to sustain a 500,000 lbs annual commercial yield. Based on 3.5 lbs/fish, the 1,000,000 lb required return would be equivalent to 286,000 shad per year (Maine Department of Marine Fisheries 1984).

c. Atlantic salmon—the program objectives did not provide detailed goals for Atlantic salmon restoration. The maximum number of salmon that could theoretically return to Brunswick (1,000 per year) was estimated to help predict fishway benefits for Atlantic salmon (Table 6-1). This value is based on recent Department of Marine Resources assumptions and analyses (Maine Department of Inland Fisheries and Game 1967).

d. The total annual fish population runs of alewife (1,000,000 per year) and American shad (85,000 per year) used as the basis for the design of the fishway are only about one-third of the runs for both alewife and American shad that are estimated as necessary to sustain the targeted commercial yields of the program (Chas. T. Main, Inc. Engineers 1977).

(Table 6-4); and the results of these two reviews were compared to determine if there was any discrepancy between the program objectives and the design capacity of the fishway. As Table 6-4 reveals, the total annual runs of alewife and shad used as the fishway design criteria are only about one-third of the runs of both alewife and shad estimated to be necessary to sustain the targeted commercial yields of the program.

6.2.2 Conclusions. There has been a steady decline in alewife passing upstream through the Brunswick fishway in the past 4 years (Table 6-3).

American shad have not established a presence in the lower Androscoggin River over the past 10 years of fishway operation (Table 6-3).

Fewer Atlantic salmon passed through Brunswick in 1992 (17) than in all but one of the previous 5 years (Table 6-3). With 14 returns, 1988 had the fewest returns in the past 6 years.

Minimum annual fish runs estimated to be necessary (Table 6-4) to achieve sustained target commercial yields (Table 6-1) are more than triple the annual design population capacity (annual fish run capacity) of the fishway for both alewife and American shad (Table 6-4).

6.3 Mitigation Costs

6.3.1 Introduction. The mitigation cost analysis for the Brunswick hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal correspondence, telephone calls, and a site visit that greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

6.3.2 Cost Summary. The annual mitigation costs at Brunswick were not obtainable broken into upstream and downstream mitigation methods. Total mitigation costs for both upstream and downstream passage/protection are discussed together. The Brunswick fish passage/protection mitigation costs (fish ladder and downstream bypass pipe) totaled $7,778,000 for the 20-year analysis period. The costs per kilowatt-hour, based on a reported annual generation of 105,200,000 kilowatt hours, is 3.7 mills (Table 6-5) or about four-tenths of a cent. The major cost item (56%) is the capital cost of constructing the facilities (Figure 6-4). A bar graph of annual costs (Figure 6-5) shows that up-front costs were the most significant.

The 500-foot long, 42-step vertical slot fish ladder, and the trapping and holding facility at Brunswick cost $4.3 million. The construction cost for the bypass pipe was estimated to cost $250,000. Over the 20-year analysis period, the ladder facility and bypass pipe contributed 2.2 mills per kilowatt-hour to the cost per kilowatt-hour generated at Brunswick. The annual operations and maintenance costs and the annual reporting cost were estimated to be $36,000, or 0.3 mills per kilowatt-hour. The lost generation flows for upstream passage/protection through the ladder ($93,000) and for downstream passage/protection through the bypass pipe ($30,000) are estimated at $123,000 annually, or 1.2 mills per kilowatt-hour.

6.4 Cost Descriptions and Assumptions

This section provides an explanation of the individual cost items and the assumptions and estimates required to quantify the cost items and derive cost totals. The item numbers correspond to the 20-year spreadsheet (Table 6-6) used to determine cost dimensions. All costs have been converted to 1993 dollars.

6.4.1 Capital Costs.

1. **Upstream—fish ladder.** The vertical slot fish ladder, the holding and sorting areas, and the hopper used to capture adult upstream migrants for truck transportation past upstream dams is estimated to cost $4,348,000.
2. **Downstream—bypass pipe.** The construction cost of the downstream bypass pipe system was not available; the construction cost is a part of the entire power plant cost. However, based on engineering judgment and rudimentary construction indices, the bypass system cost is estimated at $250,000.

Table 6-5. Costs incurred at the Brunswick project for upstream and downstream mitigation. Because of rounding, columns may not equal totals.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital and study costs	4,598,000	230,000	2.2
Annual costs	720,000	36,000	0.3
Lost generation costs	2,460,000	123,000	1.2
Total costs	7,778,000	389,000	3.7

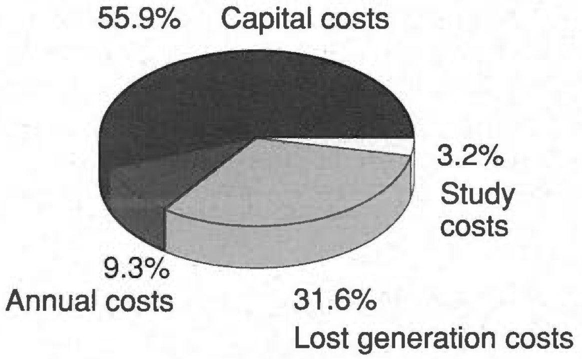

Figure 6-4. Total mitigation costs at the Brunswick project. Because of rounding, percents may not total 100%.

6.4.2 Annual Costs.

3. **Operations and maintenance.** The annual operations and maintenance costs associated with both the upstream and downstream passage/protection systems was estimated by the licensee at $33,000. The annual cost per kilowatt-hour is 0.3 mills.

4. **Annual reporting.** The annual reporting costs related to upstream and downstream passage/protection were estimated by the licensee to be $3,000. The annual cost per kilowatt-hour is 0.03 mills.

6.4.3 Lost Generation Costs.

5. **Upstream passage lost generation.** The fish ladder has continuous water releases of 100 cfs from May 1 through November 30 (214 days × 24 hours × 100 cfs = 513,600 cfs) and 30 cfs from December 1 through April 30 (151 days × 24 hours × 30 cfs = 108,720 cfs). Based on the project's annual power generation of 105,200,000 kilowatt-hours and the annual flows through the turbines of 4,000 cfs, the kilowatt-hour value per cfs of water is 3.0 kilowatt-hours/cfs [105,200,000/(4000 cfs × 365 days × 24 hours) = 3.0]. The actual power value is unknown so a per kilowatt-hour value of $0.05 is used to compute the lost generation cost for upstream fish

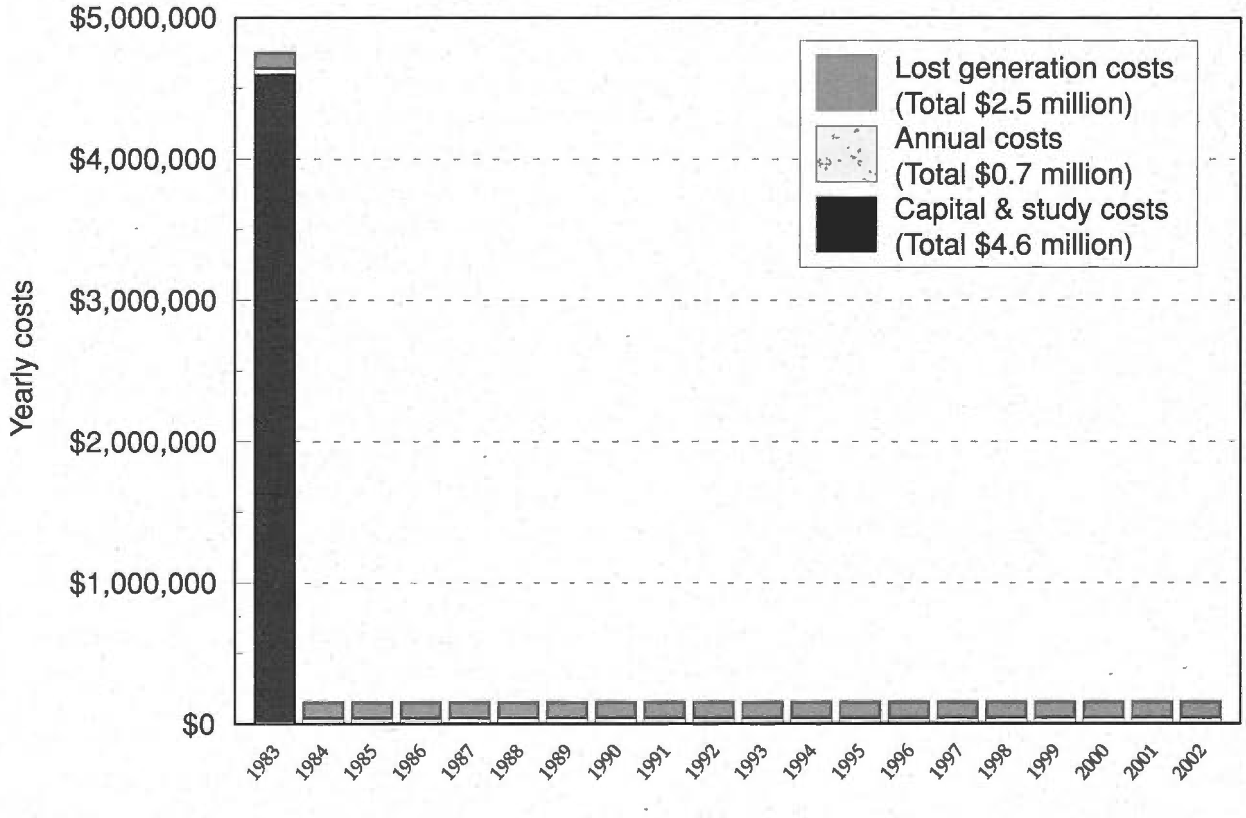

Figure 6-5. Yearly mitigation costs at the Brunswick project.

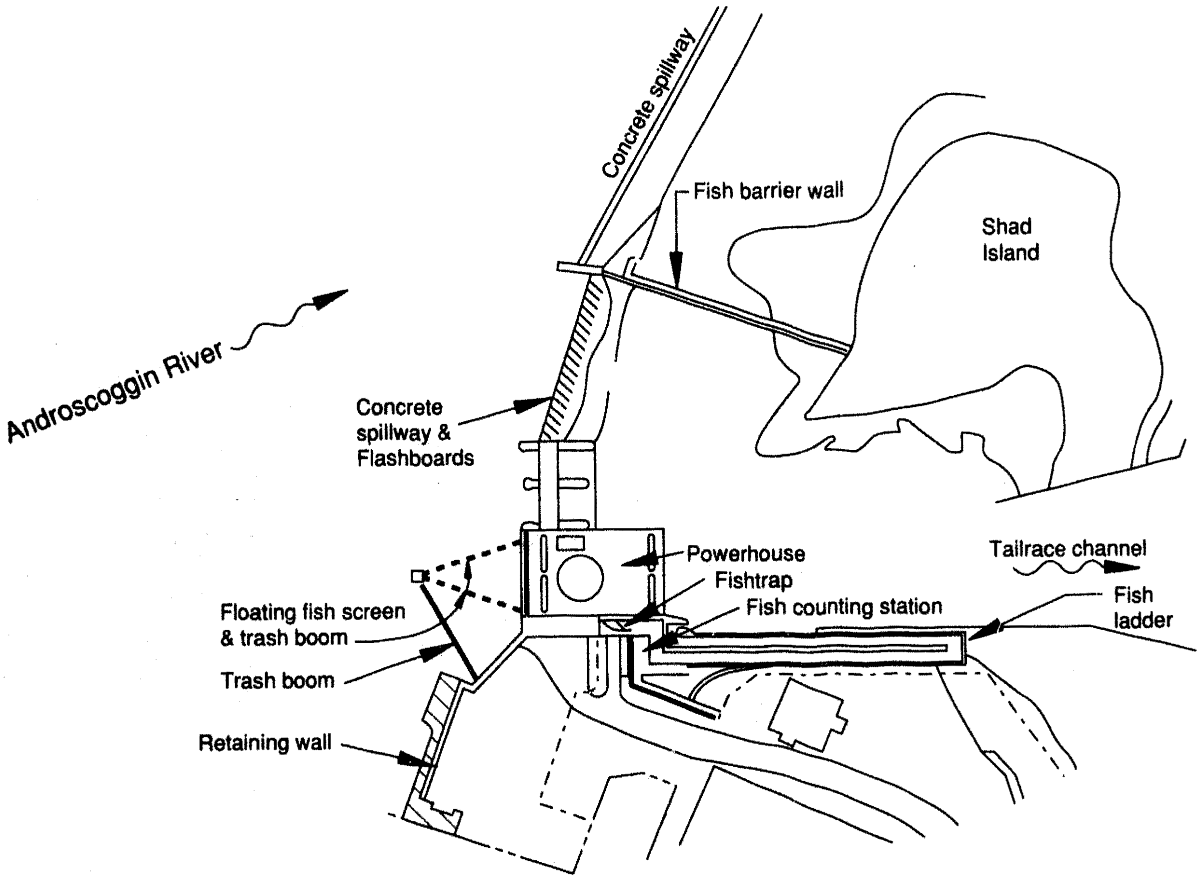

Figure 6-6. Overview of the Brunswick project.

passage/protection-related water releases of \$93,000 [(513,600 cfs + 108,720 cfs) × 3.0 kilowatt-hour/cfs × \$0.05 = \$93,348]. This is a per generated kilowatt-hour cost of 0.9 mills.

6. **Downstream passage lost generation.** Fifty cfs of continuous flows are released through the downstream bypass pipe from June 15 through November 30 (168 days × 24 hours = 4032 hours). Based on the per cfs of water value of 3.0 kilowatt-hours (discussed above) and the \$0.05 per kilowatt-hour assumption (discussed above), the cost of downstream mitigation-related lost generation is \$30,000 (4032 hours × 50 cfs X 3 kilowatt-hours/cfs × \$0.05 = \$30,240). This is a per generated kilowatt-hour loss of 0.3 mills.

6.4.4 Other Cost Considerations. The Maine Department of Marine Resources operates the trapping and hauling of adults on the Androscoggin River. The adult migrants are transported and released 22 river miles upstream from their collection at Brunswick. The state provided an estimated cost of \$150,000 for the trapping and hauling. It is unknown if this cost should be split with the other three sites that the fish are trucked past. The licensee does not pay this cost. This is a river basin system cost and the benefits are system wide, not limited to Brunswick. The intent of the cost analysis is to provide a picture of mitigation costs that a developer could encounter if a similar mitigation method were implemented. Thus, this study does not attribute the cost of trapping and hauling to Brunswick as an operations cost. If the developer did pay this \$150,000 cost, the cost per generated kilowatt-hour would be 1.4 mills.

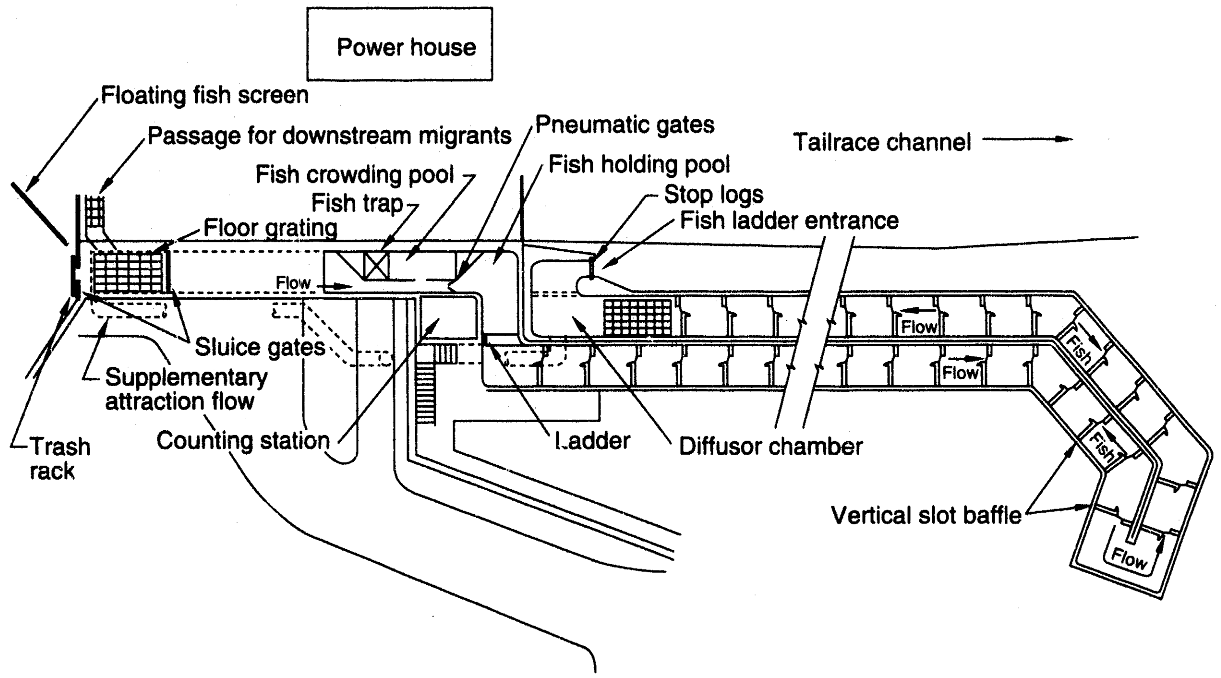

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Figure 6-7. Top view of the fish ladder at the Brunswick project.

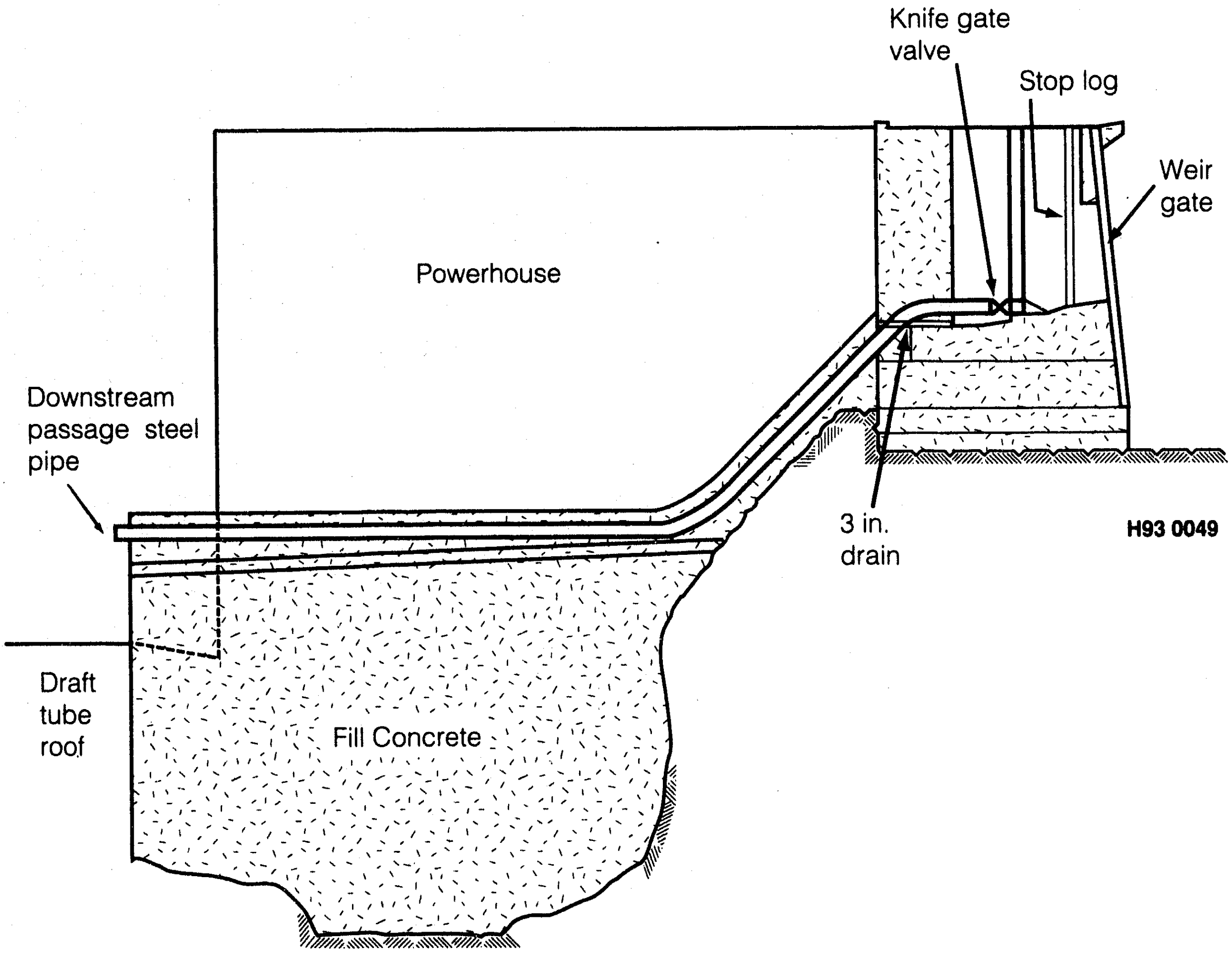

Figure 6-8. Side view of the Brunswick downstream fish bypass pipe. Downstream migrants enter the bypass pipe through the weir gate and exit to the left, above the draft tube roof.

Table 6-6. Brunswick mitigation costs.

Brunswick Project—Mitigation Cost Analysis—All Values in 1993 Dollars

9/08/93	–10	–9	–8	–7	–6	–5	–4	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	TOTALS
Capital Costs																					
1) Upstream—Fish ladder ('82)	$4,348,000																				$4,348,000
2) Downstream—Bypass pipe ('82)	$250,000																				$250,000
Annual costs																					
3) Operations and maintenance	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$33,000	$660,000
4) Annual reporting	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$60,000
Lost generation costs																					
5) Upstream passage lost generation	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$93,000	$1,860,000
6) Downstream passage lost generation	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$600,000
Subtotal capital & study costs	$4,598,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$4,598,000
Subtotal annual costs	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000	$720,000
Subtotal lost generation	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$123,000	$2,460,000
Total Expenses—1993 Dollars	$4,757,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$159,000	$7,778,000

Notes: 4.5% Index rate used to present values as 1993 dollars

7. BUCHANAN CASE STUDY

7.1 Description

The Buchanan project (FERC number 02551) is a run-of-river facility on the St. Joseph River in Berrien County, Michigan (Figure 7-1). The project has a total installed capacity of 4.1 megawatts and began operation in 1903. A 15-foot-high, vertical slot fish ladder (Figures 7-2 and 7-3) was completed in 1990 to allow the upstream migrations primarily of chinook salmon, steelhead trout, and incidentally, coho salmon and brown trout from Lake Michigan. The project has no screens to prevent turbine passage of downstream-migrating fish at this time. The project owners maintain a minimum 1-foot opening at the north crest gate during the peak migration period to provide an alternate route for downstream migrating smolts.

7.1.1 Fish Resource Management Objectives of Mitigation. The Buchanan project (Figure 7-4) is one of a series of dams on the St. Joseph River, each of which constitutes a barrier to upstream movement of anadromous and resident fish from Lake Michigan. A pool-and-weir style fish ladder was put into operation at the lowest dam on the river, Berrien Springs, in 1975. Since then, vertical slot fish ladders have been installed at Buchanan (1990), Niles (1991), South Bend (1988), and Mishawaka (aka Uniroyal; 1991). The primary objective of the fish ladders is to allow the passage of steelhead trout and chinook salmon from Lake Michigan up a 63-mile segment of the St. Joseph River as far as Mishawaka, Indiana. This will provide a sport fishery for anglers in densely urbanized areas of Michigan and Indiana.

Under the objectives of the St. Joseph River Interstate Fisheries project, the resource agencies are interested not only in passing large numbers of migratory fish upstream but also in distributing the fish throughout the St. Joseph River so that they are accessible to anglers over a wide area. As a result of this management goal, the agencies might choose to close fish ladders at certain times to prevent further upstream migrations if monitoring indicates that most of the fish are traveling all the way to the Twin Branch Dam, the uppermost limit for fish passage.

In addition to operation of fish ladders to encourage natural reproduction of migratory fish in the river, both Michigan and Indiana stock large numbers of hatchery-produced salmon and trout. The State of Michigan stocks 400,000 chinook salmon, 58,000 Michigan-strain (winter) steelheads, and 15,000 brown trout in the St. Joseph River annually. Indiana stocks 165,000 chinook salmon and 225,000 Skamania (summer) steelheads annually (Dexter, personal communication). All fish stocked by Michigan are placed below Berrien Springs. Returning adults from these fish would not be expected to try to ascend the river past Michigan ladders into Indiana, although some straying to upriver areas has been observed (Simms, personal communication).

7.1.2 Monitoring Methods. All five fish ladders on the St. Joseph River have facilities that enable fishery biologists to identify and count fish, although to date monitoring efforts have been limited to Berrien Springs, Niles, and South Bend. These sites were chosen to determine passage at the first ladder (Berrien Springs), the last ladder (Niles) before entering Indiana, and the first ladder (South Bend) in Indiana. Fish ladder counts have been conducted at the lowermost dam on the river, Berrien Springs, since 1978. The upper part of the Berrien Springs fish ladder was modified to allow videotaping or manual counting of fish through a viewing window and to allow for greater water level fluctuations in the forebay without affecting fish passage. Construction activities associated with these modifications resulted in incomplete fish ladder counts at Berrien Springs during September and early

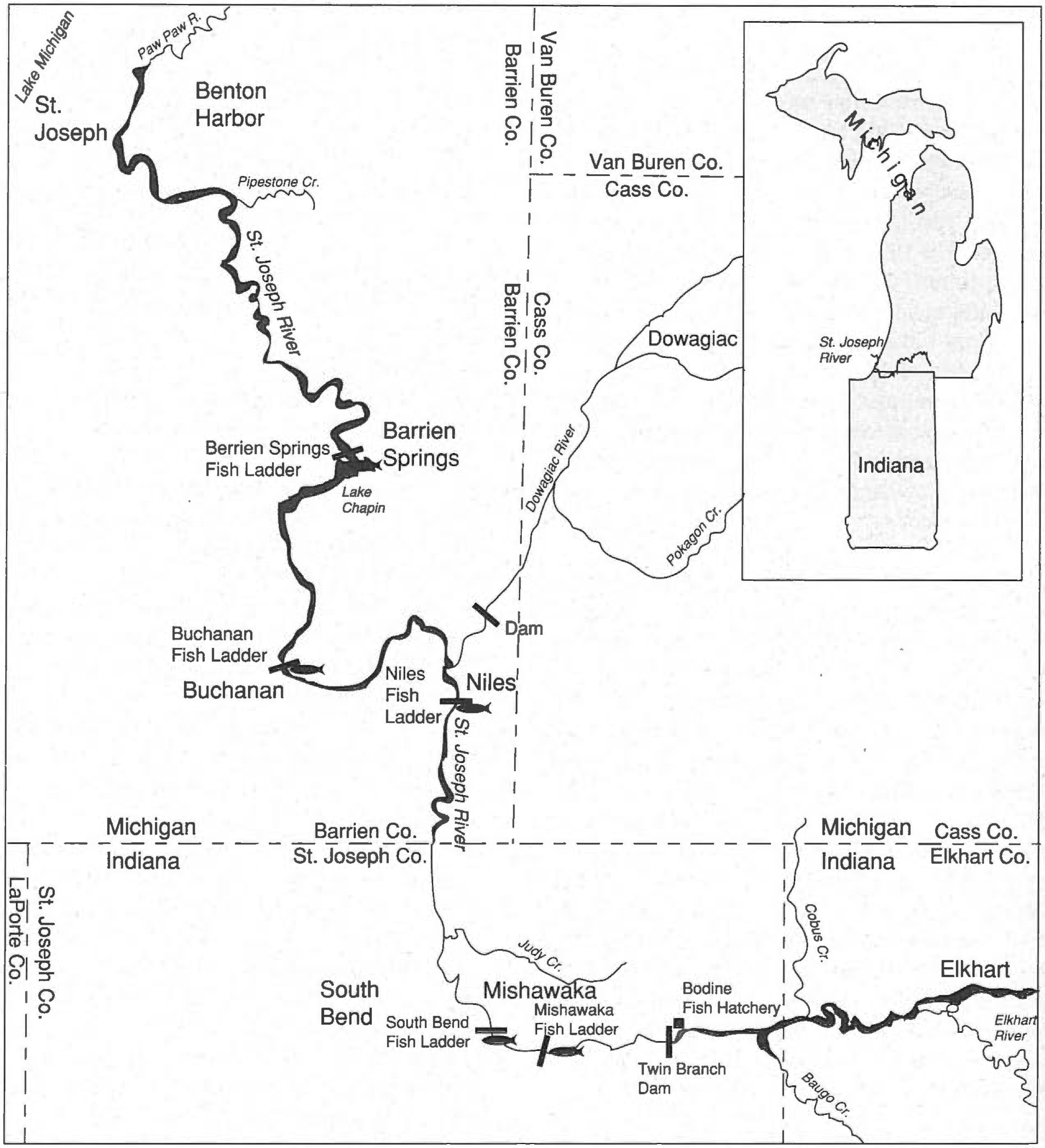

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Figure 7-1. Location of the Buchanan project and fish ladder and four other fish ladders on the lower St. Joseph River. The Buchanan project is located to the middle-left. The insert shows the St. Joseph River in relation to Indiana and Michigan.

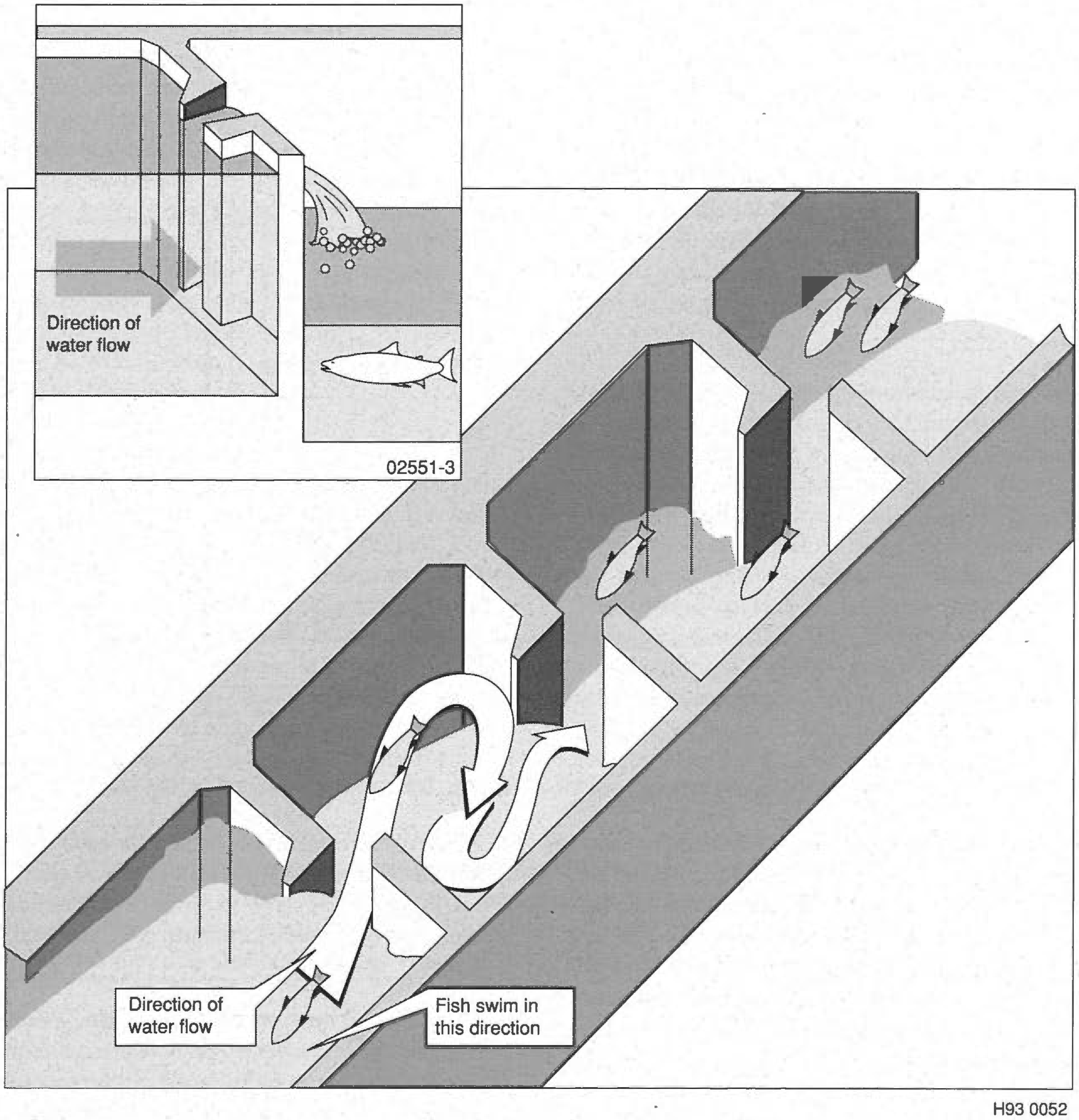

Figure 7-2. Vertical slot fish ladder used at Buchanan.

Figure 7-3. Closeup view of the vertical slot ladder used at Buchanan.

October 1992, although fish passage was apparently not hindered.

Fish that have ascended the Berrien Springs fish ladder next encounter the Buchanan Dam fish ladder, approximately 10 miles upstream. The ladder at Buchanan has a steel grate that forces the fish near the surface and over a counting board, where they can be observed more easily. The Buchanan Dam ladder was completed in 1990 and has been available for fish passage all year since that time. Unfortunately, fish passage has not yet been monitored at this site (Dexter, personal communication).

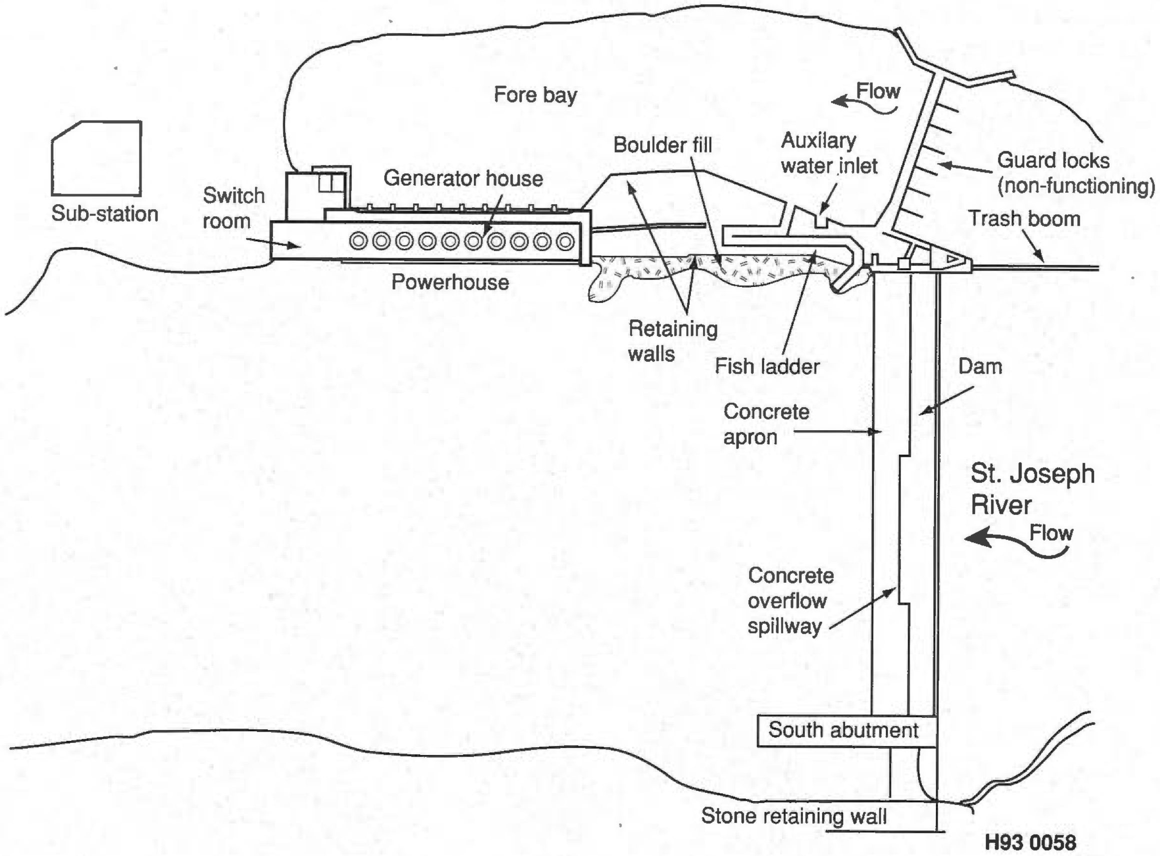

Figure 7-4. Layout of the Buchanan fish ladder, diversion dam, powerhouse and power canal.

After Buchanan, migratory fish next encounter the vertical slot fish ladder at the Niles Dam, 9 miles upstream. Like the Berrien Springs ladder, the Niles facility has a viewing window that allows fish use to be monitored either manually or by video equipment. The Niles ladder was completed in 1991, and fish passage has been monitored there since the fall of 1992.

Upstream-migrating fish returning to Indiana waters must next ascend the South Bend and Mishawaka fish ladders, 3.5 miles apart. Fish ladder counts have been made at the South Bend facility since September 1992.

Creel censuses were conducted in both the Michigan and Indiana reaches of the St. Joseph River to assess the sport fishery harvest (Dexter, personal communication). The creel census was conducted from June through December 1991 and from February through December 1992 in segments of the river below, between, and above the dams. Information collected for each species included estimated catch per hour, number caught, and total effort in terms of angler hours, trips, and days; these estimates were reported by month.

7.1.3 Performance of Mitigation. Because fish passage at Buchanan has not been monitored, it is not possible to estimate the efficiency of that fish ladder directly. However, fish ladder counts at the Berrien Springs facility (10 miles downstream) provide estimates of the numbers of upstream-migrating fish available for passage at Buchanan, whereas corresponding counts at the top of the Niles fish ladder (9 miles upstream) provide estimates of the numbers of fish that ascended both the Buchanan and the Niles fish ladders. Factors that should be accounted for in the comparison of fish ladder counts include losses of fish between dams from sport fishery harvest, mortality, taking up residence in a river section, or movement into tributaries. Data is available only for sport fishery losses, based on the creel censuses made in 1991–1992. There is no information about natural mortality between the dams. The only data about anadromous fish movements into tributaries of the St. Joseph River come from creel surveys of the Dowagiac River (between Buchanan and Niles). Movement of fish out of the river can be a major complication, especially with Skamania steelhead in the summer months. Even small cold-water tributaries as low as 5 cfs will attract substantial numbers of steelhead. There are approximately 15 good cold-water tributaries (range 5–300 cfs) to the St. Joseph River (Dexter, personal communication).

Table 7-1 provides fish ladder and creel census data for the three major species of migratory fish that might be expected to ascend the Berrien Springs, Buchanan, and Niles ladders. For example, a total of 2,034 chinook salmon were counted at the top of the Berrien Springs ladder in September and October 1992 (column A). Subtracting a sport fishery harvest of seven fish in the reach between Berrien Springs and Buchanan (column C) leaves a total of 2,027 chinook salmon available for passage at Buchanan (column F). The Niles fish ladder counts reported 1,761 chinook salmon during that same time period (column B). Adding to that the numbers of fish lost to the sport fishery in the St. Joseph River between Buchanan and Niles (column D) and in the Dowagiac River (column E) results in an estimated 1,856 chinook that had to ascend the Buchanan fish ladder (column G). The number of chinook salmon that ascended Buchanan (1,856) divided by the number available for passage (2,027) yields a passage efficiency of 92%. Steelhead had an estimated passage efficiency of 69%.

As noted earlier, natural mortality in the river and straying into tributaries add an unquantified amount of error to these estimates. Also, some of the salmon and steelhead counted at Berrien Springs might have spawned in the St. Joseph River below Buchanan or Niles, and thus would not have attempted passage at upstream ladders. These errors would tend to make the passage efficiency estimate lower than it really was. Finally, modification of the Berrien Springs fish ladder resulted in incomplete counts during September and early October, at a time when complete counts were being made upstream at Niles. Incomplete monitoring is probably the reason that

Table 7-1. Percent efficiency of the Buchanan project fish ladder (last column), based on estimated numbers of migratory fish passed at the Berrien Springs fish ladder (downstream from Buchanan), the Niles fish ladder (upstream from Buchanan), and censuses of sport fishery harvests in segments of the river downstream and upstream from Buchanan. Fish passage and creel data from September and October 1992. Data provided by Jim Dexter, Michigan Department of Natural Resources.

Species	Berrien Springs ladder counts (A)	Niles ladder counts (B)	Harvest at Site 345 (C)	Harvest at Site 387 (D)	Harvest at Site 391 (E)	Number of fish below Buchanan (A-C=F)	Number of fish passed at Buchanan (B+D+E=G)	Percent efficient (%) (G/F)
Chinook salmon	2,034	1,761	7	16	79	2,027	1,856	92
Coho salmon	147	188	1	0	79	146	267	–[a]
Steelhead trout	2,066	1,397	0	0	24	2,066	1,421	69

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a. Estimated number of fish passed at Buchanan was greater than the estimated number available for passage (i.e., in the Buchanan tailwaters), resulting in a ladder efficiency >100%. This is due to incomplete counts at Berrien Springs from September through early October because of construction.

passage efficiency could not be estimated for coho salmon (Table 7-1). Fish ladder counts at Berrien Springs were actually lower than at Niles. Obviously, at least 268 coho must have ascended the Berrien Springs ladder during September and October, 1992 (the Niles fish ladder count plus a harvest of 80 coho in the river between Berrien Springs and Niles), but only 147 were actually counted during the abbreviated monitoring period. The incomplete monitoring could also affect passage efficiency estimates for chinook and steelhead; if more fish ascended the Berrien Springs ladder than the counts indicate, then the passage efficiency at Buchanan would be lower by some unknown amount.

Another approach for evaluating the effectiveness of the fish ladders on the St. Joseph River is to focus on the movements of summer steelhead trout. Only the State of Indiana stocks summer steelhead, which is distinct from the winter strain stocked by Michigan. Summer steelhead adults enter the St. Joseph River earlier than winter steelhead (June versus late October) and attempt to return to Indiana where they were stocked. Because summer steelhead are separated in both time and space from winter steelhead, they will ascend the Michigan ladders earlier and they will also use the fish ladders in Indiana.

Table 7-2 presents data for numbers of presumed summer steelhead in the St. Joseph River system. The table lists the number of steelhead trout that ascended the Berrien Springs and Niles ladders before October 21, 1992. The steelhead counts at these ladders were relatively high at the time the ladders were first opened on September 11 and 12, 1992; the numbers subsequently dropped to near zero on October 21, before rising again. The first peak in numbers presumably coincided with the presence of the summer steelhead in the St. Joseph River and was separate from a later peak of winter steelhead, which began in late October. Table 7-2 also lists the steelhead counts at the South Bend ladder in Indiana for the entire summer and fall season; these fish are presumably the Indiana-stocked summer strain. Angler harvest of summer steelhead was relatively low upstream of Berrien Springs. Subtracting the 24 summer steelhead caught below Niles from the 1,786 fish that ascended the Berrien Springs ladder yields 1,762 summer steelhead available for passage at Niles. The total count at Niles during this period was 1,327 steelhead, which is 75% of the estimated number available. Assuming equal efficiencies of the vertical slot fish ladders at Buchanan and Niles results in an estimated passage of 87% of the available summer steelhead at each dam.

Estimated passage efficiency for summer steelhead at South Bend is somewhat higher. If the Niles count of 1,327 steelhead was the number of fish available for passage at South Bend (there was no angler harvest in the 14-mile-long segment of the river between these dams), then the 1,245 summer steelhead that ascended the South Bend ladder represented a 94% passage efficiency. As with the estimates of passage efficiency in Table 7-1, the incomplete monitoring at

Table 7-2. Summer steelhead trout that moved up fish ladders or were harvested by sport fishermen in the St. Joseph River during summer and fall, 1992. Data provided by Jim Dexter, Michigan Department of Natural Resources.

Berrien Springs ladder counts[a]	Niles ladder counts[a]	South Bend ladder counts[b]	Angler harvest at Site 345[c]	Angler harvest at Sites 387 + 391[c]	Angler harvest at Site 388[c]
1,786	1,327	1,245	0	24	0

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a. Number of steelhead trout that moved up the ladder before October 21, 1992.

b. Number of steelhead trout that moved up the ladder during summer and fall, 1992.

c. Number of steelhead trout harvested in September and October 1992.

Berrien Springs in September 1992 would tend to underestimate the number of migratory fish available for passage at upstream ladders, and thus overestimate the percent efficiency.

7.2 Mitigation Benefits

7.2.1 Benefits to Fish Populations. None of the dams on the St. Joseph River have fish screens to protect downstream-migrating smolts. Downstream mitigation on the St. Joseph River is currently limited to curtailment of nighttime operations during the peak of the smolt migration period at the Niles dam and the maintenance of a 1-foot crest gate opening at the Buchanan project for a 3 week period (Simms, personal communication). As a result, the potential fish population benefits of ladders (i.e., opening previously inaccessible areas of the river and its tributaries to spawning) may be reduced by subsequent turbine-passage mortality at those dams with hydroelectricity. However, maintenance of self-sustaining runs of salmon and steelhead via natural reproduction has not been the primary goal of these mitigative measures. A major purpose of the St. Joseph River Interstate Fisheries project is to provide an expanded trout and salmon sport fishery in a densely urbanized area, and the ladders serve that purpose by distributing the fish (and fishery) over a 63-mile-long reach of the river in Michigan and Indiana. Consistent with this, public access to fishing has been enhanced by the development of shoreline parks, campgrounds, and numerous boat ramps and shoreline fishing areas. An extensive stocking program, including operation of the Bodine State Fish Hatchery (name changed from Twin Branch State Fish Hatchery) near the Twin Branch Dam in Indiana, ensures that large numbers of salmonids will return to the St. Joseph River from Lake Michigan.

The importance of hatchery stocking to maintaining anadromous fish in the St. Joseph River is illustrated by estimates of the relative contributions to adult runs of stocked hatchery fish, wild fish, and strays from distant sources. The proportion of wild-origin adult steelheads entering the river between summer 1988 and summer 1991 ranged from 0.00 to 0.03 (Seelbach, 1992). Given that there are so few wild-origin steelhead in those runs, the ladders have not yet had much effect on population dynamics. Rather, their biggest impact may be to distribute the fishery for hatchery-stocked fish over a wide area.

7.2.2 Benefits to Fisheries. The purpose of the five fish ladders and the stocking program is to create a salmon and trout sport fishery in a 63-mile-long reach of the St. Joseph River. No such opportunities previously existed in this densely urbanized area of Michigan and Indiana. In terms of angler hours, trips, and days, the sport fishery was concentrated in two areas in 1992: below Berrien Springs Dam and below Twin Branch Dam (Table 7-3). Thus, the series of fish ladders has been successful in creating a salmon and steelhead fishery all the way to the last barrier to upstream fish movement in Indiana. Fishing effort in the intermediate reaches of the river was relatively low in 1992, despite the fact that catch/hour estimates were comparable to those below Berrien Springs and Twin Branch.

An increase of 125,000 angler days of recreational fishing each year is anticipated as a result of the St. Joseph River Interstate Fisheries project, which is a substantial increase over that estimated for 1992 (Table 7-3). The economic benefit of the overall mitigation effort is estimated to be $6.4 million annually (Dexter, personal communication).

7.3 Mitigation Costs

7.3.1 Introduction. The mitigation cost analysis for the Buchanan hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; an upstream fish passage/protection system section, discussing the upstream mitigation cost items; a brief downstream fish passage/protection system section and a similarly brief other costs section; and a spreadsheet used that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal written correspondence and from telephone calls. A site visit

Table 7-3. St. Joseph River creel survey data for the March–October 1992 sport fishing season. Data provided by Jim Dexter, Michigan Department of Natural Resources.

	Creel census areas on the St. Joseph River					
Creel census parameter	Below Berrien Springs (Sites 367 and 298)	Between Berrien Springs and Buchanan (Site 345)	Between Buchanan and Niles (Sites 387 and 391)	Between State Line and South Bend (Site 388)	Between South Bend and Mishawaka (Site 389)	Between Mishawaka and Twin Branch (Site 390)
Angler hours	197,069	3,897	8,852	6,169	3,440	27,290
Angler trips	39,220	1,530	3,387	2,670	2,216	10,550
Angler days	37,210	1,530	3,336	2,699	1,966	10,056
Catch/hour Chinook salmon	0.0059[a]	0.0018	0.0107[a]	0.1136	—	0.0080
Catch/hour Coho salmon	0.0008[a]	0.0003	0.0089[a]	0.0010	—	—
Catch/hour Steelhead trout	0.4870[a]	0.0157	0.0157[a]	—	—	0.0342

a. Catch/hour is an average for the two areas weighted by the number of angler hours.

greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

7.3.2 Cost Summary. The fish ladder at Buchanan was installed and is operated by the Michigan Department of Natural Resources. The only current direct cost to the licensee is the generation losses resulting from flows diverted out of the power canal through the fish ladder. The licensee did contribute towards the fish ladder and recreation as part of a 1984 settlement (see Upstream Fish Passage/Protection Capital Costs section). The current mitigation requirements are for upstream passage/protection. The Michigan Department of Natural Resources fish ladder costs and the lost generation costs are combined to compile the total ladder costs. Only costs associated with the fish ladder are included in the totals. Other costs for river access and downstream studies are discussed but not included in the totals because they are not part of the upstream mitigation. The upstream system costs have been levelized over 20 years, and the levelized annual cost is $212,845 (Table 7-4). The annual cost per kilowatt-hour of generated electricity is 10.6 mills, or 1.6 cents per kilowatt-hour. While the licensee is not paying this cost, the value of 10.6 mills can still be used as a basis to comprehend the fish ladder's capital and annual costs. The capital costs are the major mitigation-cost item (78%) at Buchanan (Figure 7-5) and they are primarily incurred as up-front costs (Figure 7-6).

7.3.3 Upstream Fish Passage/Protection.

7.3.3.1 Capital Costs. The fish ladder capital cost items presented on the spreadsheet (Table 7-5) are all self-explanatory; providing an item-by-item listing here would be redundant. All of the capital costs were incurred during 1990 and are presented as 1993 dollar values. The total capital cost is approximately $3.5 million. This includes all design, testing, actual construction, and all other activities associated with the construction of the ladder. The upper gate modification cost of $95,401 includes some additional design and engineering work in conjunction with the gate modification itself.

Table 7-4. Mitigation costs per kilowatt-hour, 20-year total costs, and levelized annual costs at Buchanan. Costs include capital and annual costs.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital costs	3,456,909	172,845	8.6
Annual costs	800,000	40,000	2.0
Total costs	4,256,909	212,845	10.6

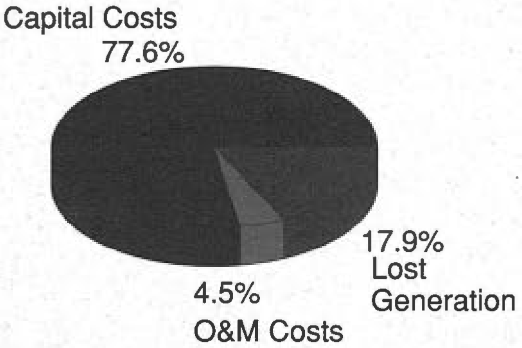


Figure 7-5. Total upstream mitigation costs at the Buchanan project. Buchanan has no downstream mitigation requirements.

It should be noted that the Michigan Department of Natural Resources constructed and operates the Buchanan fish ladder (Figure 7-7). Partial funding for the construction of the ladder complex (Figure 7-8) was provided by the licensee. The licensee (Indiana and Michigan Power), paid $2.1 million (1993 dollars) towards the construction and modification of the ladder and access sites at the Buchanan and Berrien Springs dams (Sumerix, 1992). The $2.1 million (paid May 1984) was a settlement agreement between Indiana and Michigan Power and the State of Michigan at a nonhydroelectric project (Simms, personal communication). The actual percentage directed towards the Buchanan fish ladder is unknown.

While the licensee did not directly construct the fish ladder, the capital costs can still be compared to the capacity and generation volumes as a means of appraising the magnitude of costs for this project as well as providing a comparison to ladder costs at other projects. With a capacity of 4.104 megawatts, the ladder construction cost per kilowatt of capacity is $842. Based on 3 years (1990–1992) of historical generation data (13,414 megawatt-hours), and the anticipated average generation in the future of 21,270 megawatt-hours (power plant upgrades), a weighed average generation of 20,092 (1990–2009) is used to compile costs as mills per kilowatt-hour. Leveling the capital costs over 20 years results in an average annual cost of $172,845. The annual cost per kilowatt-hour for capital costs is 8.6 mills per kilowatt-hour, or, 0.9 cents.

No studies were conducted in conjunction with the ladder construction.

7.3.3.2 Annual Costs. The licensee has estimated that the average flow of water through the ladder results in a generation loss of approximately 600,000 kilowatt-hours per year. Assuming an energy value of $0.05 per kilowatt-hour, this equates to an annual generation loss of $30,000. Based on the yearly generation of 20,092 megawatt-hours of electricity, the cost of lost generation resulting from ladder flows is 1.5 mills per kilowatt-hour.

The operations and maintenance of the ladder is handled on a part-time basis by a member of the state department of natural resources, and that expense as well as any equipment costs for the ladder have been estimated to cost $10,000 per year. Based on the yearly generation of 20,092 megawatt-hours of electricity, the operations and maintenance cost is estimated to be 0.5 mills per kilowatt-hour.

The total annual cost for operations and maintenance, and lost generation is 2.0 mills per kilowatt-hour of generated electricity.

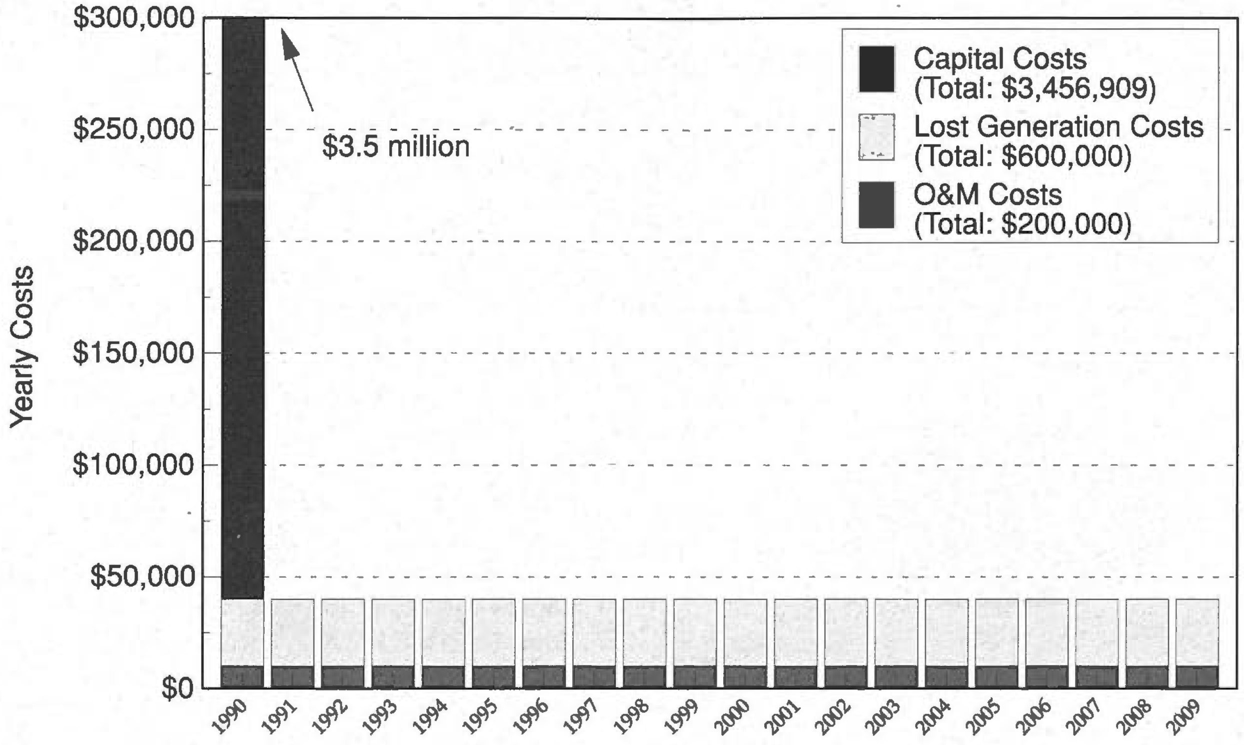


Figure 7-6. Yearly upstream mitigation costs at the Buchanan hydroelectric plant.

7.3.4 Downstream Fish Passage/ Protection. There is currently no requirement in place for a downstream fish passage/protection system. A consultant funded by the licensee did perform a 15-month smolt study during 1991 and 1992. The cost for this study was $442,000 (1993 dollars). The plant operator initiated spills over the north crest gate at the project spillway during the peak downstream migration period. The license estimates an average annual generation loss of 73,000 kilowatt-hours. Assuming an energy value of $0.05 per kilowatt-hour, the dollar loss equates to $3,650 per year, or about 0.2 mills per generated kilowatt-hour. Potential requirements for a downstream system are unknown. This cost has not been added to the total costs and is only included for reader interest.

7.3.5 Other Costs. Three access sites for fishing have been installed at the Buchanan site. These are wood fishing/viewing platforms with an installed total cost of $556,030. These costs have not been included in the totals as they are not upstream or downstream mitigation requirements.

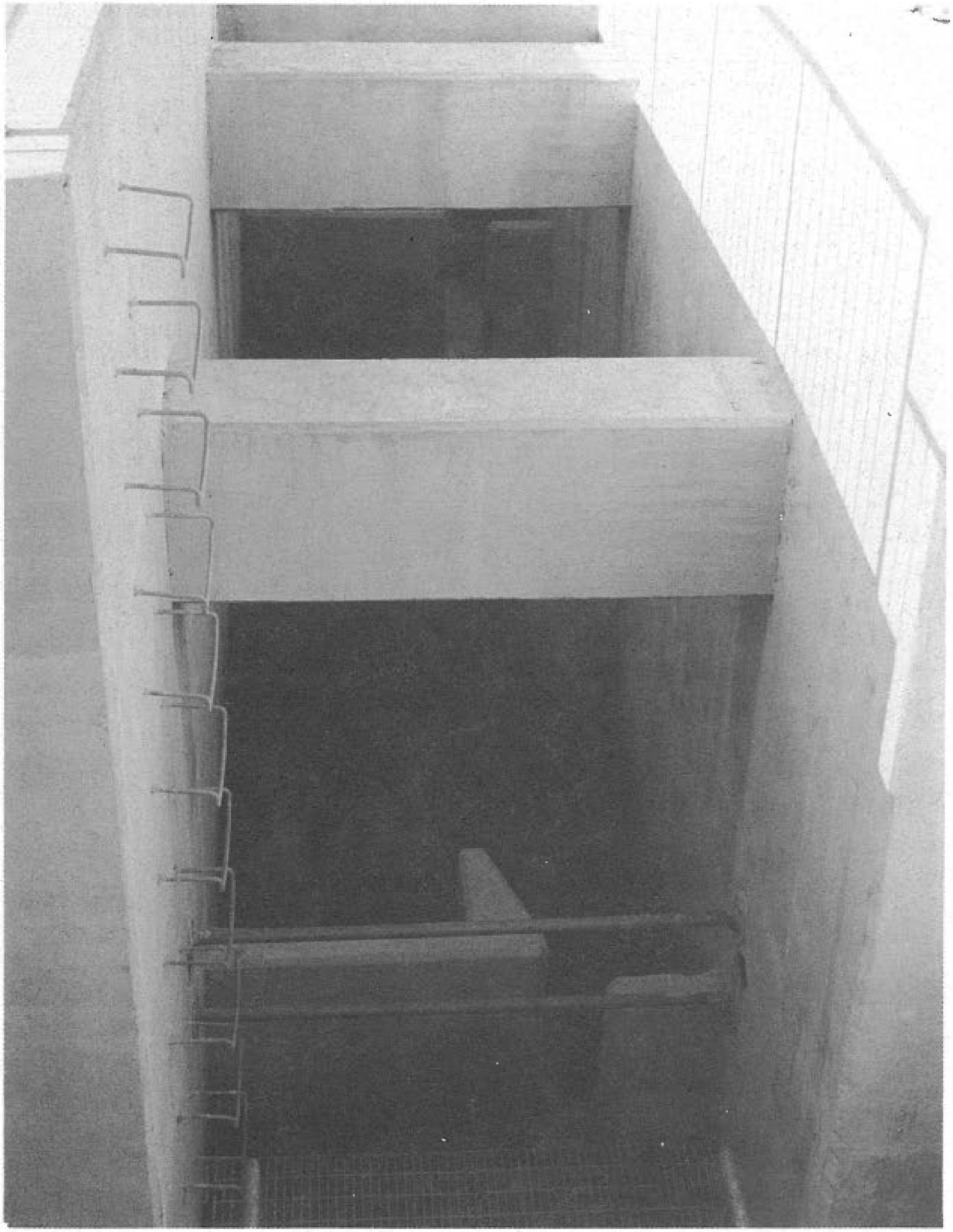


Figure 7-7. Fish ladder at Buchanan.

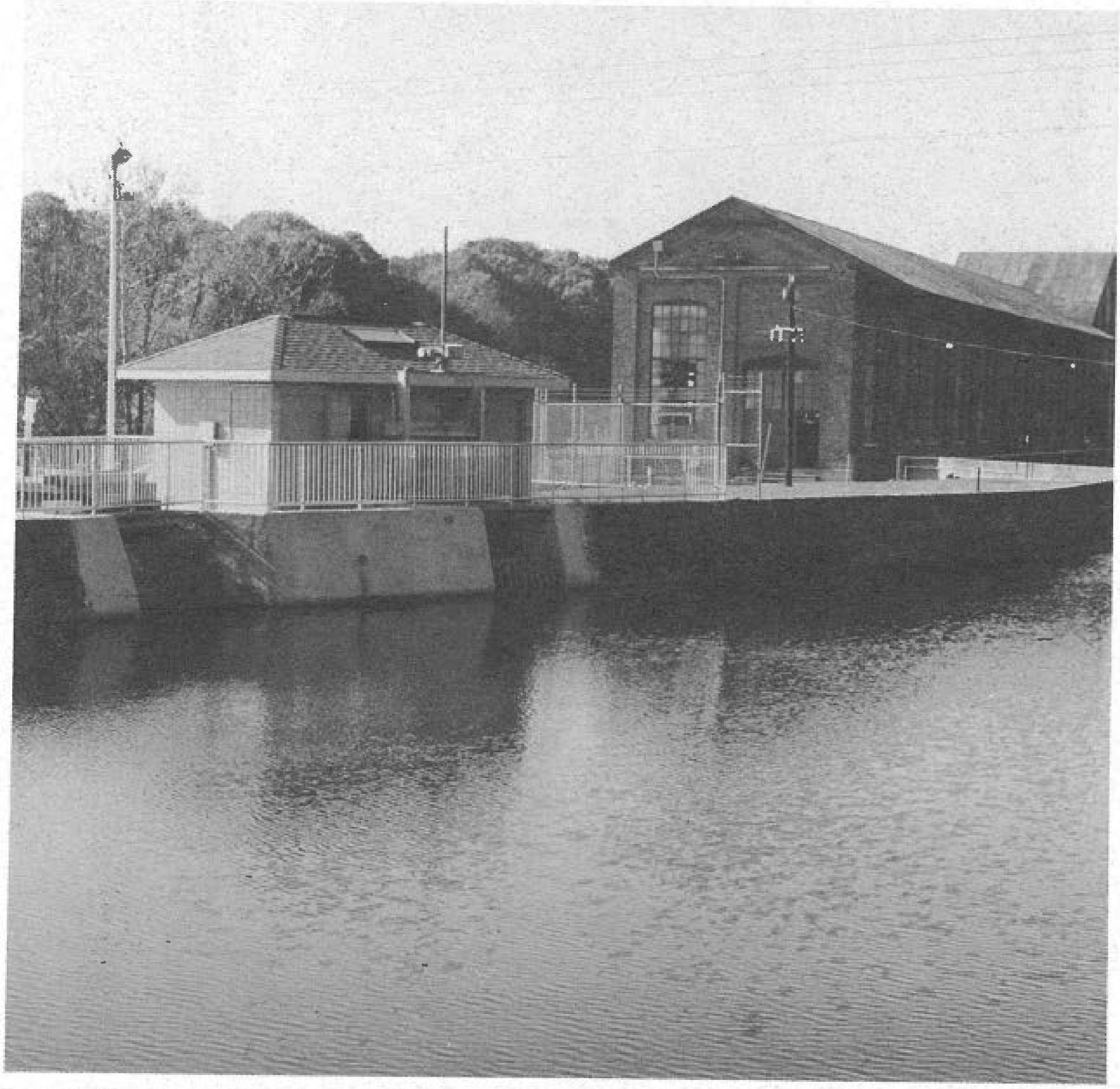


Figure 7-8. Forebay fish ladder exit and powerhouse at Buchanan.

Table 7-5. Buchanan mitigation costs.

Buchanan Project—Mitigation Cost Analysis—All Values in 1993 Dollars

9/09/93	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	TOTALS
UPM—Capital Costs—Fish Ladder																					
1) Construction Cost	$2,782,988																				$2,782,988
2) Engineering Design & Inspections	$522,665																				$522,665
3) Design Consultants	$34,235																				$34,235
4) Soil Borings	$10,064																				$10,064
5) Concrete Testings	$7,450																				$7,450
6) Miscellaneous Plan Review	$2,482																				$2,482
7) Debris Cleanup & Miscellaneous	$1,624																				$1,624
8) Upper Gate Modification	$95,401																				$95,401
UPM—Annual Operations & Maintenance																					
9) Equipment & Parttime Personnel	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$200,000
Annual Generation Losses																					
10) UPM—Annual Generation Losses	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$600,000
Subtotal Capital Costs	$3,456,909	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$3,456,909
Subtotal Annual O&M & lost generation	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$800,000
Total Expenses—1993 dollars	$3,496,909	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$4,256,909

Notes: 4.5% Index rate used to present values as 1993 dollars
Some costs are estimated, see mitigation cost text for details
Subtotal Capital Costs includes items: 1, 2, 3, 4, 5, 6, 7, 8
Subtotal Annual Costs includes items: 9, 10

8. CONOWINGO CASE STUDY

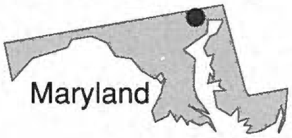
8.1 Description

Conowingo Hydroelectric Project (FERC number 00405) is the largest hydroelectric generating station in Maryland (Figure 8-1). The project has a peak capacity of 512 megawatts and a turbine capacity at peak output of 85,000 cfs (PPRP, 1991). The hydroelectric project began operation in 1928.

Conowingo Dam is the first of a series of dams (Figure 8-2) on the Susquehanna River that block the upstream movements of both resident fish and historically large runs of anadromous fish (e.g., American shad, blueback herring, alewife, striped bass, white perch, American eel) from the Chesapeake Bay. A mechanical fish lift was put into operation at Conowingo Dam in 1972 to assist the upstream migration of fishes, especially American shad. This lift (the West Fish Passage Facility) elevates fish approximately 40 feet and deposits them in a sorting tank (Figure 8-3). American shad and other species targeted for upstream transport are manually removed from the sorting tank, transferred to a tank truck, and transported upstream for release. Because three other upstream dams (Holtwood, Safe Harbor, and York Haven) lack upstream fish passage/protection facilities, anadromous fish are presently released above the uppermost dam, York Haven.

A second fish lift (the East Fish Passage Facility) began operation in the spring of 1991, in time for the American shad upstream migration. The East Lift (Figure 8-4) has three fish entrances with attraction flow provided from the head pond via a modified regulating gate (Figure 8-5). Fish can be released either to sorting tanks for upstream truck transport or to a trough from which they can swim into Conowingo Pond. Fish collected by the East Lift will continue to be trucked upstream until fish passage/protection facilities are installed at the other three upstream dams.

8.1.1 Fish Resource Management Objectives of Mitigation. Although Susquehanna River stock of American shad formerly supported important commercial and recreational fisheries (Foote et al., 1993), the numbers of adults had declined to very low numbers during the 1970s (Figure 8-6). For example, the annual catch of shad at the West Lift averaged 110 fish from 1972 to 1980 (McElroy, personal communication). The stock had declined to the point that the American shad fishery in Maryland waters of the Chesapeake Bay has been closed to sport and commercial fishing since 1980 (SRAFRC, 1992).



Operation of the East and West Lifts at Conowingo is part of a larger, cooperative private, state, and Federal effort to restore American shad and other migratory fishes to historic spawning and nursery areas in the Susquehanna River. Efforts to rebuild stocks have been based on releases of hatchery-reared fry and fingerlings, distribution of prespawning adults from other rivers into upstream tributaries of the Susquehanna River, and, as the stock rebuilt in the 1980s, natural reproduction of adult shad collected at the Conowingo Dam fish lifts and transferred upstream to spawn. Consistent with that objective, the overall goal of the upstream fish passage/protection facilities at Conowingo Dam is to transport as many migratory fishes (American eel, river herring, American shad, and striped bass) upriver as possible (SRAFRC, 1992). Based on a historical review of the historical fish populations, the Susquehanna River Anadromous Fish Restoration Committee established an annual passage goal for Conowingo of 3 million American shad and 20 million river herring (alewife and blueback herring combined) (Foote et al., 1993).

8.1.2 Monitoring Methods. The effectiveness of American shad restoration efforts are assessed by monitoring both fish passage at the Conowingo fish lifts and population studies of American shad in both the Susquehanna River and the upper Chesapeake Bay. Most recent monitoring methods are given in the annual reports of the Susquehanna River Anadromous Fish

Figure 8-1. Conowingo power plant and fish lifts. East fish lift is the large facility on the right end of the power plant towards mid-stream and the west fish lift is the small facility by the shore line in the left of the photograph.

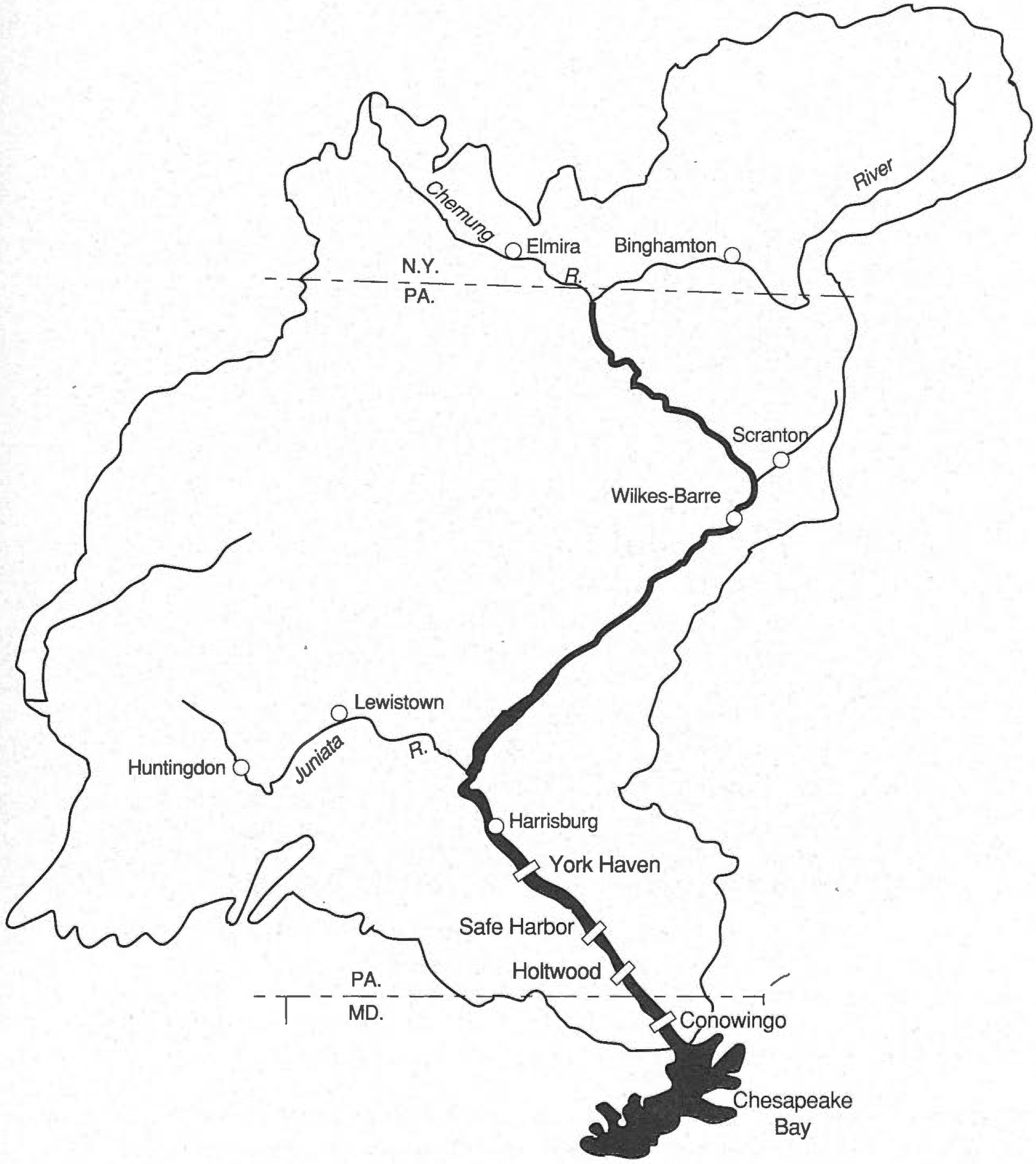


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Figure 8-2. Location of the Conowingo project on the Susquehanna River. Also shown are the Holtwood, Safe Harbor, and York Haven projects. Conowingo, located at the bottom right, is the most downstream dam on the Susquehanna River.

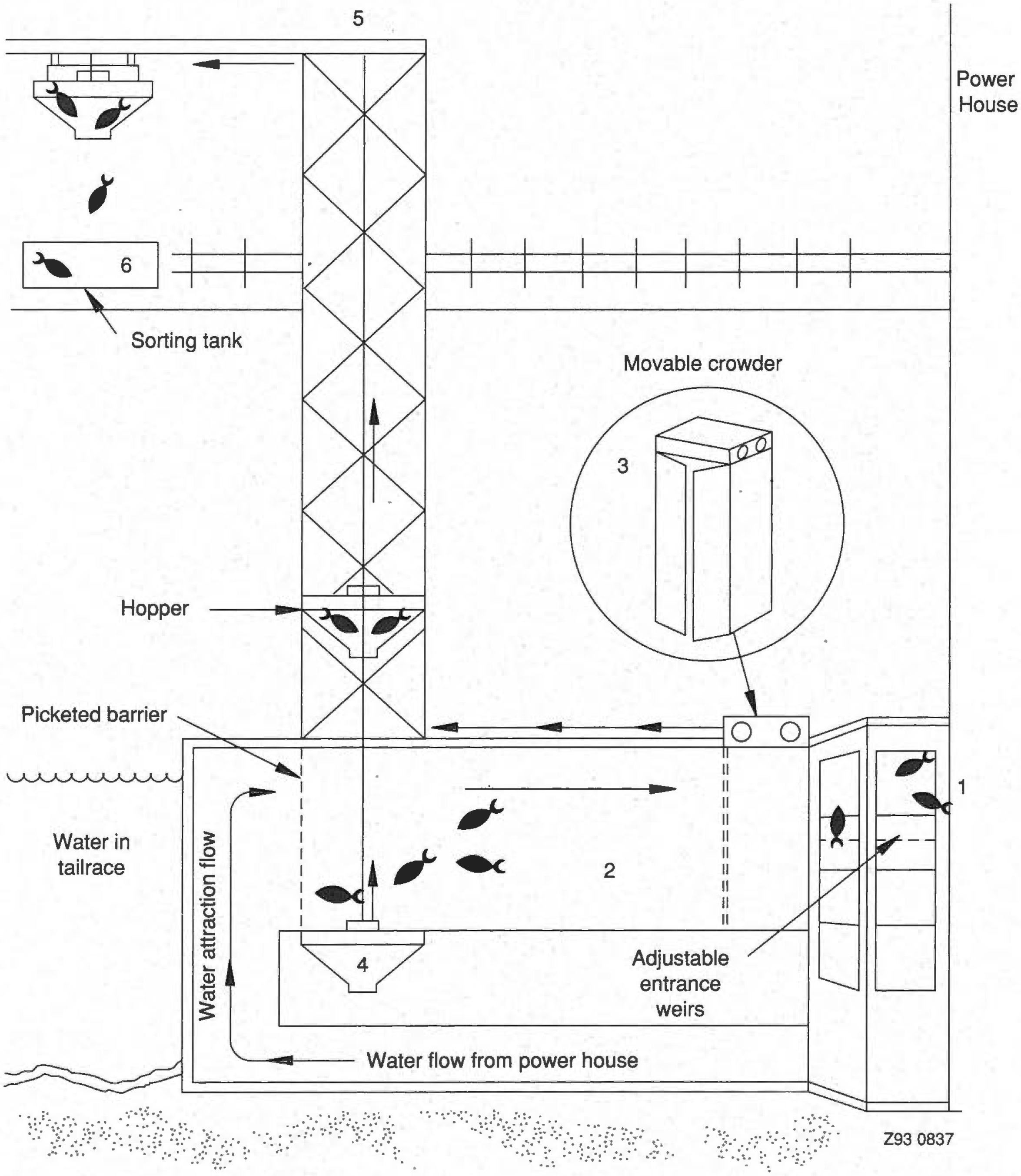


Figure 8-3. Conowingo Dam West Fish Passage Facility. The shad are attracted to the entrance weirs (1) because of their instinct to swim against fast moving water. Once in the holding pool (2), the gates of the moveable crowder (3) are periodically closed and the crowder is moved to crowd the fish over the submerged hopper (4). The overhead crane (5) hoists the hopper, then travels horizontally and releases the collected fishes into the sorting tank (6) for biological studies, or directly into a truck for transport to an upriver sites. Source: SRAFRC (1992).

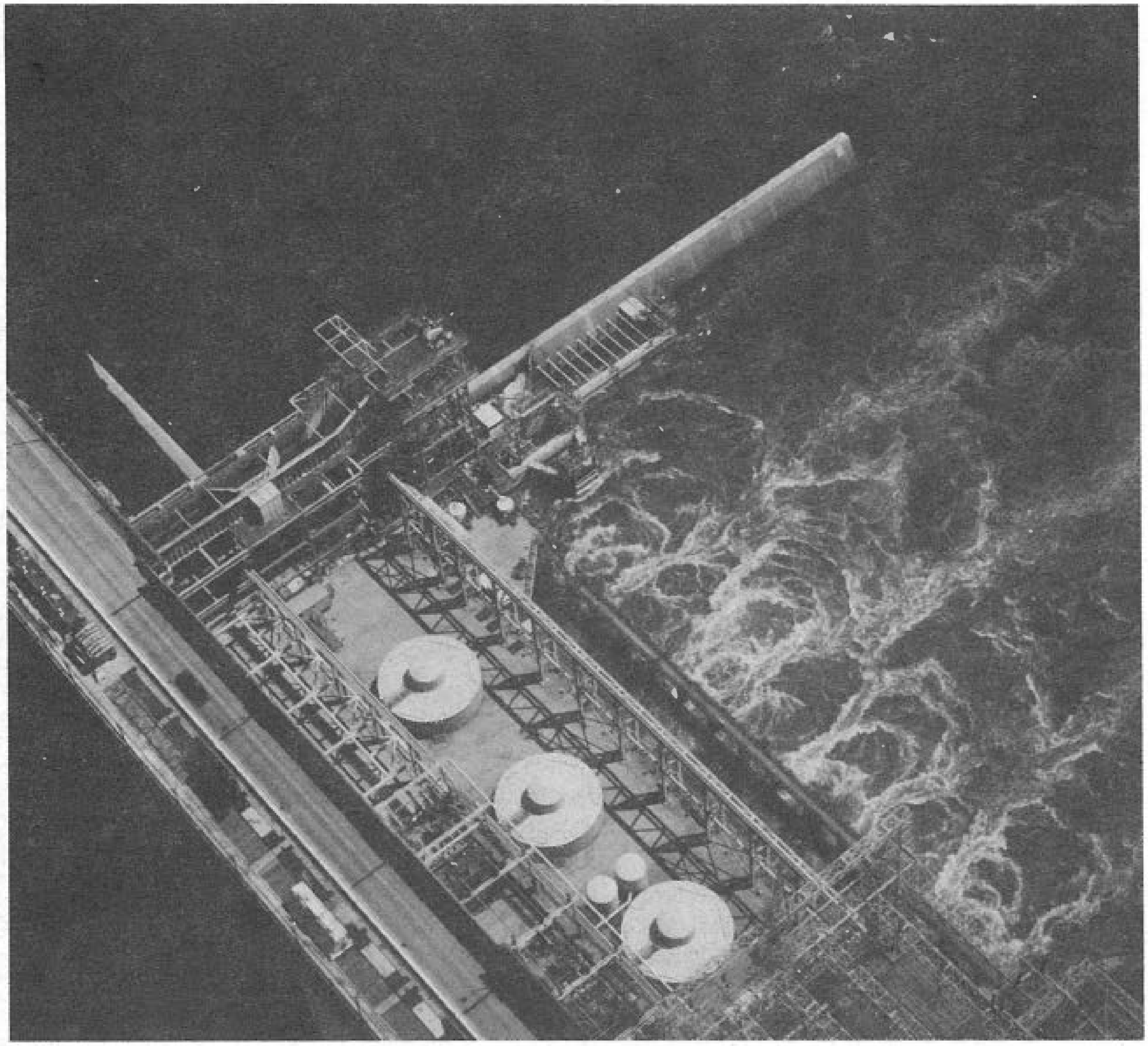


Figure 8-4. Conowingo Dam East Fish Passage Facility.

Restoration Committee (SRAFRC, 1992); the 1991 monitoring program is summarized here.

Surveys of the river are conducted in March to determine when adult shad arrive below Conowingo Dam and when to begin operation of the fish lifts. By agreement, turbine units 1 and 2 are shut down when river flows are less than 65,000 cfs in order to improve the efficiency of the West Lift. Lifts are operated between 7 a.m. and 7 p.m. during the peak migration season. Lift frequency and/or fishing time (i.e., the amount of time that fish are allowed to collect in the hopper before being lifted to the sorting tanks) are determined by fish abundance. During peak abundance, lifts at the East facility were conducted at least hourly throughout the day.

Fishes in the sorting tanks were either counted or estimated (when large numbers were present) after each lift. Generally, if 100 or more prespawning American shad were collected in a day, shad and river herring were transported upstream of the York Haven Dam; otherwise fish were released back to the tailrace or held overnight in shoreside holding tanks for next day transport.

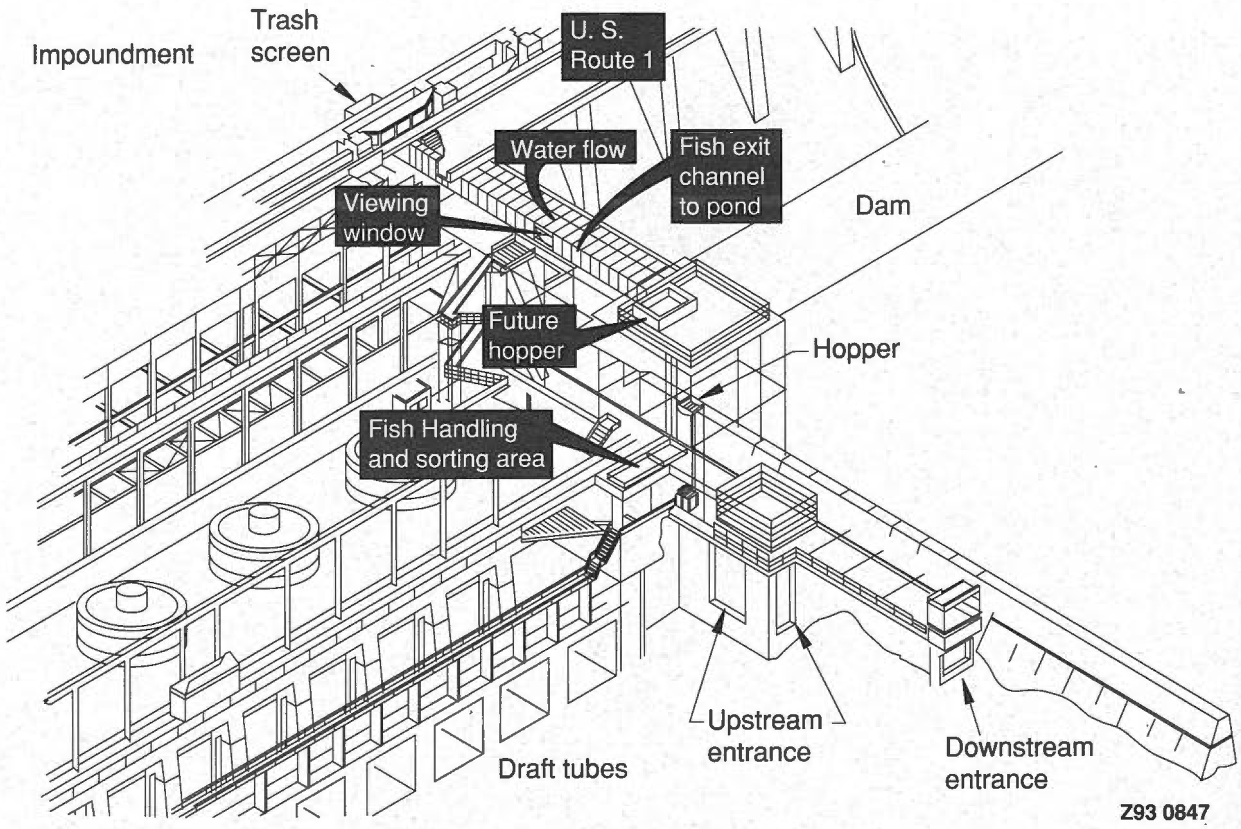


Figure 8-5. Conowingo Dam East Fish Passage Facility. Source: SRAFRC (1992).

The Maryland Department of Natural Resources monitors the number of adult American shad present in the upper Chesapeake Bay during the spring spawning season. In addition to providing an estimate of the spawning population, the survey also collects length, age, sex, and spawning history information. Adult American shad numbers are estimated by a mark-recapture technique. Adult shad are collected by a combination of pound net sampling, and hook and line sampling in the Conowingo tailrace. Tagged shad are then recaptured by the Conowingo fish lifts. Subsequent reproductive success is estimated by a juvenile recruitment study using haul seines and electrofishers.

8.1.3 Performance of Mitigation. The effectiveness of the West and East Lifts can be assessed by comparing the numbers of fish transported by the lifts with estimates of the numbers of fish in the Conowingo tailrace. Table 8-1 provides these data for 1984–1992. In response to restoration efforts, both the numbers of American shad in the tailrace and the numbers transported by the fish lifts has generally increased during this period. The percent of shad in the tailrace that were transported by the lifts ranged from 4.7% to 35.1%, and averaged 23.7%. In 1991, 24,662 of the 27,004 American shad collected by the lifts were transported to upstream spawning areas, with less than 3% transport mortality (SRAFRC, 1992). Mortality resulting from mechanical operation of the lift, handling, and holding procedures was 0.6% and 0.1% at the West and East Lifts, respectively. This level of lift-associated mortality was consistent with that observed at the West Lift in previous years.

The comparison of tailrace population estimates with fish lift counts provides only a rough estimate of effectiveness. For example, certain assumptions used in the population estimate methodology render it useful only as an indicator of trends in abundance (St. Pierre, personal

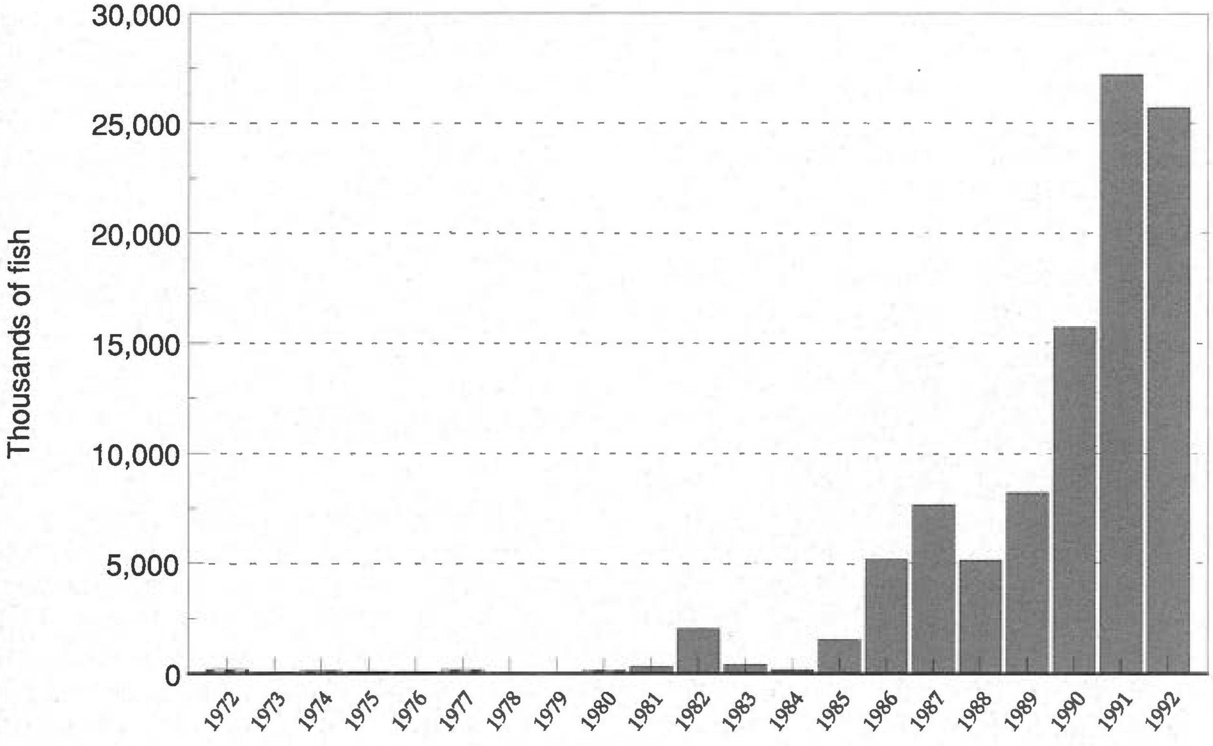


Figure 8-6. Numbers of American shad transported by the fish lifts at Conowingo Dam, Susquehanna River, 1972–1992. Source: Foote et al. (1993).

Table 8-1. Numbers of American shad in the Conowingo Dam tailrace and transported by the East and West fish lifts, 1984–1992. The East Lift began operation in 1991. Data taken from SRAFRC (1992) and Foote et al. (1993).

Year	Number of American shad in the Conowingo tailrace	Number of American shad transported by the lifts	Percent of American shad in the tailrace transported by lifts
1984	3,516	167	4.7
1985	7,876	1,546	19.6
1986	18,134	5,195	28.6
1987	21,823	7,667	35.1
1988	28,714	5,146	17.9
1989	43,560	8,218	18.8
1990	59,420	15,719	26.5
1991	83,990	27,004	32.2
1992	86,416	25,721	29.7

communication). Not all fish which reach the tailwaters are imprinted to continue upstream; only about 70% of the shad collected in 1989–1992 are known to be of upstream, hatchery origin, although an additional percentage are of upstream, wild origin.

Site-specific factors influenced the American shad catches at the two lifts. Collections at the West Lift were affected by the generation status of the two closest turbines, Units 1 and 2; over 91% of the American shad catch at the West Lift occurred when Units 1 and 2 were shut down (SRAFRC, 1992). On the other hand, the catch of American shad at the East Lift increased when its nearby Units 10 and 11 were in operation. Numbers of fish collected increased dramatically during off-peak operations (i.e., weekends). Some of the shad that are not transported by the lifts spawn in the river below the dam, so they may still contribute to production of the shad population (Richard St. Pierre, U.S. Fish and Wildlife Service, personal communication).

In addition to the 27,004 American shad caught by the fish lifts, an estimated 1,156,995 fish of other species were collected in 1991 (SRAFRC, 1992). Other species transported by the fish lifts included gizzard shad (over 81% of the total catch at each lift), comely shiner, blueback herring, channel catfish, and carp. Because nontarget fishes are routinely returned to the tailrace, they may be collected several times and, thus, their relative abundance may be overestimated.

8.2 Mitigation Benefits

8.2.1 Benefits to Fish Populations. Annual estimates of the American shad populations have increased in the last decade in both the upper Chesapeake Bay (Figure 8-7) and in the Conowingo Dam tailrace (Figure 8-8). The 1991 population estimates were the highest to date for both the upper Bay and tailrace, and represent increases of 13% and 42%, respectively, over 1990 estimates (SRAFRC, 1992). While other

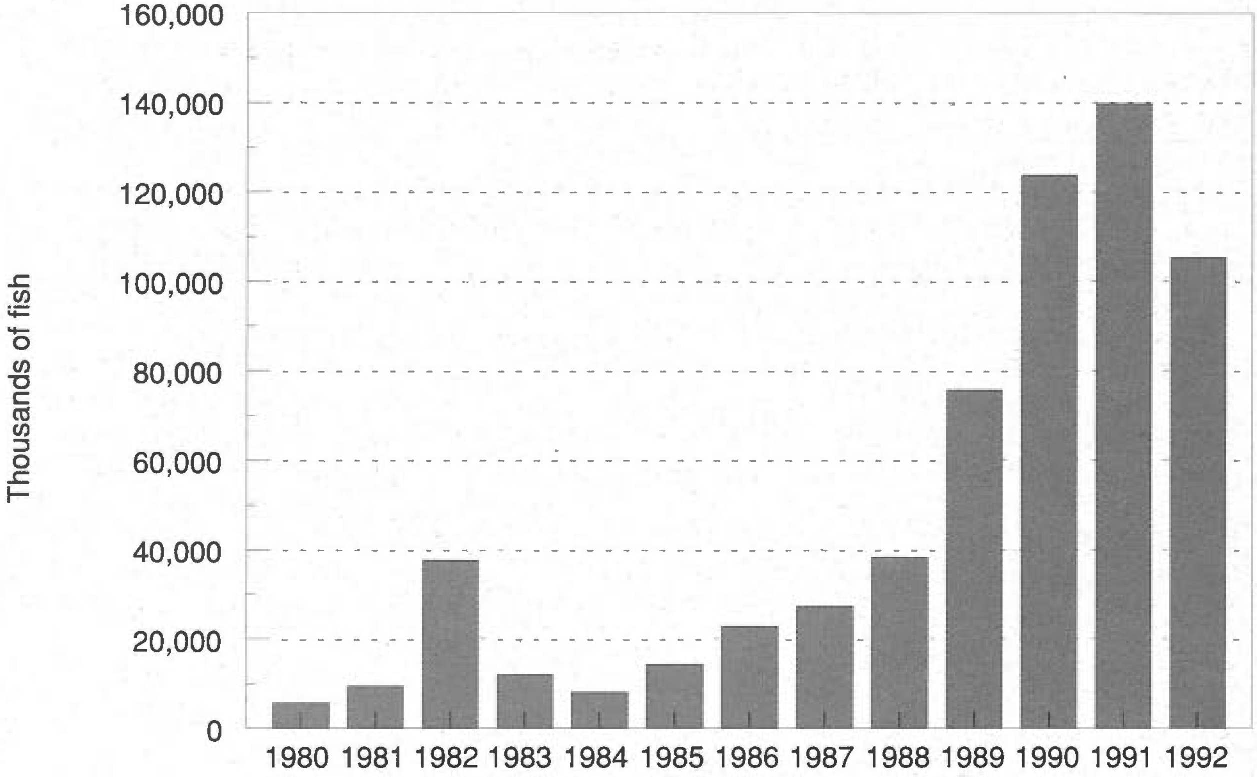


Figure 8-7. American shad population estimate for upper Chesapeake Bay and the lower Susquehanna River, 1980–1992. Source: Foote et al. (1993).

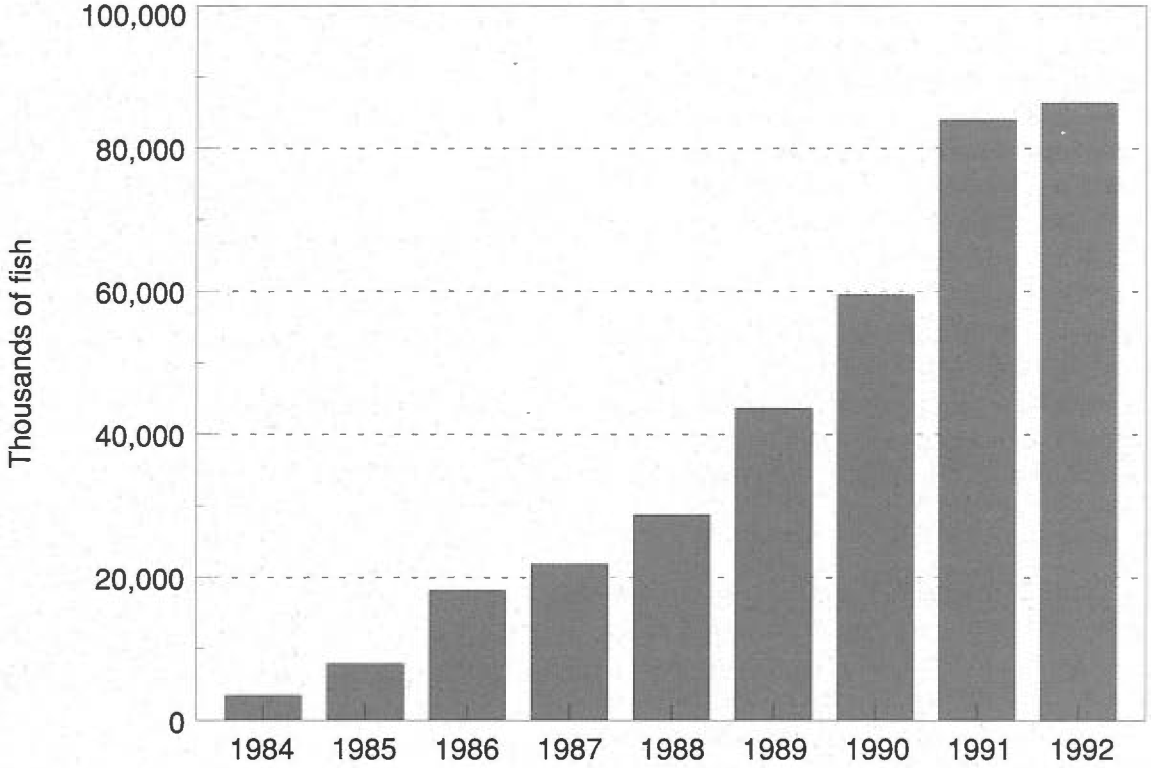


Figure 8-8. American shad population estimate in the Conowingo Dam tailrace, 1984–1992. Source: Foote et al. (1993).

aspects of the overall American shad restoration program contributed to the increasing numbers of this stock in the last decade, effective operation of the Conowingo fish lifts is essential to allowing shad to complete their life cycle. Recreational and commercial fisheries remain closed in Maryland waters, but American shad from Susquehanna River stock may be taken in the offshore intercept fishery (PPRP, 1991).

8.2.2 Benefits to Fisheries. There are presently no benefits of the Conowingo fish lifts to sport or commercial fisheries because the fishery is closed while the American shad stock is restored (Dumont and Foote, 1993).

8.2.3 Conclusions. As a result of the success of fish passage/protection facilities at Conowingo, and in accordance with an earlier settlement agreement, upstream hydroelectric licensees at Holtwood, Safe Harbor, and York Haven projects have completed design and cost analyses for similar facilities (USFWS, 1991). Final designs, including optimal placement of fish passage entrances, will be based on results of 1992 adult shad movement studies. These facilities would not be built simultaneously at all projects, but are to be phased in accordance with the number of fish approaching each dam. In October 1992, the three utilities operating the upstream hydroelectric dams agreed to construct two fish lifts at Holtwood by 1997, one fish lift at Safe Harbor by 1997, and one fish lift at York Haven by 2000 (Foote et al., 1993).

8.3 Mitigation Costs

8.3.1 Introduction. The mitigation cost analysis for the Conowingo hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The mitigation costs reported for Conowingo are for upstream mitigation. The downstream migrants pass through the turbines and no downstream mitigation costs were reported.

The cost information obtained and presented for this case study came from informal correspondence, telephone calls, and a site visit that greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

8.3.2 Cost Summary. The total 20-year cost for upstream fish passage/protection mitigation at Conowingo is $30.1 million. The average annual cost is $1.5 million and, based on the average annual generation of 1,738,000 megawatt-hours, the upstream mitigation cost per generated kilowatt-hour is 0.9 mills (Table 8-2).

The majority of costs result from capital (49%) and annual (41%) cost requirements (Figure 8-9). The lost generation costs, $79,600 annually during 1982–1990, doubled to $159,200 with the advent of the operation of the east-side lift in 1991. The cost year with the largest costs is 1990, when 41% of the costs occurred (Figure 8-10). This was the year the east-side lift was constructed. This lift cost almost four times as much as the west-side lift (both in 1993 dollars). The cost difference is driven by the differences in size and complexity; the west-side lift's operations can be partially performed on land.

8.4 Cost Descriptions and Assumptions

This section provides an explanation of the individual cost items and the assumptions and estimates required to quantify the items and derive individual and total costs. The item numbers correspond to the 20-year spreadsheet (Table 8-3) used to determine costs. All costs have been converted to 1993 dollars and are discussed as such.

8.4.1 Capital Costs.

1. **West-side fish lift (1972).** The west-side lift is a considerably smaller structure than the east-side fish lift, and it is assumed that this influences the differences in the two costs. The west-side lift was constructed in 1972 and is shown in 1982 for analysis purposes. The lift cost a total of $3,024,000 (1993 dollars).

2. **East-side fish lift.** The east-side lift was constructed in 1990 and started operating in 1991. The difference in the cost for this lift ($12.0 million) and the west-side lift ($3.0 million) is driven by the increased complexity of the east-side lift, including the inclusion of an exit channel to the headpond. The west-side lift is constructed on the west-side bank of the river and many of the lift-related functions are performed on the river bank. The higher cost east-side lift is located at the end of the power plant. in mid-stream, with no river bank to support lift-related operations. The east-side lift is more of a stand-alone lift and this is reflected in the higher lift cost.

Table 8-2. Costs incurred at the Conowingo project for upstream mitigation. Because of rounding, columns may not equal totals.

	20-year total ($)	Levelized annual costs ($)	Cost per kWh (mills)
Capital costs	15,006,000	750,000	0.43
Study costs	550,000	27,500	0.02
Annual costs	12,753,400	638,000	0.37
Lost generation costs	2,467,600	123,400	0.10
Total costs	30,777,000	1,538,900	0.9

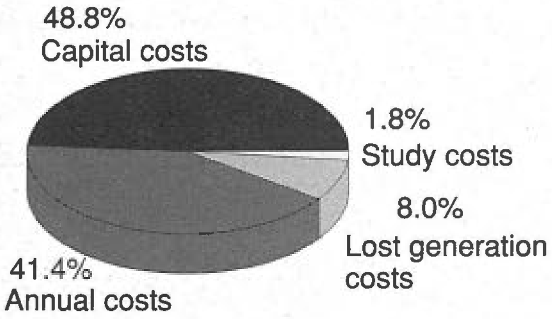


Figure 8-9. Total mitigation costs at Conowingo.

8.4.2 Study Costs.

3. **Radio telemetry.** A radio telemetry study was conducted from 1982 through 1989. The estimated total cost for the 8 years of study is $550,000.

8.4.3 Annual Costs.

4. **West-side fish lift O&M, monitoring** (Operations and maintenance, and fish count monitoring). This is the annual cost to operate the west-side fish lift and to monitor passage rates. This cost includes the costs for population species composition and transportation and mortality studies. These costs were not available as separate costs. The annual cost is $400,000, or 0.02 mills per kilowatt-hour.

5. **East-side fish lift O&M, monitoring** (Operations and maintenance, and fish count monitoring). This is the annual cost to operate the east-side fish lift and to monitor passage rates. For the cost analysis, this cost is assumed to start during 1991 as this is the first year the east-side fish lift

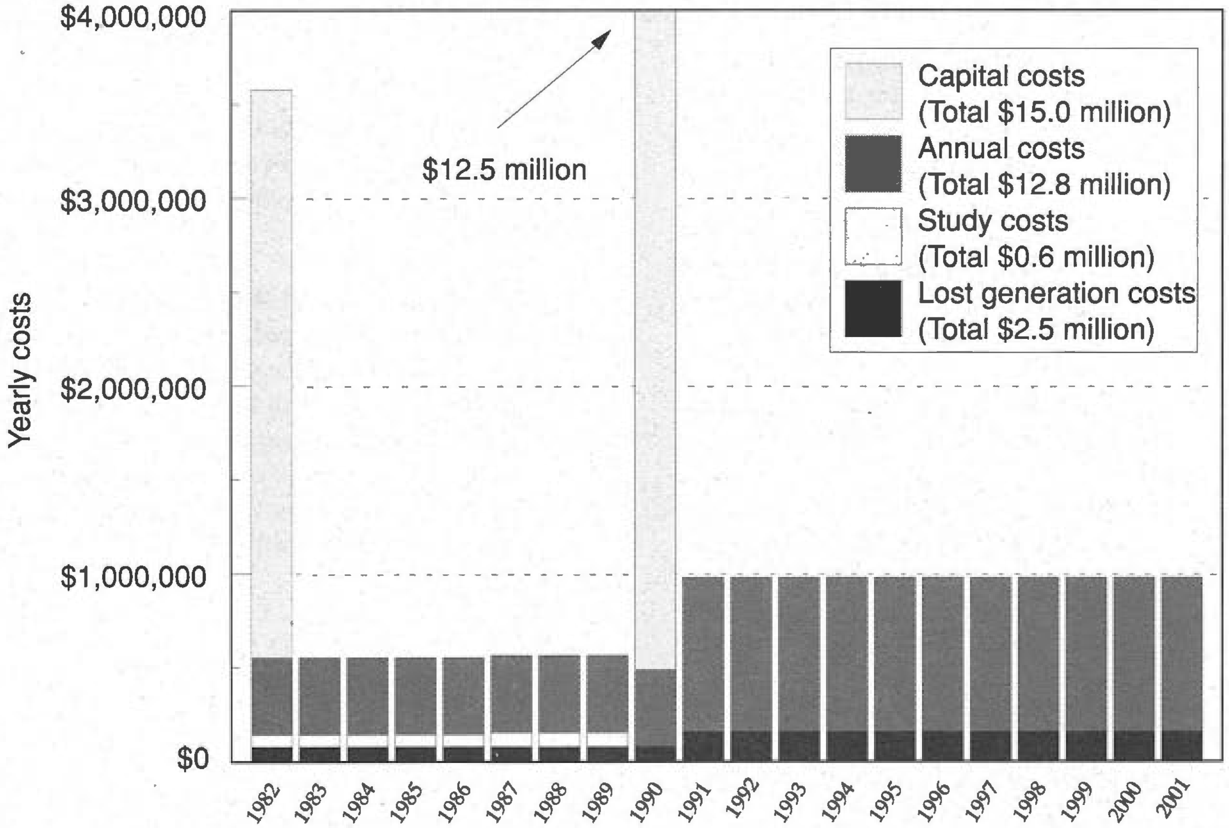


Figure 8-10. Yearly mitigation costs at the Conowingo project.

operated. This cost includes the costs for population species composition and transportation and mortality studies. These costs were not available as separate costs. The annual cost is $400,000, or 0.02 mills per kilowatt-hour.

6. **West-side fish lift reporting.** The annual cost for fish passage/protection mitigation-related reporting requirements is estimated at $11,400. For the cost analysis, this cost is incurred since 1982 as this is the first year of the 20-year cost analysis. In actuality, the annual costs have been incurred since 1972, the first year the west-side fish lift operated. The cost per kilowatt-hour is 0.01 mills.

7. **East-side fish lift reporting.** The annual cost for fish passage/protection mitigation-related reporting requirements is estimated at $11,400. The cost per kilowatt-hour is 0.01 mills.

8. **West-side fish lift lost generation.** To estimate a dollar value for the cost of lost generation resulting from attraction flow, several assumptions are applied.

   a. The licensee reports average annual generation of 1,738,000,000 kilowatt-hours and an average annual flow through the turbines of 29,000 cfs.

      29,000 cfs × 24 hours × 365 days = 254,040,000 cfs

      Dividing 1,738,000,000 kilowatt-hours by 254,040,000 cfs gives a kilowatt-hour value of 6.8 per cfs of water.

   b. The combined attraction flow for both lifts is estimated to be in the 300–900 cfs range. 600 cfs total is assumed for both lifts, and 300 cfs is assumed to be the average attraction flow for each individual lift.

   c. The lifts operate for 12 hours a day (7 a.m. to 7 p.m.), 65 days a year (April 12 to June 15). The total per lift is 780 hours per year (12 × 65).

   d. The actual per kilowatt-hour value of energy is unknown. A value of $0.05 is assumed for the analysis.

Based on the above assumptions, the computed annual lost generation value for the west-side fish lift attraction flows is

6.8 kWh/cfs × 300 cfs × 780 hours/year × $0.05 = $79,600.

The west-side fish lift lost generation is assumed for the entire 20-year analysis. The total is $1,592,000, or 0.05 mills per kilowatt-hour of generation.

9. **East-side fish lift lost generation.** The same assumptions are applied to this cost as are used to derive the yearly cost of $79,600 for the west-side fish lift. The east-side fish lift started operating during the spring of 1991, so 11 years of costs are incurred at a total of $875,600, and the per kilowatt-hour cost is again 0.05 mills.

Table 8-3. Conowingo mitigation costs.

Conowingo Project—Mitigation Cost Analysis—All Values in 1993 Dollars

11/08/93	–11	–10	–9	–8	–7	–6	–5	–4	–3	–2	–1	0	1	2	3	4	5	6	7	8	
	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	TOTALS
Capital Costs																					
1) West–side fish lift (1972)	$3,024,000																				$3,024,000
2) East–side fish lift									$11,982,000												$11,982,000
Study costs																					
3) Radio telemetry	$65,000	$65,000	$65,000	$65,000	$65,000	$75,000	$75,000	$75,000													$550,000
Annual costs																					
4) West–side fish lift O&M, monitoring	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$8,000,000
5) East–side fish lift O&M, monitoring										$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$400,000	$4,400,000
6) West–side fish lift annual reporting	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$228,000
7) East–side fish lift annual reporting										$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$11,400	$125,400
Lost generation costs																					
8) West–side fish lift lost generation	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$1,592,000
9) East–side fish lift lost generation										$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$875,600
Subtotal capital	$3,024,000	$0	$0	$0	$0	$0	$0	$0	$11,982,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$15,006,000
Subtotal study costs	$65,000	$65,000	$65,000	$65,000	$65,000	$75,000	$75,000	$75,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$550,000
Subtotal annual costs	$411,400	$411,400	$411,400	$411,400	$411,400	$411,400	$411,400	$411,400	$411,400	$822,800	$822,800	$822,800	$822,800	$822,800	$822,800	$822,800	$822,800	$822,800	$822,800	$822,800	$12,753,400
Subtotal lost generation costs	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$79,600	$159,200	$159,200	$159,200	$159,200	$159,200	$159,200	$159,200	$159,200	$159,200	$159,200	$159,200	$2,467,600
Total Expenses—1993 Dollars	$3,580,000	$556,000	$556,000	$556,000	$556,000	$566,000	$566,000	$566,000	$12,473,000	$982,000	$982,000	$982,000	$982,000	$982,000	$982,000	$982,000	$982,000	$982,000	$982,000	$982,000	$30,777,000

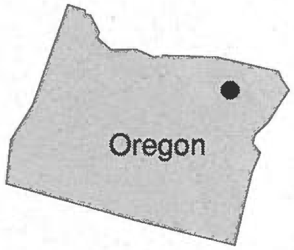
Notes: 4.5% Index rate used to present values as 1993 dollars

9. JIM BOYD CASE STUDY

9.1 Description

The Jim Boyd project (FERC number 07269) is located at river mile 10.0 of the Umatilla River (Figure 9-1), within the Columbia River Basin, in Umatilla County, Oregon. It is a run-of-river development utilizing the hydraulic potential of approximately 31 feet of stream profile and has a licensed hydraulic capacity of 500 cfs. The project (Figure 9-2) began operation in December 1986 and generates an average of 4,230 megawatt-hours of electrical energy annually. The powerhouse contains four 300 kilowatt generating units. The project has a design head of 33 feet. Water is diverted to the power canal by a 3.5-foot high concrete diversion weir with a span of 120 feet. The power canal intake structure is located on the left bank and is equipped with trash racks, fish screens, and flow bays (Figure 9-3). The power canal is 5,300 feet long.

The project is situated at a stream location where both upstream and downstream migration of anadromous salmonid fishes, primarily spring chinook salmon and steelhead trout, can be affected. Anadromous salmonids do not spawn near the project site. Resident fish species inhabit areas above and below the project. The resident species are primarily rainbow trout, mountain whitefish, largescale sucker, and squawfish.



A notched opening of the diversion weir, for downstream and upstream fish passage/protection (Figure 9-4), a downstream juvenile fish passage/protection structure, and a tailrace adult barrier structure are operated to protect anadromous fish from the project's operation.

The downstream juvenile fish passage/protection system is placed downstream of a trash rack and is angularly oriented to a training wall structure (Figure 9-5). The training wall structure provides a pressure head for maintaining constant sweeping (2.0 fps minimum) and approach (0.5 fps maximum) velocities across the screen facings, to facilitate juvenile fish out-migration past the project intake structure. The juvenile fish

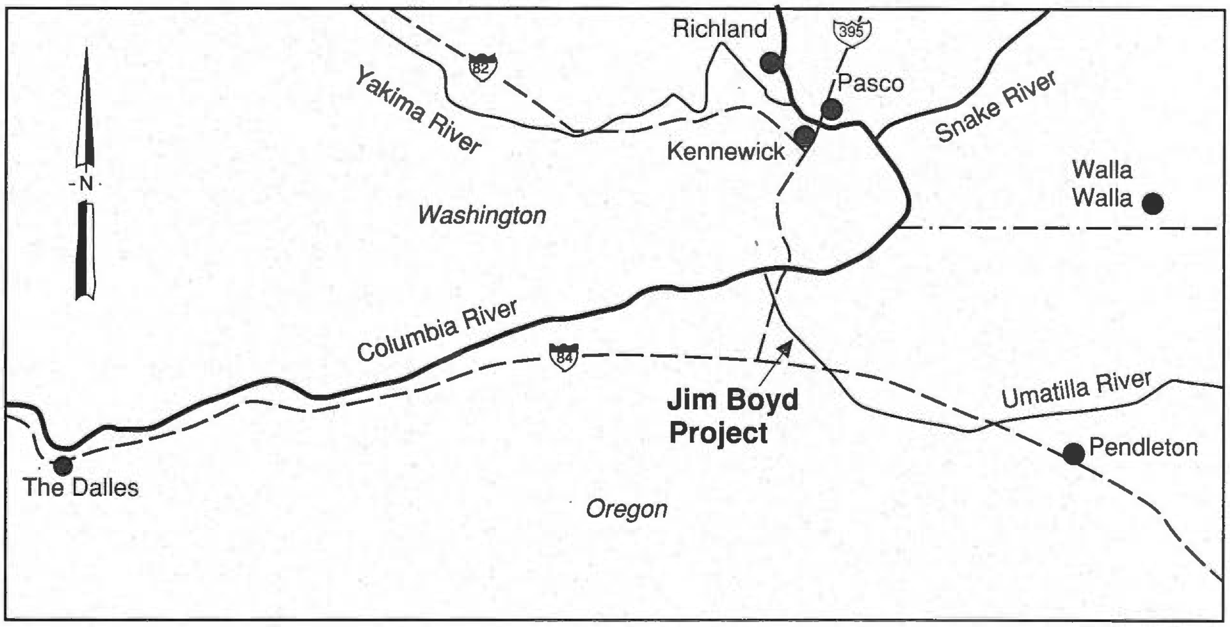


Figure 9-1. Location of the Jim Boyd project on the lower Umatilla River.

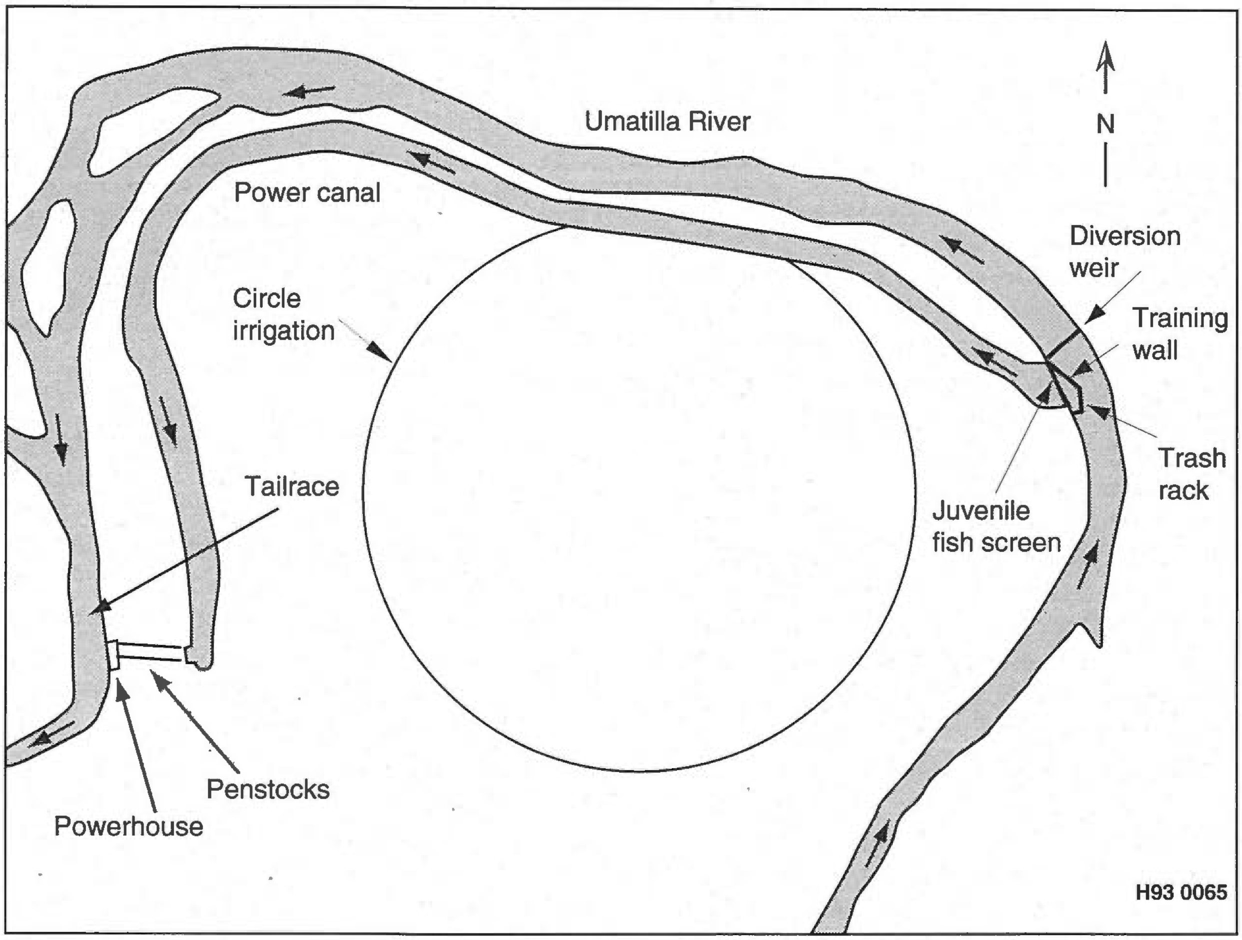


Figure 9-2. Overview of the Jim Boyd project.

screening system contains 10 intake bays with inclined, 16 GA stainless steel perforated fish screens (11.5-foot width by 12.0-foot height) with mesh openings of 0.5-inch width by 0.125-inch depth (Figures 9-6 and 9-7). The juvenile fish bypass of the screen structure is located at the downstream endpoint where the fish screen and training wall structures meet; the fish bypass of the juvenile screen structure is a 3-feet wide by 5-feet deep opening with a slide gate mechanism. The fish screen structure was designed in manner to facilitate self-cleaning of debris from the screen facings by hydraulic action, but a mechanical travelling brush is used for cleaning fine debris from the facings.

A notched opening in the diversion weir (left bank) serves as a mechanism for upstream passage of adult fish. This notch is 12 feet wide by 1.5 feet deep, and is located on the left bank of the diversion weir.

The adult fish barrier structure of the project's tailrace is constructed of steel and is approximately 28 feet high and 51 feet wide. The barrier consists of vertical bars (2.0 by 0.25 inches) with 1.5-inch wide spacings.

9.1.1 Fish Resource Management Objective of Mitigation. The resource management objective of the upstream and downstream passage/protection facilities for the Jim Boyd project is predicated on the fisheries agencies policy that no induced mortalities of anadromous and resident fish species will result from the operation of the project components. The objectives include specifications that the fish passage/protection structures must be operated in the

Figure 9-3. Jim Boyd trash racks, training wall and fish screen support structure.

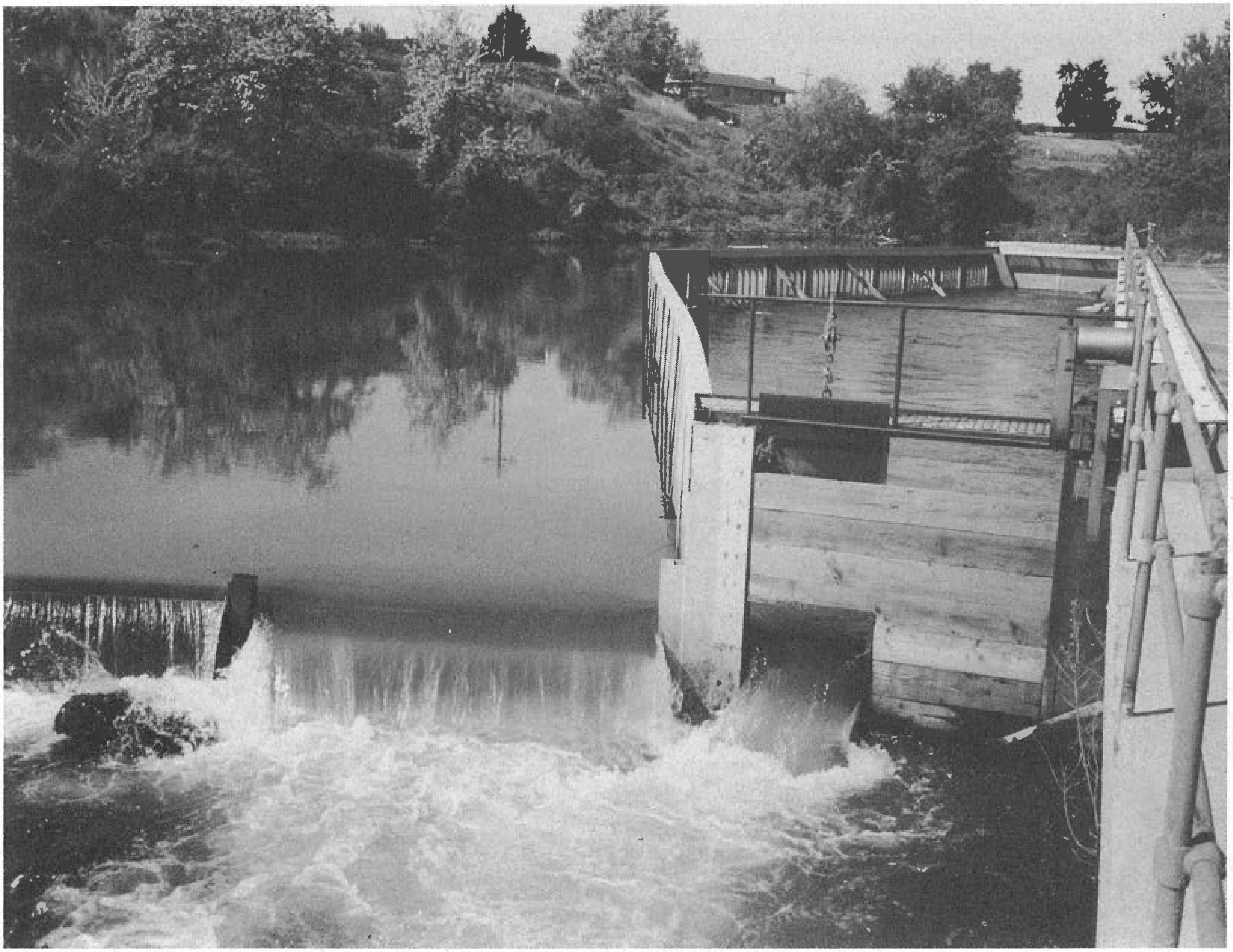


Figure 9-4. Weir notch in diversion and fish attraction gate at Jim Boyd. Viewed from downstream.

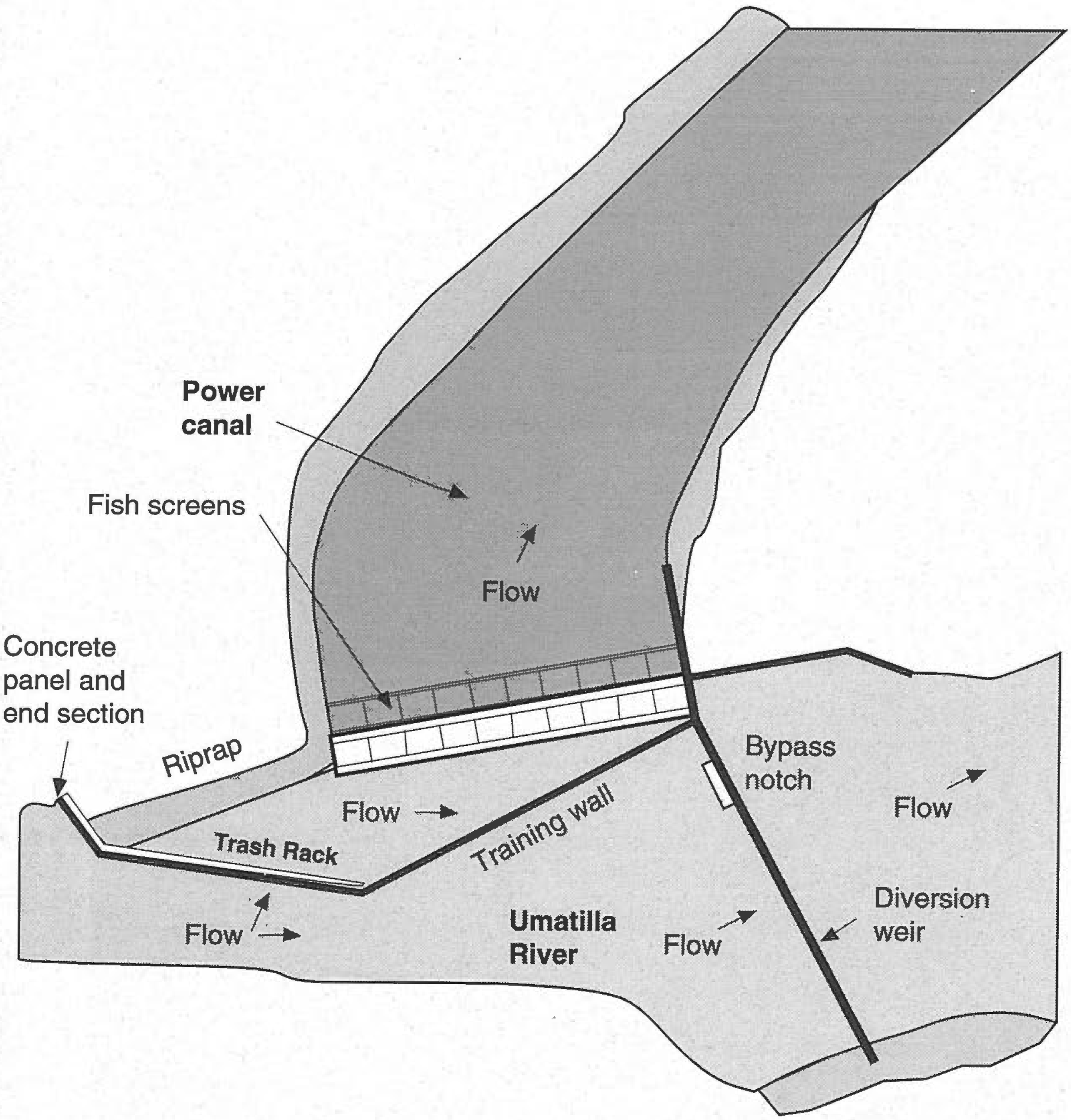


Figure 9-5. Overview of Jim Boyd diversion weir and fish protection facilities.

manner agreed upon by the fisheries agencies and the project owner, velocities in the juvenile and adult fish passage/protection structures (fish screens and notched weir) must be maintained according to specified criteria (velocities past the screen surface of $\geq$ 2.0 fps and through the screen openings of $\leq$ 0.5 fps), and upstream migration of adult fish (e.g., spring Chinook and steelhead trout) within the project bypass reach (river miles 9 and 10) must not be abnormally delayed by project operation.

9.1.2 Monitoring Methods. As required by the terms and conditions of the FERC permit, the project funded a study by the Oregon Department of Fish and Wildlife to evaluate the impacts of

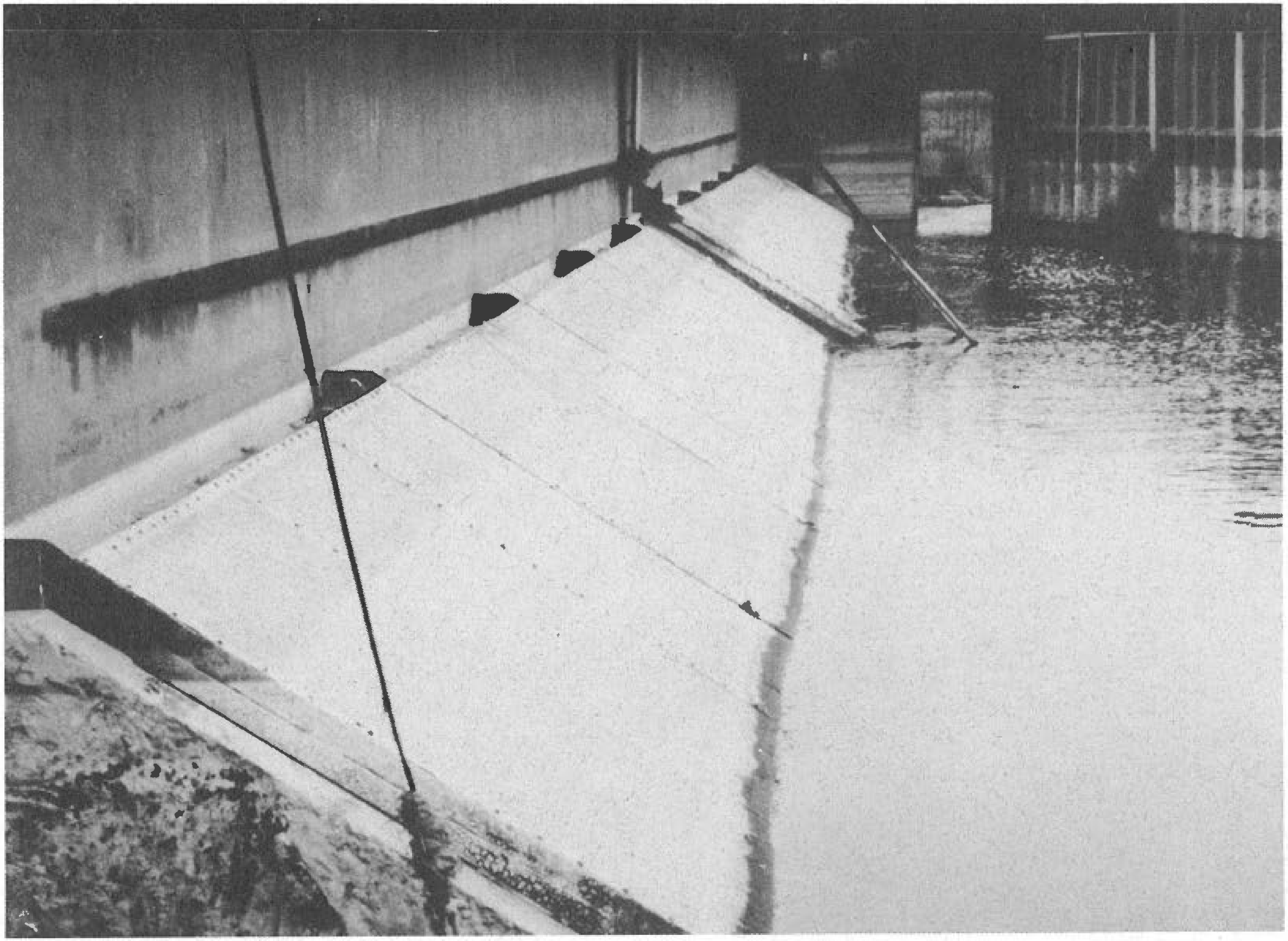


Figure 9-6. Jim Boyd power canal fish screens during low water.

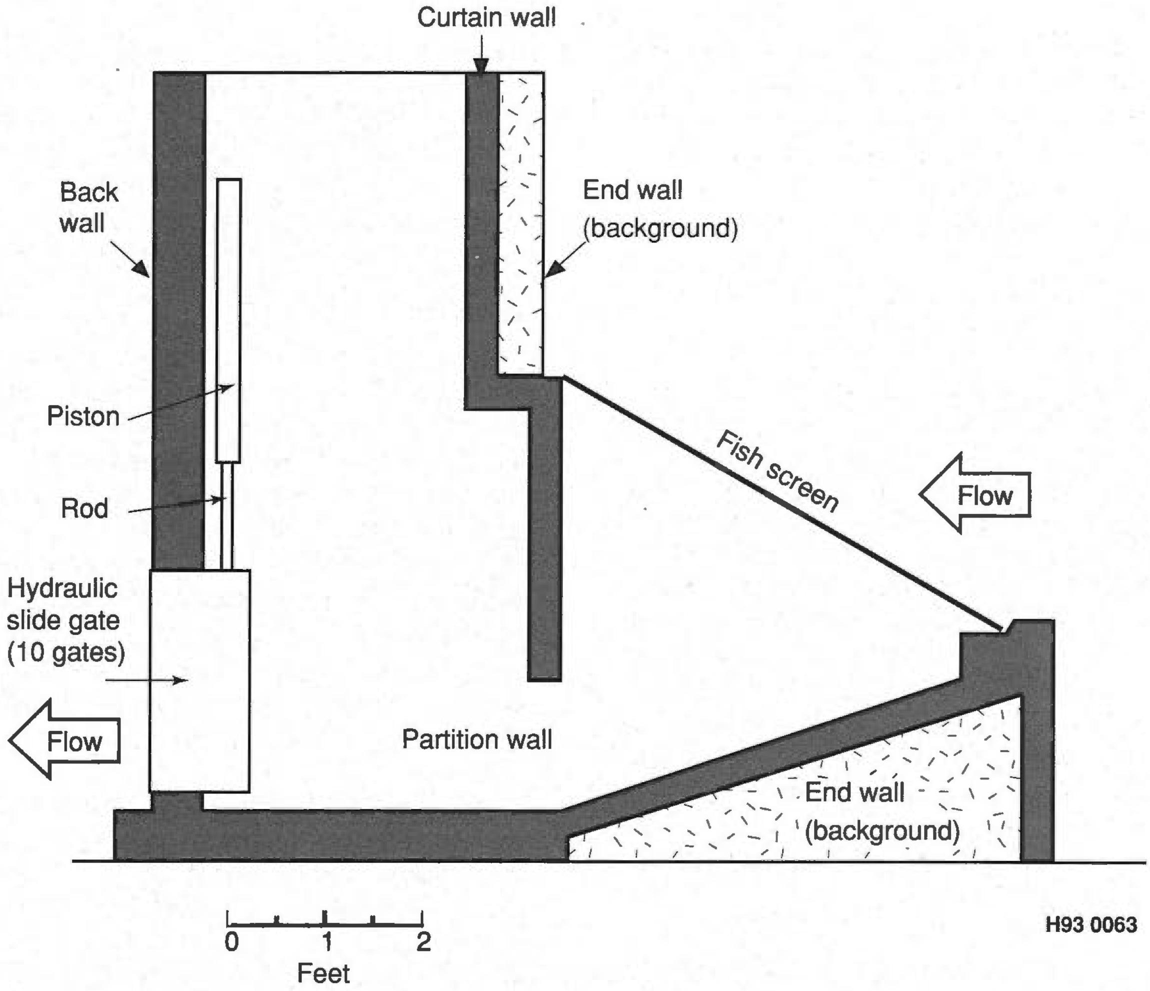


Figure 9-7. Cross-sectional view of Jim Boyd fish screen structure.

project operational components (diversion, screening, canal, powerhouse, and tailrace barrier structures) on anadromous fish within the river reach between river miles 9 and 10. The Oregon Department of Fish and Wildlife conducted monitoring and testing activities in accordance with an agreed upon evaluation plan. This study determined that project components are operating according to the terms and conditions set forth in the FERC licensing permit.

Fish agencies personnel (primarily Oregon Department of Fish and Wildlife, and Confederated Tribes of the Umatilla Indian Reservation) periodically monitor the project to determine that the project is operating according to agreed upon fish protection criteria for upstream and downstream passage/protection facilities. This periodic monitoring activity encompasses visual observations for (a) impingement on the screen facings and entrainment of juvenile fishes in the power canal; and (b) abnormal delay of adult migrants at the powerhouse tailrace and at the diversion weir structure.

9.1.3 Performance of Mitigation. To date, fish passage/protection facilities of the project have performed in the manner that impacts (i.e., induced mortalities) to fisheries resources have been negated from the operation of these facilities.

9.2 Mitigation Benefits

9.2.1 Benefits to Fish Populations. The downstream and upstream fish passage/ protection components of this project are monitored, and currently achieve the performance standards for protection of anadromous fish species migrating past the project. The direct benefits of the fish passage/protection facilities to fish populations cannot be determined presently due to the remnant status of the spring chinook salmon and steelhead trout stocks within this stream basin. The benefits of these passage/protection facilities should be realized in the future as these fish stocks rebuild.

9.3 Mitigation Costs

9.3.1 Introduction. The mitigation cost analysis for the Jim Boyd hydroelectric plant consists of a cost summary section; a cost descriptions and assumptions section, which describes each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal correspondence. Site visits greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

9.3.2 Cost Summary. Most mitigation efforts at hydroelectric plants can be identified as intended to facilitate the upstream or downstream migration of a species or several species of fish. For instance, screens are usually intended to provide passage/protection for downstream migration, and fishways provide upstream passage/protection. At the Jim Boyd project this distinction is not always well defined. For instance, as part of the upstream mitigation, the training wall, with its 17 degree angle to the fish screens, is intended to provide velocities that would prevent adults from lingering in front of the screens and to ensure adequate velocities through the fish gate for the upstream migration attraction of adults. For the purpose of downstream mitigation, the training wall is also used to control the velocities past the fish screen surfaces at 2 fps as an aid in the cleaning of the screens. The louvered trash rack at the upstream end of the training wall also has dual functions. It was designed to prevent large debris from entering into the fish screen area and at the same time encourage upstream migrating adults to pass through the trash rack. Similarly, the studies that were performed were not demarcated for either upstream of downstream mitigation. Because of these multipurpose functions, the costs for the Jim Boyd project are not broken down into upstream of downstream mitigation costs. The costs are discussed in terms of capital, study, annual, and lost generation costs.

Some of the initial capital and study costs were encountered before plant operations commenced. These costs were converted to 1993 dollar values based on the year the costs were incurred and shown as 1987 costs as this was the inception of plant operations. The cost analysis assumed 20 years of operation to recoup these costs. If the analysis assumed to post these costs to the pre-1987, pregeneration period, then the estimated per kilowatt-hour mitigation costs would be higher because no generation occurred prior to 1987 to recover these costs.

The majority of the mitigation costs at the Jim Boyd hydroelectric project have been for capital equipment and studies. Mitigation-required structures and studies have comprised 46% (Figure 9-8) of the total 20 years of costs. The total estimated mitigation cost of $1,785,260 may not be viewed as substantial when compared to mitigation costs at large hydroelectric facilities such as those located on the Colombia or Snake Rivers. But viewed in the context of project size, the mitigation costs take on a different magnitude. Based on the average annual energy production of 4,230 megawatt-hours, the cost of mitigation is 21.1 mills (Table 9-1) per kilowatt-hour of generated electricity. This is the equivalent of over 2 cents per kilowatt-hour for mitigation costs.

Forty-nine percent of all costs (Figure 9-9) were occurred as up-front (1987) costs. Because the benefits are enjoyed over time, a 20-year levelized annual cost was used to reflect accurately the costs of mitigation at the Jim Boyd project in terms of the levelized benefits.

This project has a year-round minimum instream flow requirement of 100 cfs. This minimum flow is supplemented with additional flows for upstream migration during September,

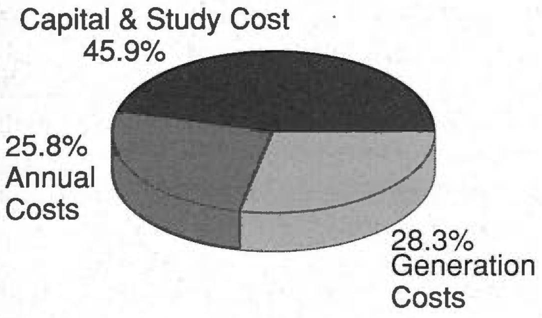


Figure 9-8. Capital, annual, and generation costs for mitigation at the Jim Boyd project.

October, and November. Only these 3 months of supplemental flows that are required for upstream migration have been included in the mitigation costs. If the mitigation costs are considered aside of lost generation costs (6.0 mills) the per kilowatt-hour costs for mitigation are 15.1 mills, or 1.5 cents per kilowatt-hour.

9.4 Cost Descriptions and Assumptions

This section provides an explanation of the individual cost items and the assumptions and estimates required to quantify the items and derive individual and total costs. The item numbers correspond to the 20-year spreadsheet (Table 9-2) used to determine costs. All costs have been converted to 1993 dollars and are discussed as such.

Table 9-1. Jim Boyd costs incurred for upstream and downstream mitigation.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital and study	820,260	41,010	9.7
Annual	460,000	23,000	5.4
Lost generation	505,000	25,250	6.0
Total costs	1,785,260	89,260	21.1

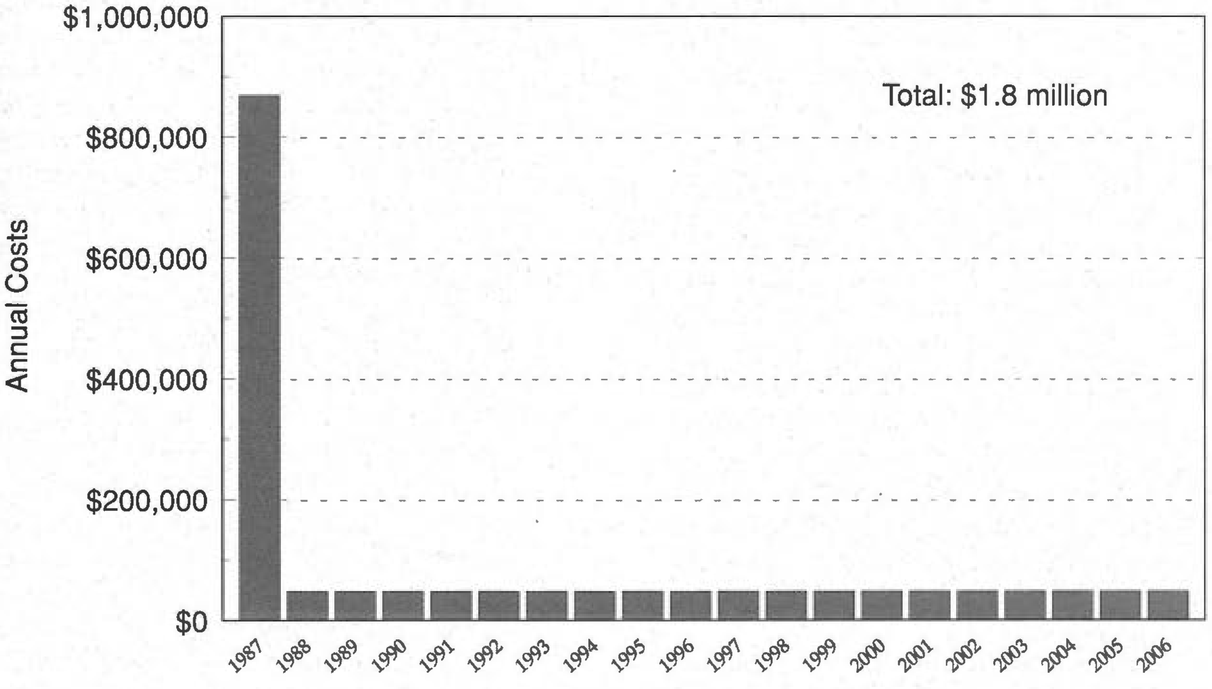


Figure 9-9. Yearly costs of upstream and downstream mitigation at the Jim Boyd project.

9.4.1 Capital Costs.

1. **Concrete Support Structure (1986).** Installed in 1986, this structure supports the fish screens. It is the single largest cost at $326,620.

2. **Fish Screen (1986).** Installed in 1986 at a cost of $54,440, the stationary screens are set at an angled and have a traveling brush for cleaning.

3. **Gates & Hydraulics (1986).** The gates and hydraulic systems associated with the power canal fish screens were installed in 1986 at a cost of $27,220.

4. **Engineering & Design—Fish screens (1985).** Incurred in 1985, the engineering and design costs for the fish screen system, the system hydraulics associated with the fish screen system, and the fish passage/protection facilities cost $71,110.

5. **Weir, Training Wall, Trash Racks (1985).** The total cost to install the weir, training wall, trash racks, and adult fish barrier structure was $213,320. Several of these items provide multiple functions in relation to upstream and downstream fish mitigation. The louvered trash racks at the upstream end of the training wall were designed to prevent large debris from entering into the fish screen area and at the same time encourage upstream migrating adult to pass through. The 17 degree angle of the training wall to the fish screens produces an even velocity past the screen surface from the upstream to the downstream end. Water flow through the fish screens and into the power canal is even throughout the length of the screens with no hot spots (areas where one section of the screen passes more water than another section). Velocities through the screen openings do not exceed 0.5 fps.

   The need and positioning of the training wall is multipurpose. Screening criteria established by the National Marine Fisheries Service and by the Oregon Department of Fish and Wildlife requires a velocity past the screen surface of no less than 2 fps. The velocity requirement is intended to aid in the cleaning of the fish screens and to prevent lingering of either adults or juveniles in the screen area.

   The weir was constructed to provide hydraulic control to ensure that flows comply with criteria required for proper screen operation and to ensure minimum flows for upstream and downstream migration. Adult migration during the fall requires a minimum of 150 cfs or 200 cfs, with the flow concentrated in two separate fishways. One fishway is the notch provided in the weir, the other is the gate located at the downstream end of the fish screens and training wall.

9.4.2 Study Costs.

6. **Study Costs ('81 & '82).** This study, conducted during 1981 and 1982, determined the stream flow quantities required for both fish habitat and upstream mitigation. During the 2-year study, a fisheries biologist/engineer observed three sections of a 1 mile bypass reach of the Umatilla River. The three sections were selected by the National Marine Fisheries Service, the Oregon Department of Fish and Wildlife, and the United States Fish and Wildlife Service as cross sections to determine river width, depth, and velocity over a range of flows. Water temperature, sediment, and water quality tests were also conducted. The bypassed reach of the stream was also studied to identify potential spawning beds. The study objective was to determine the magnitude of instream flows required both for instream habitat and upstream passage. It was difficult to determine what percentage of study costs should be assumed as an instream flow or upstream mitigation cost. While the exact percentage of study costs that should be assigned to upstream mitigation is uncertain, it was recognized that some cost should be assigned to best rep-

resent the true costs. For the sake of simplicity and the lack of better information, half the known study cost is assumed to be for upstream mitigation. To arrive at a 1993 dollar value each half cost was further halved between the years 1981 and 1982, and inflated to 1993 dollars. The estimated total cost for the upstream mitigation 1981 and 1982 study is $62,230 (1993 dollars).

7. **Study Costs (1987).** A study was conducted in 1987 by the Oregon Department of Fish and Wildlife and paid for by the project licensee. It was a radiotelemetry study to monitor salmonid movements in the project vicinity and to collect baseline data on travel time and behavior that would be used to determine if project operations were causing any delay or injury to adult salmonids. It was also used to assist project operations to develop operating procedures that optimize hydraulic conditions. The total study cost was $65,320.

9.4.3 Annual Costs.

8. **Operations & Maintenance.** This is the estimated yearly cost ($20,000) for mitigation operations and maintenance. The project is observed 24 hours a day for the 7 months a year it operates to ensure that the fish screens and trash racks are kept clean. This cost includes the actual cleaning of the screens and trash racks.

9. **Mitigation Related Management.** The licensee reports that approximately 100 hours are spent annually on mitigation issues such as agency and local meetings. Assuming an hourly rate of $30, it is estimated that this function costs $3,000 per year.

9.4.4 Lost Generation Costs.

10. **Generation Lost—Upstream Mitigation.** The Jim Boyd project has a minimum stream flow requirement of 100 cfs from December 1 through August 30. During the September 1 through November 30 period, a minimum flow of 200 cfs is required for a 21 day period during peak upstream migration. The minimum stream flow during the remaining 70 days of the September 1 through November 30 period is 150 cfs. The increased minimum flows (beyond the original 100 cfs minimum flow) during the September 1 through November 30 period is for the upstream migration of salmonids. To measure the lost generation due to upstream mitigation the following assumptions are employed:

- 100 cfs is the year-round minimum instream flow requirement
- An additional 100 cfs (200 cfs total) is required for 21 days
- An additional 50 cfs (150 cfs total) is required for 70 days
- Each cfs has a kilowatt value of 2.21.

The additional 100 cfs, 21-days requirement equates to a kilowatt-hour loss of 100 (cfs) × 2.21 (kWh value) × 24 (hours) × 21 (days) = 111,384 kilowatt-hours.

The additional 50 cfs, 70-days requirement equates to a kilowatt-hour loss of 50 (cfs) × 2.21 (kWh value) × 24 (hours) × 70 (days) = 185,640 kilowatt-hours.

The total kilowatt-hour generation loss for upstream mitigation is111,384 kWh + 185,640 kWh = 297,024 kilowatt-hours.

With an average energy value of 85 mills, the annual dollar value of lost generation due to upstream mitigation is 297,024 kWh × 85 mills = $25,250.

The 20-year total generation loss for upstream mitigation is $505,000.

Table 9-2. Jim Boyd mitigation costs.

Jim Boyd Project—Mitigation Cost Analysis—All Values in 1993 Dollars

9/09/93	–6	–5	–4	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	TOTALS
Capital Costs																					
1) Concrete Support Structure (1986)	$326,620																				$326,620
2) Fish Screen (1986)	$54,440																				$54,440
3) Gates & Hydraulics (1986)	$27,220																				$27,220
4) Engineering & Design—Fishscreens (1985)	$71,110																				$71,110
5) Weir, Training Wall, Trash Racks (1985)	$213,320																				$213,320
Study Costs																					
6) Study Costs ('81 & '82)	$62,230																				$62,230
7) Study Costs (1987)	$65,320																				$65,320
Annual Personnel Cost																					
8) Observations, Operations & Maintenance	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$400,000
9) Mitigation Related Management	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$60,000
Annual Generation Lost																					
10) Generation Lost—Upstream Mitigation	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$505,000
Subtotal Capital and Study Costs	$820,260	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$820,260
Subtotal Annual Costs	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$460,000
Subtotal Annual Costs	$843,260	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$23,000	$1,280,260
Generation Lost	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$25,250	$505,000
Total Expenses—1993 Dollars	$868,510	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$48,250	$1,785,260

Notes: 4.5% Index rate used to present values as 1993 dollars
Subtotal Capital and Study Costs include items: 1, 2, 3, 4, 5 & 6
Subtotal Annual Costs include items: 7, 8, 9 & 10

10. KERN RIVER NO. 3 CASE STUDY

10.1 Description

The Kern River No. 3 project (FERC number 2290) is a run-of-river project in Kern and Tulare counties, California (Figure 10-1). The project has a total installed capacity of 36.8 megawatts and began operation in 1921.

The Kern River No. 3 project incorporates both a fish ladder (Figure 10-2) and fixed intake screens (Figure 10-3). The fish ladder is a 9-step, Alaska steeppass design. The ladder was installed in the early 1960s to allow the upstream movement of resident rainbow trout past the approximately 26-foot-high diversion dam.

Fixed barrier screens were installed at the diversion dam prior to 1960. The total screen array consists of eight panels, each of which is approximately 6-feet wide by 11-feet high. Bars in the screens are 0.25 inches thick and are spaced 0.5 inches apart. Screen sections can be pivoted on vertical bars to parallel the intake flow in order to prevent clogging under icing conditions. The barrier screens are intended to prevent the entrainment of resident trout into the intake tunnel. There is no current means for downstream passage of screened fish, but a provision for downstream passage has been incorporated into a proposed design for a continuous sandbox flushing system.

10.1.1 Fish Resource Management Objectives of Mitigation. The Kern River both above and below the project has been managed as a put-and-take rainbow trout fishery, supported by the California Department of Fish and Game's stocking of hatchery rainbow trout. The California Department of Fish and Game proposes to manage the Kern River upstream of Lake Isabella for Kern River rainbow trout, a distinctive, heavily spotted trout from the upper Kern River (Moyle, 1976). This trout management area encompasses the Kern River No. 3 project. Consequently, the California Department of Fish and Game has asked the project operator (Southern California Edison) to temporarily block the fish ladder to prevent the upstream migration of previously stocked rainbow trout, as well as squawfish, a possible predator of trout. Because other agencies also have jurisdiction over the Kern River resources, the California Department of Fish and Game request to close the Kern River No. 3 fish ladder has been given to them for their concurrence (Rabone, personal communication).

Agencies would like Southern California Edison to modify the screens to incorporate a smaller mesh or slot size in order to protect Kern River rainbow trout fry, and FERC is asking for studies of the effectiveness of the existing screens. As an alternative to studies and possible screen modifications, the California Department of Fish and Game has requested that the project operator establish a trust fund. The trust fund proceeds would fund the California Department of Fish and Game's Upper Kern River Fishery Management Plan project (Rabone, personal communication).

10.1.2 Monitoring Methods. The fixed screens were monitored in 1964 and 1965 by releasing rainbow trout of different size classes into the sandbox and subsequently recovering them. Because the results were inconsistent, FERC has requested updated studies of fish mortality and the effectiveness of the screens in preventing entrainment. These studies have not yet been carried out, nor has a decision been made on the screens or trust fund agreement.

The fish ladder was monitored in March, 1990 during the rainbow trout spawning season. Every other day the ladder was observed for the presence of fish. In a total of 33 days, nine rainbow

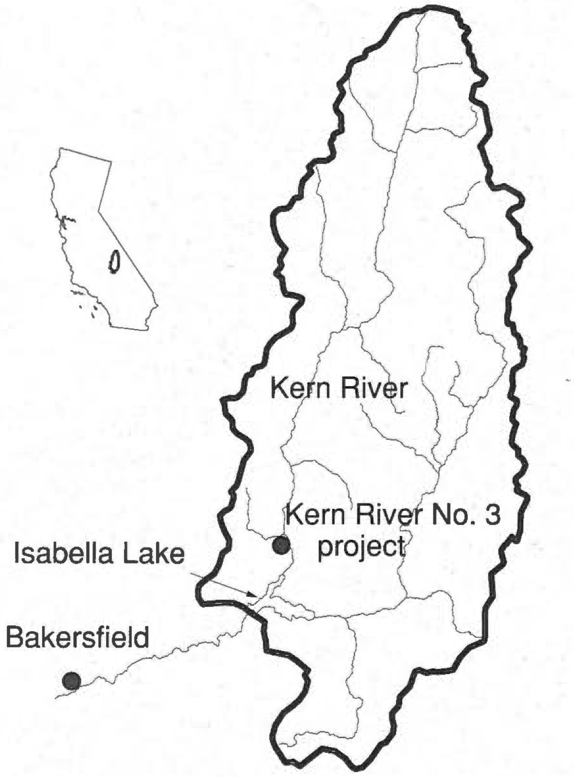


Figure 10-1. Location of the Kern River No. 3 project on the Kern River.

trout and one Sacramento squawfish were seen using the ladder (Rabone, personal communication). No estimates were made of the numbers of these fish available for passage up the ladder.

10.1.3 Performance of Mitigation. Because little performance monitoring has been conducted for the fish passage/protection measures, the effectiveness of these devices is not proven. However, based on the California Department of Fish and Game's request to close the ladder in order to prevent the future movement of these species into the reach above the diversion, the fish ladder must allow the upstream passage of hatchery-planted rainbow trout as well as squawfish past the diversion dam. The reach above the diversion is the location of the wild Kern River rainbow trout population. This request has not yet been approved by other resource agencies.

10.2 Mitigation Benefits

10.2.1 Benefits to Fish Populations. No information is available about the benefits of these mitigative measures to resident rainbow trout populations.

10.2.2 Benefits to Fisheries. No information about the effects of these mitigative measures on the recreational fishery.

10.3 Mitigation Costs

10.3.1 Introduction. The mitigation cost analysis for Kern River No. 3 consists of a cost summary section, discussing the mitigation costs in general terms; an upstream fish passage/protection system section which discusses the upstream mitigation costs; and a downstream fish passage/protection system section, discussing the downstream mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal written correspondence and from telephone calls. A site visit greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

10.3.2 Cost Summary. A 30-plus-year-old fish ladder is used to provide upstream fish passage for the resident rainbow trout at an estimated cost of 0.05 mills per kilowatt-hour of generated electricity. The fish screens used for downstream mitigation are also 30-plus years old and their estimated cost is 0.04 mills per kilowatt-hour of generated electricity.

The historical costs of upstream and downstream mitigation of the plant are limited to the two capital costs (Table 10-1). The number of years that the ladder and screen have been used may suggest that applying the 20-year levelized annual cost to this plant may not be appropriate. However, the 20-year levelized annual cost has been used as a standard throughout this report to establish costs per kilowatt-hour of electricity. The total cost of 0.09 mills per kilowatt-hour equates to about one-hundredth of a cent per kilowatt-hour.

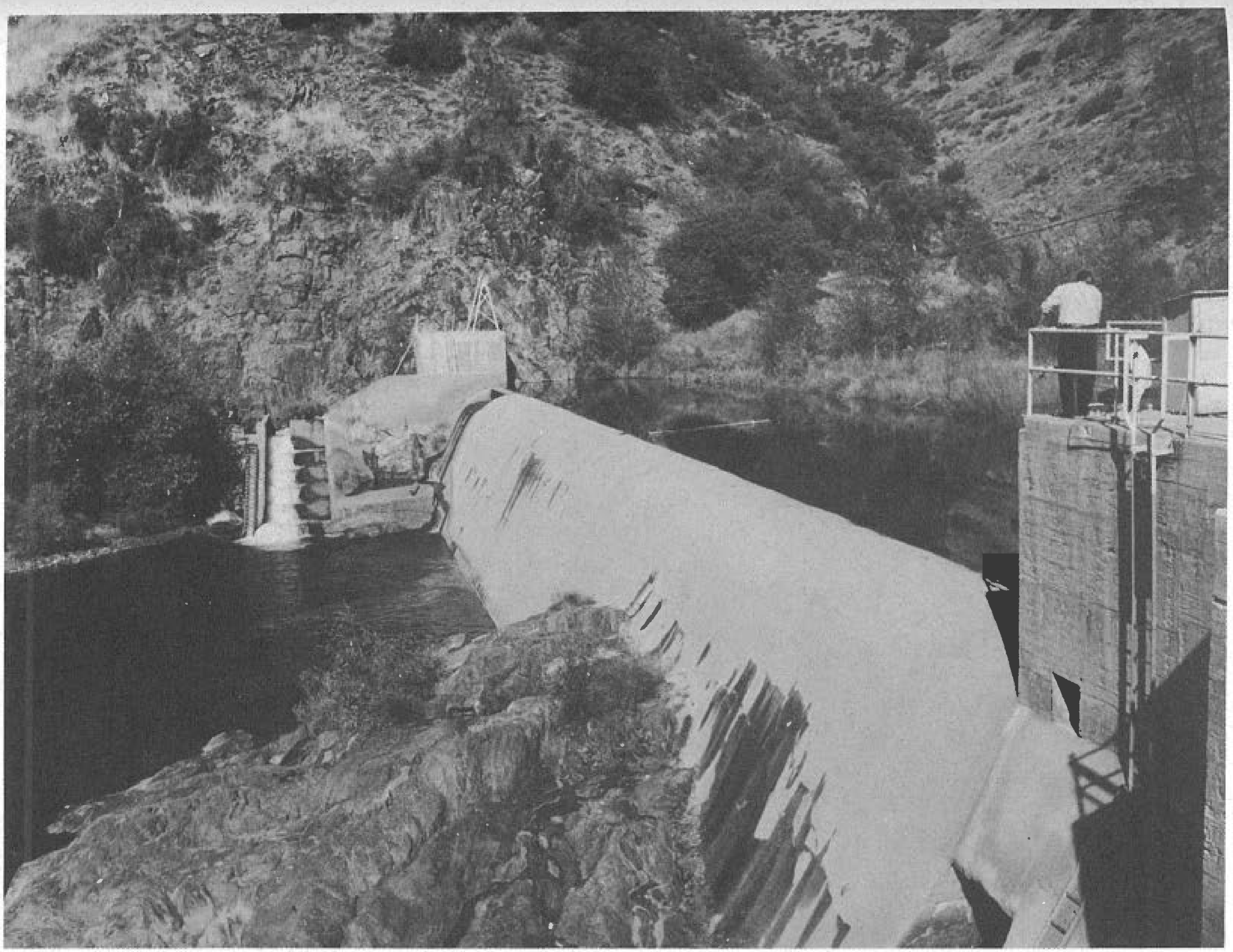


Figure 10-2. Kern River No. 3 Alaska steeppass fish ladder (left ladder) and original concrete ladder and diversion dam.

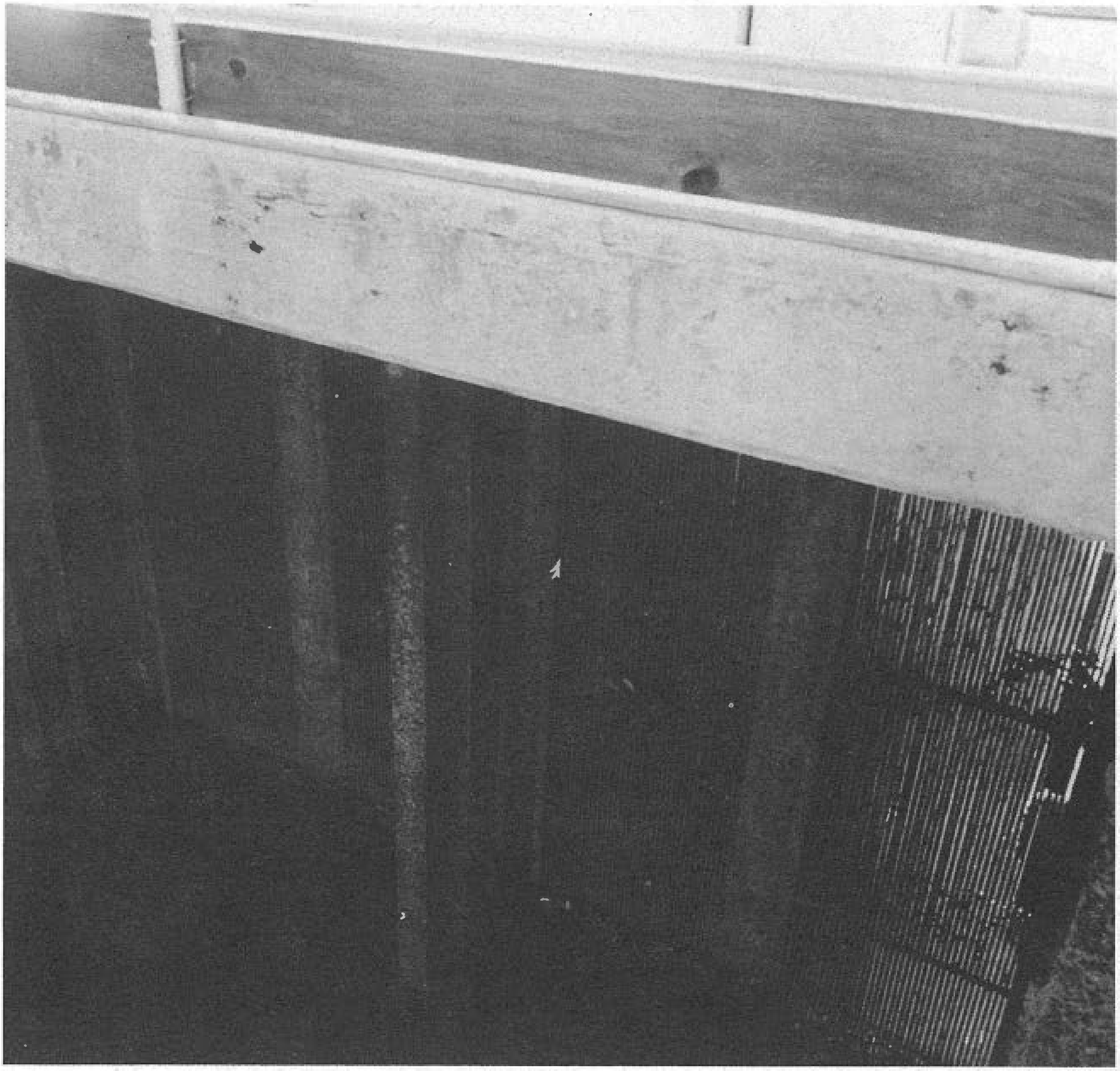


Figure 10-3. Kern River No. 3 fish protection screens located at the downstream end of the sand box.

Table 10-1. Kern River No. 3 project's upstream and downstream mitigation costs.

Capital costs	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Fish ladder	176,000	8,800	0.05
Fish screens	154,000	7,700	0.04
Total costs	330,000	16,500	0.09

Using a 30-year levelized annual cost might better represent the operational longevity of the ladder and screens, and a 30-year levelized annual cost equates to about six-hundredths of a mill (about six-thousandths of a cent) per kilowatt-hour of generated electricity.

10.3.3 Upstream Fish Passage/Protection. The plant was placed in operation in 1921, and a nine-step fish ladder was installed for the passage of adult rainbow trout. An Alaska steeppass fish ladder was incorporated as part of the fish ladder system in the early 1960s as required as a term of the plant's license.

Due to the age of the fish ladder, it is difficult to obtain historical costs. However, licensee engineers have estimated that to construct a similar fish ladder today would cost $176,000 (1993 Dollars). Spreading this cost over a period of 20 years produces a levelized annual cost of $8,800. With an average annual energy production of 186,357 megawatt-hours (1974–1989), the cost of the upstream fish ladder system equates to an average of 0.05 mills per kilowatt-hour of electricity generated.

There is no lost generation due to fish ladder flows as the 13 cfs fish ladder flows are part of the minimum instream flows required for recreation and the fishery. Fish passage counts are not performed, and the operations and maintenance costs are minimal for the upstream fish ladder. The licensee has not been required to support any recent upstream passage studies, and information concerning possible study costs from the early 1960s is unavailable.

10.3.4 Downstream Fish Passage/Protection. The downstream fish mitigation system consists of screens to protect resident rainbow trout from entering the power canal that leads to the power plant. The water passes through a trash rack and into two large sand boxes that are used to decrease water velocity, allowing suspended debris to settle to the bottom of the sand box. The fish screens are perpendicular to the flow, at the downstream end of the sand boxes. Four screens are located side-by-side at the downstream end of each of the two parallel sand boxes. Each of the eight screens is 5 feet 10 inches wide, and 10 feet 9 inches high. The combined width of the four screens in each of the sand boxes is 23 feet 4 inches wide, providing a total screen width in the intake canal of 46 feet 8 inches. The screens are constructed of steel bars, each 0.25-inch thick, spaced 0.5-inch apart.

The screens were installed prior to 1960, and the historical costs are unavailable. The cleaning requirements of the screens, which are located downstream of the sand boxes and the trash rack, are minimal with no appreciable costs. Licensee engineers have estimated that the cost to replace the current screens, with screens of a similar design, would be $154,000 (1993 dollars). There are no other costs associated with the screens. Spreading this cost over a period of 20 years produces a levelized annual cost of $7,700. With an average annual energy production of 188,922 megawatt-hours (1971–1985), the cost of the downstream fish screen equates to an average of 0.04 mills per kilowatt-hour of electricity generated.

The current relicensing process may result in the establishment of a fisheries trust fund, or studies to determine the effectiveness of existing screens and potentially a requirement for a finer mesh screen. The study scope is being developed at the present time and estimates of potential costs are unavailable.

11. LEABURG CASE STUDY

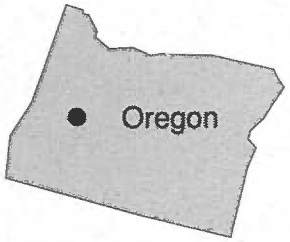
11.1 Description

The Leaburg Hydroelectric project (FERC number 02496) is a run-of-river development located on the McKenzie River (average annual discharge of 4,780 cfs), within the Willamette River Basin (Figure 11-1), in Lane County, Oregon. A diversion dam (Figure 11-2) diverts water through a five-mile-long power canal to an 89-foot high powerhouse penstock. The project generates approximately 97,300 megawatt hours of electrical energy annually (1984–1990). Each of the two turbines are rated at 7.5 megawatts capacity.

The project is located at a river location that affects the upstream and downstream passage/protection of anadromous and resident fish species. Upstream and downstream fish passage/protection systems are designed and operated to primarily facilitate the passage of anadromous salmonid species around the project. Anadromous salmonid species that migrate past the project include spring chinook salmon and steelhead trout. Table 11-1 lists other resident fish species (salmonid and nonsalmonid) that are present in the river sub-basin above and below the project.

The upstream passage/protection system consists of right-bank and left-bank fish ladders (Figure 11-3) that originally went into operation in 1930. The right-bank fish ladder is currently inoperative and will be replaced in 1995 with a vertical slot fish ladder having specifications similar to the reconstructed left-bank fish ladder. The left-bank fish ladder, reconstructed in 1969, is a pool-weir design (Figure 11-4) with submerged orifices. The fishway proper has 30 cfs flow supplemented with 100 to 160 cfs auxiliary attraction water, supplied through a grated diffuser located in a major pool near the entrance cell.

The downstream juvenile passage/protection system has a unique facility design (U.S. Patent Number 4,740,105). Located 400 feet downstream of the power canal intake, the passage/protection facility consists of three vertically "V" arranged stainless steel screens that span the canal width, and a fish bypass. A steel bar trash rack to remove larger debris spans the canal just upstream of the screen panels.



Each of the stainless steel profile wire screens is approximately 45 feet in total length, and is composed of three 15 × 15 foot sections. The opening between the screen bars is 2 millimeters. The approach velocity of the flow at the screen facings is ≤0.7 fps and the sweeping velocity is ≥4.0 fps. The sweeping velocity of canal flow transports fish into the throat of each screen "V" section, where an underdrain chute diverts fish and debris under the canal into a bypass flume and back to the river (Figure 11-5). Excess water diverted into the bypass flume is pumped back into the canal to maintain canal flows and to minimize excessive flows at the bypass discharge, which could attract fish (Figure 11-6).

Figure 11-1. Location of the Leaburg project on the McKenzie River.

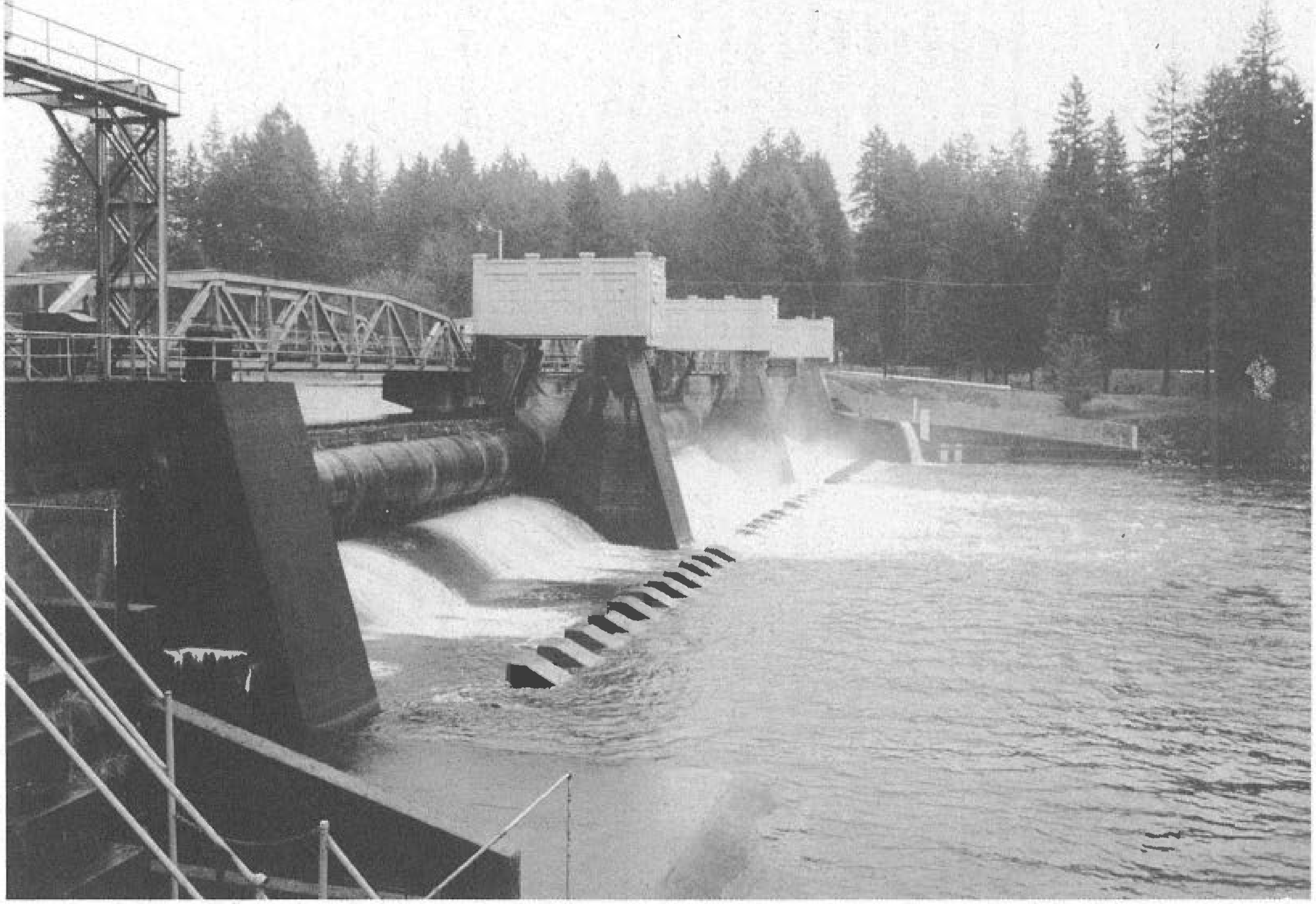


Figure 11-2. Leaburg diversion dam, viewed from the right bank. Left-bank spill is for left-bank fish ladder attraction flows.

Table 11-1. Fish species occurring within the McKenzie River sub-basin.

Lampreys
  Pacific brook lamprey
  Western brook lamprey
  Pacific Lamprey

Minnows
  Chiselmouth
  Peamouth
  Northern squawfish
  Longnose dace
  Speckled dace
  Redside shiner

Sculpins
  Paiute sculpin
  Shorthead sculpin
  Reticulate sculpin

Stickleback
  Threespine stickleback

Sturgeons
  White sturgeon

Suckers
  Largescale sucker

Sunfishes
  Bluegill[a]
  Largemouth bass[a]
  White crappie[a]

Trouts
  Coho salmon
  Chinook salmon
  Mountain whitefish
  Cutthroat trout
  Rainbow trout (resident and steelhead)[a]
  Bull trout
  Brook trout[a]

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a. Introduced.

The screening system is equipped with a permanently-mounted rotary spray backwash device, controlled by microprocessor activated valves, which removes debris that accumulates on the screen panels. The downstream passage/protection facility was recently equipped with adjustable baffles to help distribute the flow equally across the entire screen face.

11.1.1 Fish Resource Management Objective of Mitigation. The resource management objective of the upstream and downstream passage/protection systems for this project is predicated on a "no net loss" protection standard of the fisheries agencies. This management objective is facilitated by the design and operation of the upstream and downstream passage/protection systems to attract and effectively route adult and juvenile fish species (primarily anadromous) past the project's headworks and powerhouse generating units. The project may mitigate for anadromous fish losses under 5.0 %, but losses greater than 5.0% will trigger the need to modify either the upstream or downstream fish passage/protection system.

11.1.2 Monitoring Methods. Upstream passage of adult anadromous fish at the project is monitored via video camera as the fish pass through the left-bank fish ladder. Technicians later read the videotape and record daily, monthly, and annual passage of anadromous salmonids.

The Oregon Department of Fish and Wildlife provides angler-returned records of annual harvest of adult salmon and steelhead in the river sub-basin, and these data are separated into the catch above and below the project. The Oregon Department of Fish and Wildlife also provides an accounting of adult salmon and steelhead returning to fish culture facilities in the river sub-basin. These data provide information on relative escapement and abundance of salmon and steelhead populations.

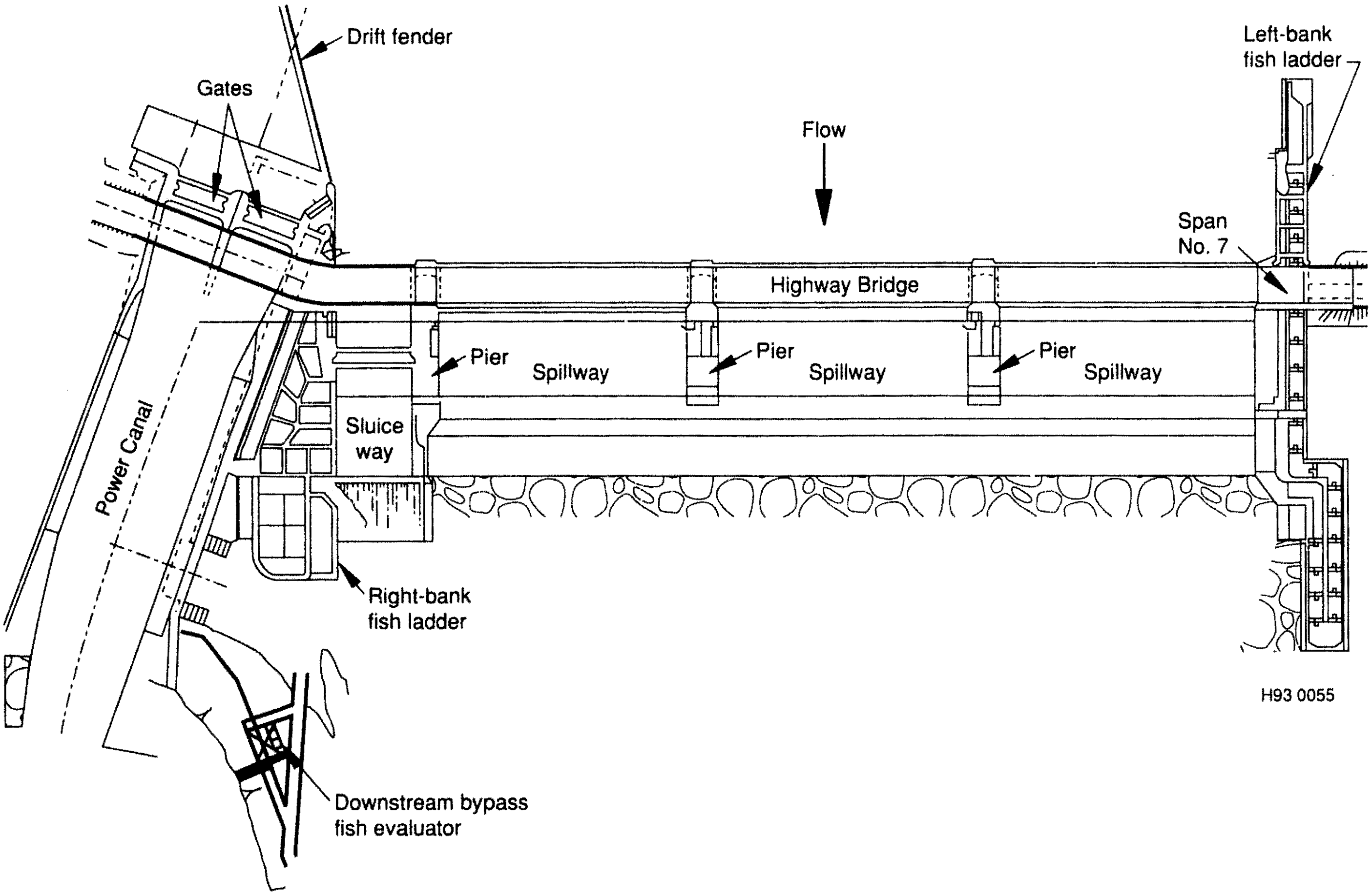


Figure 11-3. Overview of the Leaburg dam, power canal inlet, right-bank fish ladder, and left-bank fish ladder. The fish evaluator, bottom left, is used to evaluate downstream migrants as they are returned from the power canal into the river below the dam.

The project operator annually funds aerial surveys of the river sub-basin in late September to record numbers of spawning salmon redds. The project operator also annually monitors the number of salmon redds in a spawning channel, which is located about 50 river miles upstream of the project.

Downstream migration of anadromous fish is monitored annually at a specially-constructed evaluation facility placed near the discharge of the project's downstream fish bypass. Tests of the efficiency of the downstream migration and protection provided by the downstream passage/protection system are conducted in two primary ways:

1. **River-run Tests**—Simple observation of species (enumeration and physical condition) and estimation of mortality are made for fish that enter the canal and are diverted into the project screen evaluator. Some of the live fish captured in the evaluator are held in isolated tanks for 72 hours to measure delayed, or latent mortality.

2. **Controlled Tests**—Experimental populations of fish (control and test groups) of known numbers and physical condition are introduced at locations within the canal and screen facility structures. Physical condition of these fish at recapture is compared to that of a similar group of fish released into the bypass flume immediately above the evaluator. The difference between the test and control groups is indicated as the effects of the treatment.

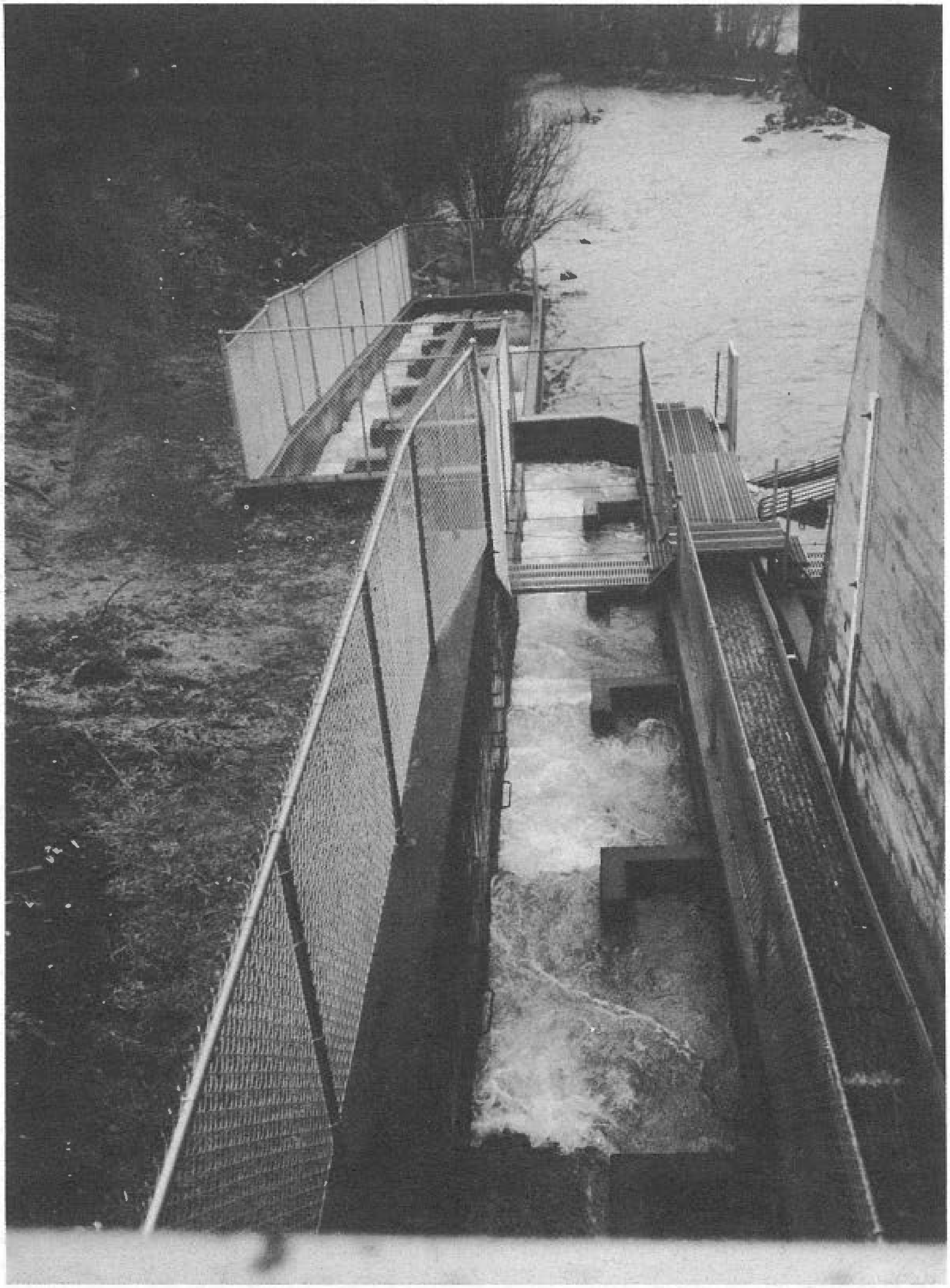


Figure 11-4. Leaburg left-bank fish ladder, looking downriver.

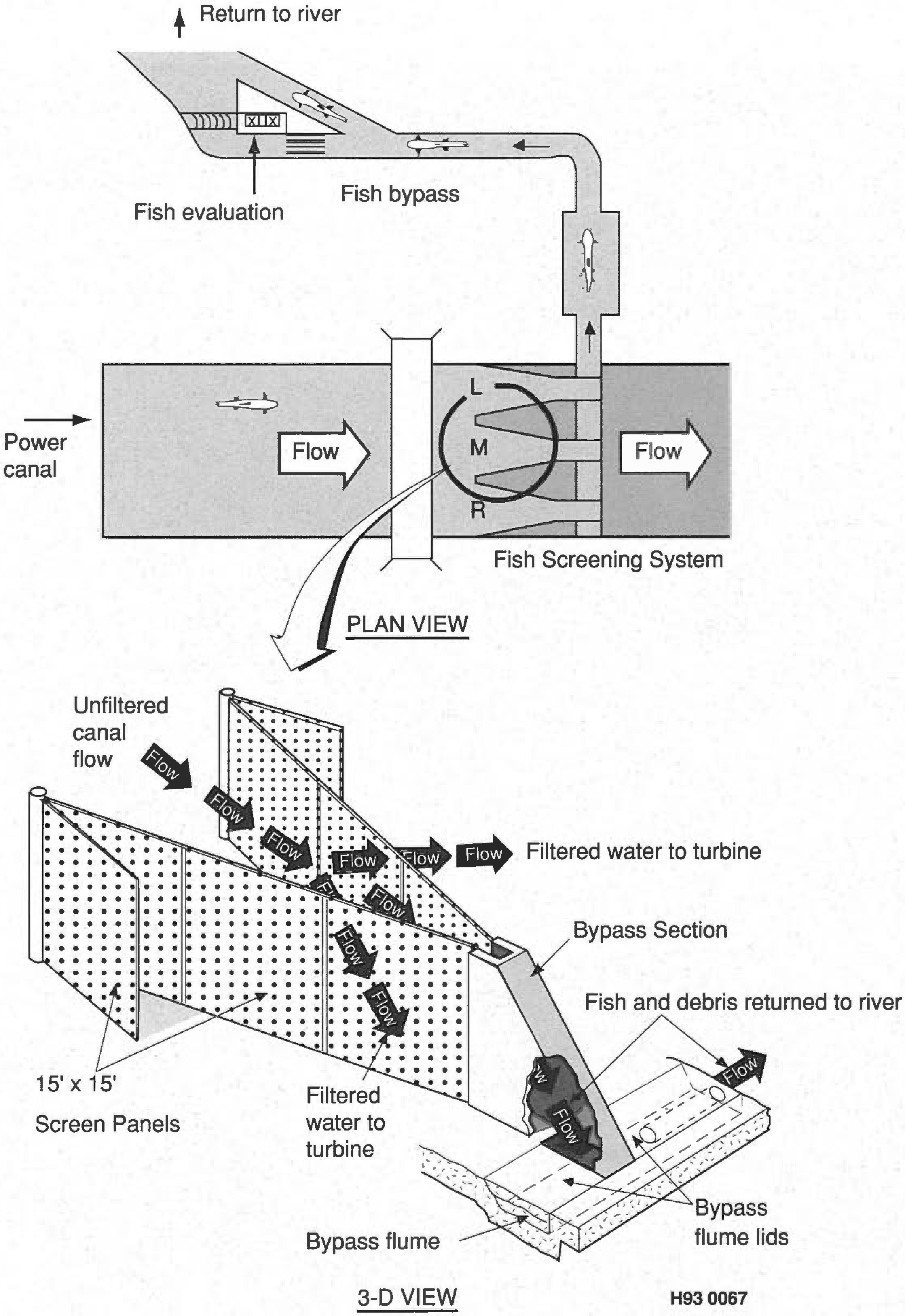


Figure 11-5. Leaburg power canal fish screens and downstream fish bypass.

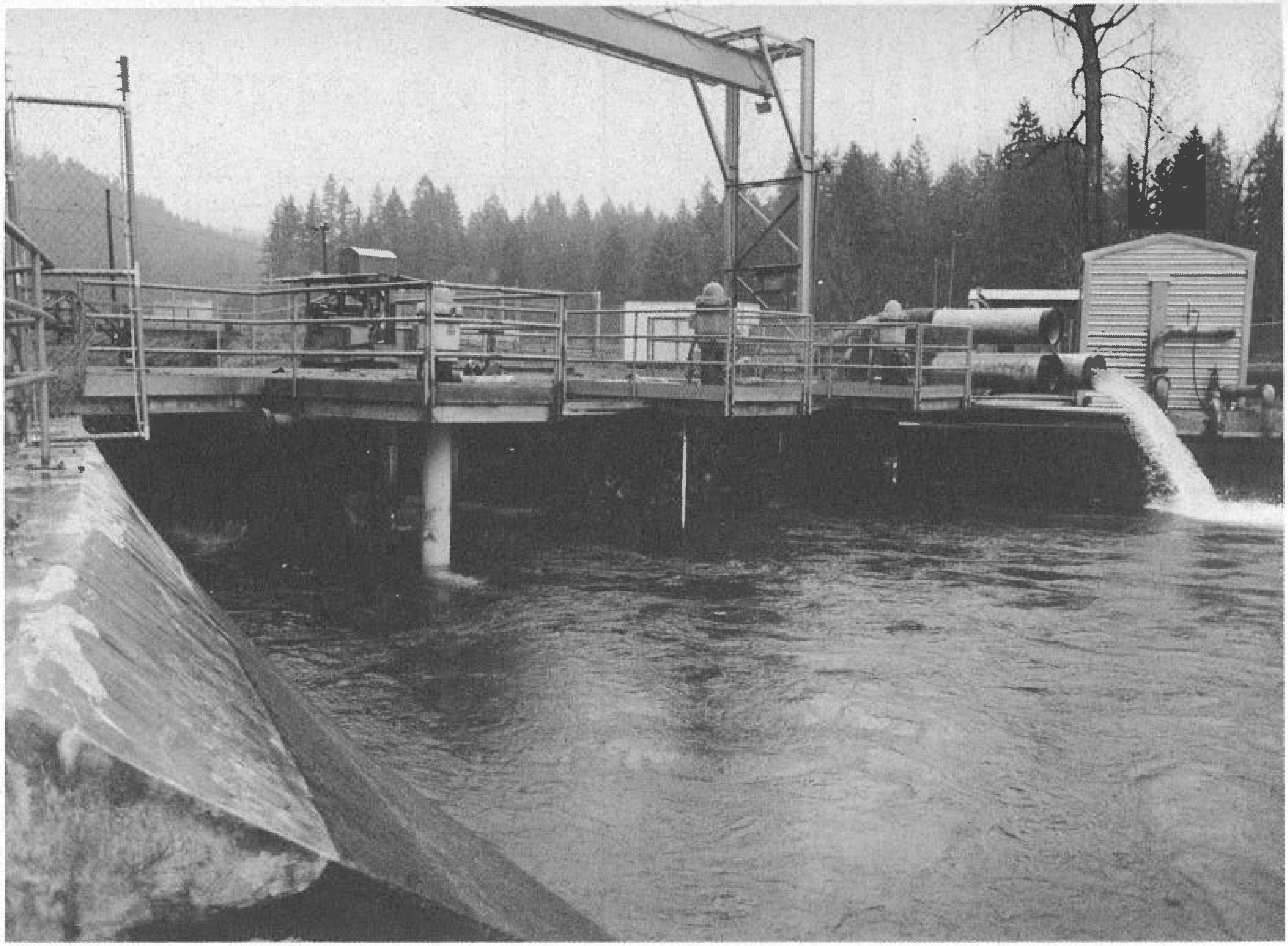


Figure 11-6. Leaburg bypass flume excess water pumpback and downstream side of fish screens. Power canal water can be seen flowing through screens under platform.

11.1.3 Performance of Mitigation.

11.1.3.1 Upstream Fish Passage/Protection. The Oregon Department of Fish and Wildlife's stated fishery management goal for spring chinook salmon in the river sub-basin is to achieve an annual return of 18,000 adult and jack salmon. Although this level of return has not been achieved in recent years, the estimated return of spring chinook salmon to the river has averaged 11,790 in the 4-year period 1988–1991. This mean return to the river is a marked improvement over past estimates (Table 11-2). In addition, the index of spring chinook spawning redds in the river sub-basin and in the spawning channel (50 miles upstream of the project) has generally indicated an increased trend in most recent years (Figures 11-7 and 11-8).

11.1.3.2 Downstream Fish Passage/ Protection. Mortality tests conducted by the Oregon Department of Fish and Wildlife in 1982 indicated a 28% loss to populations of smolt-size (10–25 cm) spring chinook salmon resulting from turbine passage. Mortality of smolt-size anadromous fish was almost immediately reduced to less than 5% after installation of the passive screen device near the entrance to the project's power canal in 1983.

However, newly emerged salmon fry (35–40 mm) migrate down the river past the project from January through April each year. Providing adequate protection for these fry has been the goal of screen modification and subsequent reevaluation each year since 1984. Over this period, recovery rates of groups of test fry (Figure 11-9) and mortality rates of test fry (Figure 11-10) have constantly improved to within the ranges specified by the fishery agencies.

Table 11-2. Estimated Return of spring chinook to the McKenzie River sub-basin, 1970–1991. (Catch in 1990 and 1991 is projected. Escapement below Leaburg Dam = Number of redds below Leaburg × 4.5 fish/redd).

				Below Leaburg Dam				
Year	Dam count	Hatchery return	Catch	Redds	Escapement	Total return	Return as % Willamette Falls	WF count (×1000)
1970	2991	20	525	278	1251	4787	14.0	34.2
1971	3602	232	621	415	1868	6323	14.2	44.5
1972	1547	301	1125	177	797	3770	14.4	26.2
1973	3870	56	1510	556	2502	7938	18.9	42.0
1974	3717	0	1022	689	3101	7840	17.6	44.5
1975	1374	0	461	346	1557	3392	17.8	19.1
1976	1899	396	139	409	1841	4275	19.3	22.2
1977	2714	1517	1071	850	3825	9127	22.8	40.0
1978	3058	1464	924	599	2696	8142	17.1	47.5
1979	1219	798	303	155	698	3013	11.3	26.6
1980	1980	807	381	219	986	4154	15.4	27.0
1981	1078	784	493	282	1269	3624	12.0	30.1
1982	2241	1460	627	241	1085	5413	11.7	46.2
1983	1561	821	221	172	774	3377	11.0	30.6
1984	1000	1901	618	271	1220	4739	10.9	43.5
1985	825	1923	467	381	1715	4930	14.3	34.5
1986	2061	1705	383	315	1413	5567	14.2	39.1
1987	3455	1593	1368	212	954	7370	13.4	54.3
1988	6753	2487	1216	484	2178	12533	17.9	70.5
1989	3976	3154	1864	228	1026	10020	14.5	69.2
1990	7115	3206	1704	160	720	12745	17.9	71.3
1991	4359	4483	2200	161	725	11767	23.7	49.7
Ave.	2836	1323	375	345	1555	6588	15.7	41.5

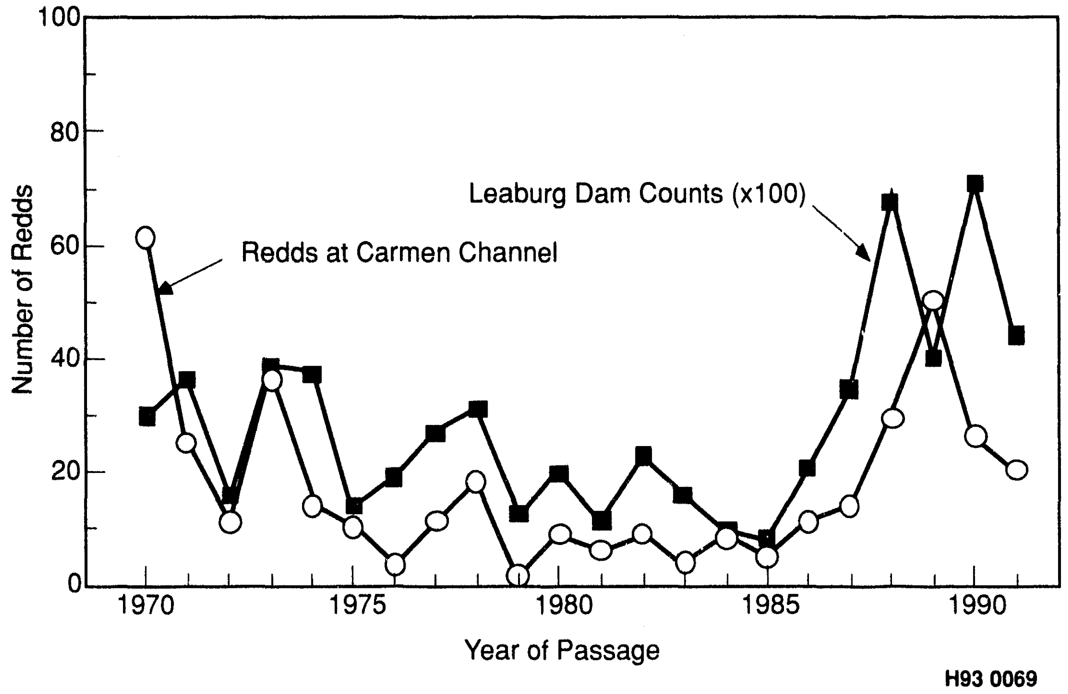


Figure 11-7. Annual salmon counts at the Leaburg dam and redd counts at the upriver spawning channel.

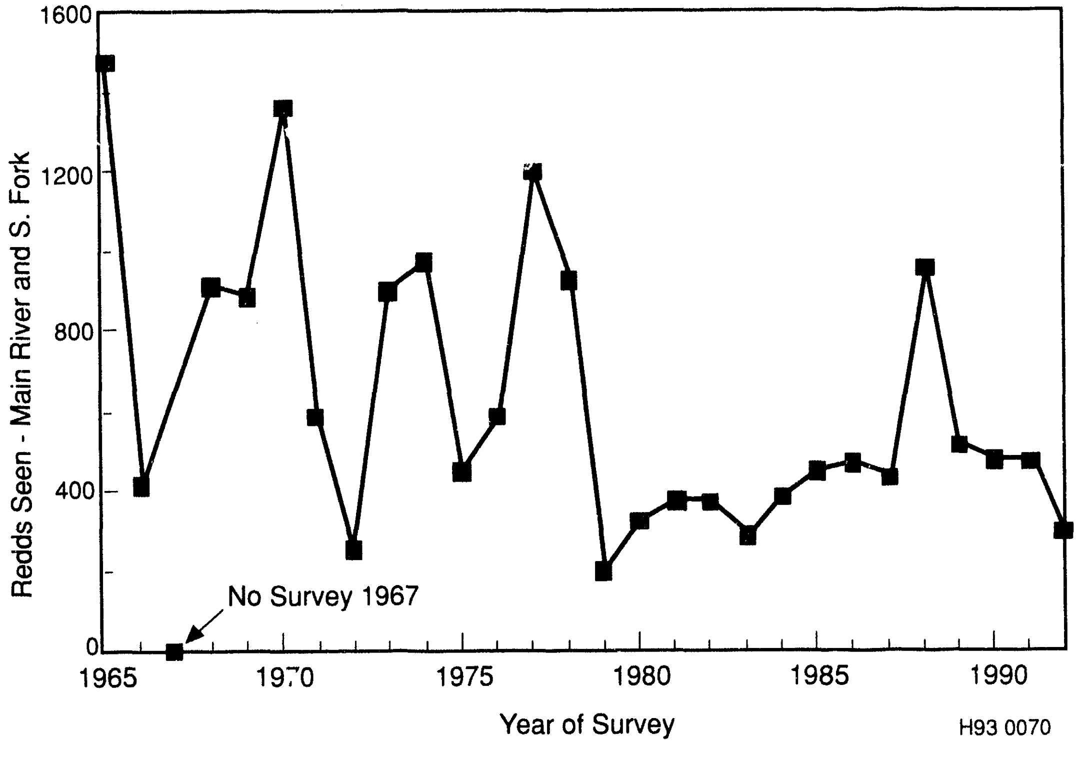


Figure 11-8. Redd counts of spring chinook salmon in the McKenzie sub-basin, 1965–1991.

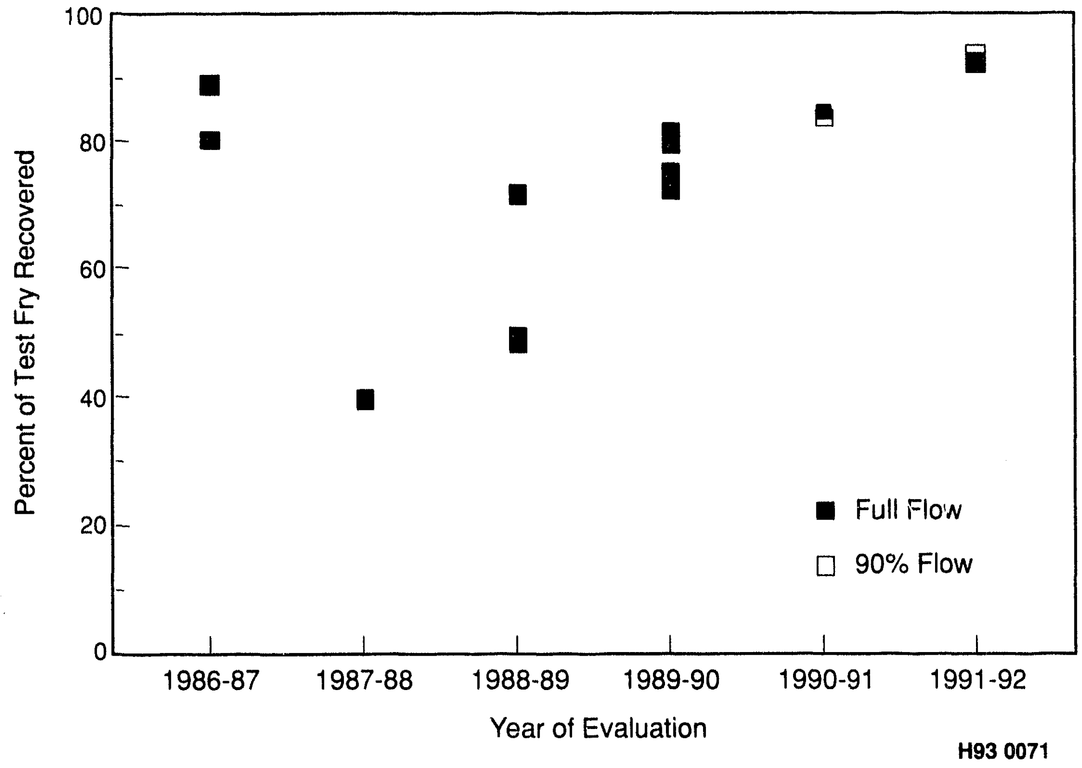


Figure 11-9. Recovery rates of salmonid fry released at Leaburg for evaluation of the downstream passage/protection system, 1986–1992.

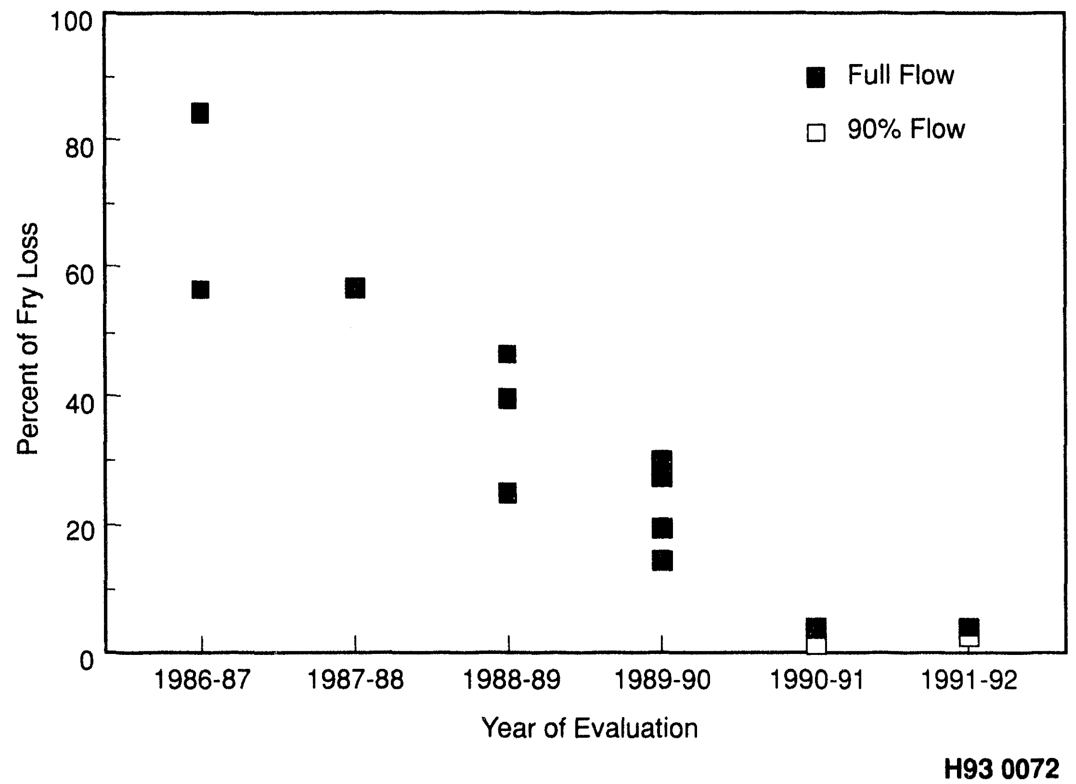


Figure 11-10. Salmonid fry loss measured at Leaburg for evaluation of the downstream passage/protection system, 1986–1992.

11.2 Mitigation Benefits

11.2.1 Benefits to Fish Populations and Associated Fisheries. The upstream and downstream fish passage/protection systems of this project have mitigated for the impacts of the project's hydroelectric generating operations and assisted in the maintenance of anadromous fish populations. These fish populations contribute to significant sports and commercial fisheries above and below the project.

Improvements in the return of spring chinook to the river sub-basin in recent years cannot be directly attributed to the improvements to passage/protection at the project. However, improvements to these passage/protection facilities and increased survival rates are an integral component of a systematic multiagency approach toward achieving fishery and recreation goals in the river sub-basin.

Both the upstream and downstream passage/protection systems are monitored, and monitoring results indicate that they currently achieve the performance standards for protection (in terms of a "no net loss" standard) of anadromous fish species migrating through the project.

As the result of FERC relicensing requirements, the project owner is in the process of initiating actions to benefit fisheries, recreation, and power generation at the project. These actions are related to modifications in the upstream and downstream passage/protection systems and the power generation components. Subsequent studies of these modifications will be conducted in order to evaluate their fish passage/protection performance, in terms of a "no net loss" standard.

11.2.2 Future Plans. Primarily as the result of FERC relicensing requirements, the project owner will complete the following actions to benefit fisheries, recreation, and power generation at the project:

Upstream Passage/Protection Related Actions

- Rebuild the currently defunct fish ladder on the right bank of the dam.
- Modify the river bottom substrate in the vicinity of the new ladder to facilitate the entrance of upstream-migrating fish.
- Evaluate the efficiency of the new fish ladder and modify as needed to achieve effective adult passage.
- Provide public viewing of the fish passing the project.
- Devise and evaluate a methodology (structural or operational) to minimize delay of upstream-migrating fish at the powerhouse tailrace.
- Continue annual inventories of fish passage.
- Continue to subsidize annual aerial surveys of salmon redds in the river sub-basin.

Downstream Passage/Protection Related Actions

- Continue evaluation of the downstream passage/protection system of the project.
- Complete studies of the effects of downstream fish passage under the rollgates at the dam, as ordered by FERC. Cooperate with fishery agencies to develop a rational mitigation process justified by the results of these studies.

Power Generation Related Actions

- Raise the impoundment by 18 inches as a benefit to power generation.
- Reevaluate the downstream passage/protection system after the impoundment raise is completed. Complete any facility modifications dictated by the results of these mortality studies in order to maintain a high level of fish protection.

- Modify the left-bank fish ladder as needed to accommodate the rise in the impoundment elevation.

- Consult with the resource agencies to arrive at any justified mitigation for loss of wildlife resources associated with the impoundment rise.

11.3 Mitigation Costs

11.3.1 Introduction. The mitigation cost analysis for the Leaburg hydroelectric project consists of a cost summary section, discussing the mitigation costs in general terms; an upstream fish passage/protection system section, discussing the upstream mitigation costs; a downstream fish passage/protection system section, discussing the downstream mitigation costs; a lost generation cost section; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal written correspondence and telephone calls. Two site visits greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

11.3.2 Cost Summary. Identifying the components and costs of the upstream and downstream passage/protection systems is a fairly straightforward process at the Leaburg project, with the possible exception of indirect functions such as administration and reporting. However, these costs are of a relatively small nature (~3%) in comparison to the total costs. A minor misstatement or assignment of these types of costs to the wrong type of mitigation would not result in a major misrepresentation of the costs of either the upstream or downstream mitigation systems. Distorting the costs of lost generation, which is a significant percentage (33%) of the total mitigation costs at Leaburg, would seriously skew the costs of either mitigation system (Figure 11-11). Sufficient information is not available to divide lost generation costs into either upstream or downstream mitigation costs; instead, the lost generation costs are discussed as a separate issue.

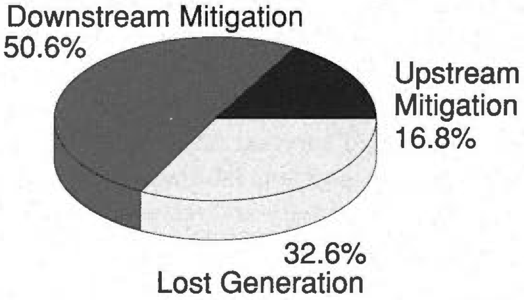


Figure 11-11. Lost generation, upstream mitigation, and downstream mitigation costs at the Leaburg project.

The 20-year total cost of mitigation at Leaburg is $10.1 million, and the levelized annual cost is $507,500 (Table 11-3). Based on the 7-year (1984–1990) average generation of 97,312 megawatt-hours, the cost of mitigation at the Leaburg project is 5.2 mills per kilowatt-hour of electricity. The variations in yearly costs (Figure 11-12) are driven by downstream mitigation-related capital costs (such as 1983) and the construction costs for the two fish ladders (1983 and 1995).

Table 11-3. Mitigation costs incurred at Leaburg.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Upstream	1,701,000	85,100	0.9
Downstream	5,135,800	256,800	2.6
Lost generation	3,312,900	165,600	1.7
Total costs	10,149,700	507,500	5.2

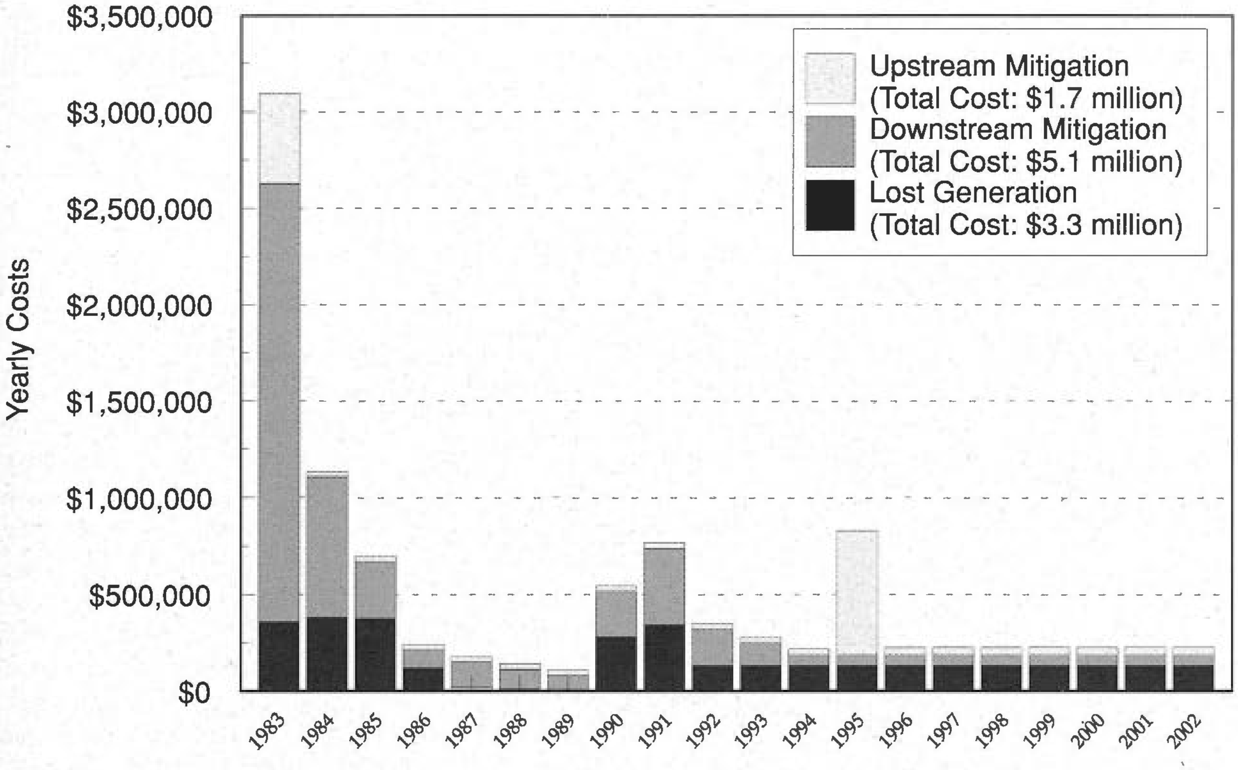


Figure 11-12. Yearly costs of lost generation, and upstream and downstream mitigation incurred by the Leaburg hydroelectric plant.

Future mitigation activities and requirements have been identified, but specific actions and cost estimates have not been compiled to date. However, these future activities should be acknowledged as having a potential cost. These future activities include

- Raising Leaburg Lake 18 inches to offset lowered generation resulting from reduced flows through the downstream bypass screens into the power canal
- Modifying fish ladders to accommodate the rise in the lake elevation
- Compensation to lakeside property owners, as needed, for property losses that may occur as the result of raising the lake
- Replacement of the boat launch that will be inundated by the lake rise
- Determining any wildlife or wetlands impacts from the raising of the lake and identifying possible mitigation for such.

11.3.3 Upstream Fish Passage/Protection. The total estimated amount for the upstream passage/protection system for 20 years is $1,701,000 (Table 11-4). The levelized annual cost is $85,100 for the upstream fish passage/protection ladder system. Over 20 years the total upstream fish passage/protection capital and annual costs are 0.9 mills per kilowatt hour of electricity produced.

The left-bank fish ladder was rebuilt in 1969 at a cost of $445,700. The right-bank ladder, scheduled for substantial rebuilding in 1995 at an estimated cost of $604,400, is of an older design and is largely inoperable due to its rather contorted pool and weir design (Figure 11-13), substandard attraction flows, and river subsurface deficiencies. The operational left-bank ladder includes a fish counting window. The total cost to rebuild the left- and right-bank ladders will be

Table 11-4. Mitigation costs incurred at Leaburg for upstream mitigation. Columns may not total due to individual rounding.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital costs	1,050,100	52,500	0.5
Annual costs	650,900	32,500	0.3
Total upstream costs	1,701,000	85,100	0.9

$1,050,100. The 20-year levelized annual cost for the construction of the ladders is $52,500. This equates to a cost of 0.5 mills per kilowatt hour of electricity produced.

The annual cost of cleaning the left-bank fish ladder, auxiliary attraction water screen, and viewing window is $14,000. When the right bank ladder is operational in 1995 the annual operations and maintenance costs for both ladders is estimated to be $21,000. Other annual costs include the monitoring of passage rates. This function has been handled by the Oregon Department of Fish and Wildlife since 1984 and is scheduled to end after 1993. The yearly monitoring contract with the Oregon Department of Fish and Wildlife includes upstream as well as downstream monitoring. The total 20 year upstream monitoring cost is estimated at $152,900 and the levelized annual cost is $7,600. The annual reporting and administrative costs were also reported by the licensee as totals for upstream and downstream mitigation. Using a simple equal division of costs, the yearly estimate for annual reporting and administrative is $8,100. Excluding any estimated generation losses for upstream mitigation, the 20 year total cost for annual operations is $650,900 and the levelized annual cost is $32,500 per year. The project has generated 97,312 megawatt hours of electricity annually (1984–1990) and the $32,500 levelized annual cost for annual operations equates to a per kilowatt hour of electricity cost of 0.3 mills.

11.3.4 Downstream Fish Passage/Protection System Costs. The total 20-year cost of the downstream mitigation system is $5,135,800. The 20-year levelized annual cost is $256,800 and the cost per kilowatt hour of electricity generated is 2.6 mills (Table 11-5).

The downstream passage/protection system costs include the patented wedgewire screen panels ($776,500) and the screen frames, support structure, bypass, and permanent crane for screen removal ($1,486,700) for a combined cost of $2,263,200. Because of debris loading on the screens, a microprocessor-controlled, rotating, spray-nozzle screen-cleaning system was installed to keep the screens free of debris. The nozzle system was installed and modified over 3 years at a cost of $968,000. A 1987 hydraulics study identified salmon fry impingement on the right-bank screen. The result was a reconfiguration of the subchannel bypass at a study and reconfiguration cost of $115,200. A baffle system was installed during 1990 to even approach velocities to the screens. A solid baffle system was initially used ($170,200) but was replaced during 1991 with an adjustable baffle system ($227,500). The total cost to develop and install the baffle system was $397,700. During 1992 the concrete bypass flume was dewatered and reworked for smoothing and to eliminate leaks to increase smolt passage survival rates at a cost of $31,800. The total capital cost for the downstream bypass system was $3,775,900. When the $3,775,900 is leveled over the 20 years of analysis, the levelized annual cost is $188,800 for the downstream passage/protection system. Equating this to the average (1984–1990) generation of 97,312 megawatt hours of electricity, the capital costs for downstream mitigation averages 1.9 mills per kilowatt hour of electricity.

The downstream bypass system's operations and maintenance requirements are estimated to cost a total of $664,900 (1989–2002). The annual monitoring and evaluation, totaling $533,000, is scheduled to cease after 1993 because the efficiency of the system appears to be acceptable to

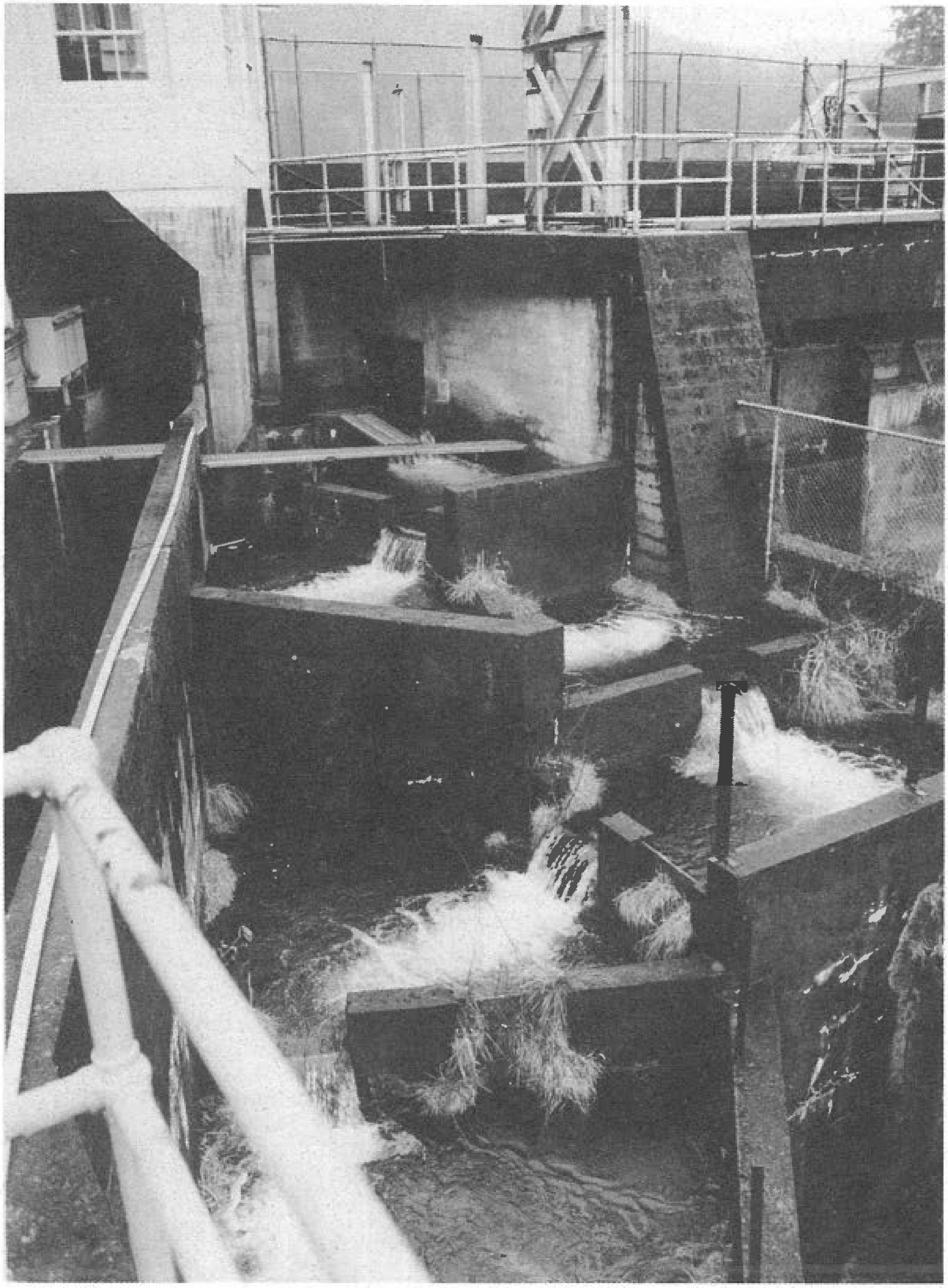


Figure 11-13. Older, largely inoperable right-bank fish ladder at Leaburg.

Table 11-5. Costs incurred for downstream mitigation at Leaburg.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital and study cost	3,775,900	188,800	1.9
Annual costs	1,359,900	68,000	0.7
Total downstream costs	5,135,800	256,800	2.6

the Oregon Department of Fish and Wildlife. The annual reporting and administrative costs averaged $8,100 for a total of $162,000 over 20 years. The total 20-year cost of annual downstream mitigation operations is $1,359,900 and the levelized annual cost is $68,000. The cost per kilowatt hour of electricity generated is 0.7 mills.

11.3.5 Lost Generation Costs. The lost generation costs were not identified as specific to either upstream or downstream mitigation. For this reason the lost generation costs are presented as a separate cost section. Some of the activities that precipitated generation losses include canal closures to install and modify the mitigation facilities, reductions in power canal flows to reduce screen velocities, and power canal closures to remove adults from the power plant tailrace. The early yearly variations in lost generation costs are associated with long-duration canal closures to make major fish screen facility modifications (Figure 11-14). The 20-year lost generation cost resulting from upstream and downstream mitigation activities totals $3,312,900. The annual levelized cost is $165,600. Based on an average annual generation of 97,312 megawatt-hours, the cost per kilowatt-hour is 1.7 mills (Table 11-6).

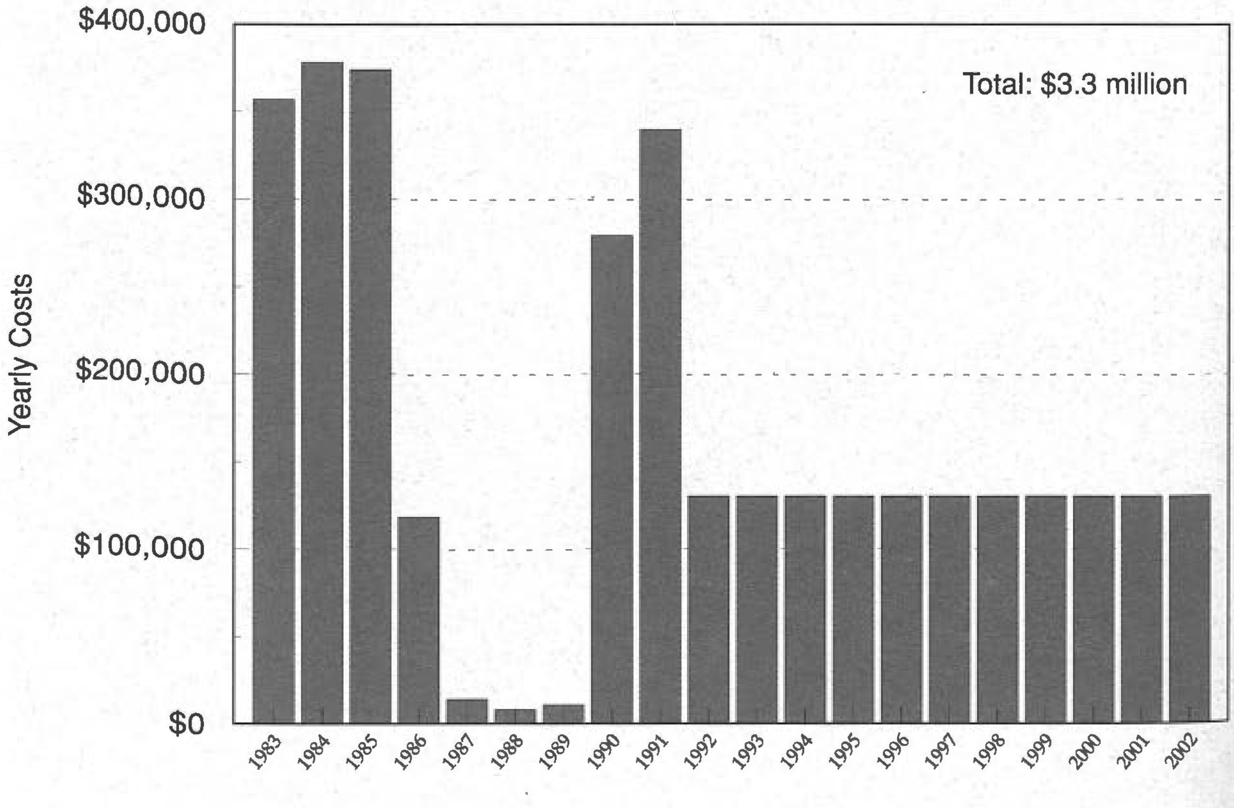


Figure 11-14. Yearly lost generation costs at the Leaburg project.

Table 11-6. Costs incurred for lost generation.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Lost generation	3,312,900	165,600	1.7

11.4 Cost Descriptions and Assumptions

This section provides an explanation of the individual cost items and the assumptions and estimates required to quantify the respective items and derive totals. The item numbers correspond to the 20-year spreadsheet (Table 11-7) used to determine costs.

11.4.1 Capital and Study Costs.

1. **UPM—Left Fish Ladder.** The original left-bank fish ladder was rebuilt in 1969. The rebuild allowed enhanced upstream passage past the diversion structure. While the ladder was modified during 1969, the cost is shown in 1983, and the original cost has been indexed to 1993 dollars. The rebuild cost was $455,700.

2. **UPM—Right Fish Ladder.** The project owner's engineers have estimated what it will cost to modify the existing right-bank ladder in 1995. The $604,400 estimated cost includes $33,000 for design and $571,000 for construction. The old fishway will be largely removed, although some of the old concrete cells and foundation piers will be salvaged to support the new fish ladder cells. Many of the new fish ladder cells will be prefabricated and moved to the site.

3. **DWM—Screen Panels.** The $776,500 cost is for the wedgewire screen panels. Three 15 × 15 foot sections make up each side of the three vertically "V" arranged stainless steel screens used for downstream passage/protection. Eighteen panel screens, with 2 millimeter openings, are always in use, and an extra 15 × 15 foot screen section is onsite for immediate replacement (Figure 11-15) in the event of a failure. An overhead crane is in place to change screens.

4. **DWM—Screen\Const\Frames\Trashrack** (Downstream Mitigation Screen Construction and Installation, Screen Frame Fabrication, and Trashrack). The $1,486,700 cost is for the additional hardware to support the screens, the crane assembly to install/remove screens, and the dewatering system that pumps excess water back to the power canal. The pump-back operation is cost-effective except for when power values are at their very lowest. During these times, money would be saved by allowing the water to flow down the bypass flume. However, allowing full bypass flow to go down the flume to the river would interfere with the ongoing fish sampling procedures because the fish evaluation facility can handle bypass flows only up to 25 cfs. The pump-back operation also precludes a false upstream attraction at the downstream bypass from higher flows. The pump-back screen is cleaned by simply shutting the pumps down temporarily, creating a "flume flush." A sensor detects when the dewatering sump level is dropping, indicating the pump-back screen is clogging with debris. This sensor activates a microprocessor that shuts the pumps down for about a minute, and the debris on the flat screen is washed down the bypass flume.

5. **DWM—Instl\Mod Bckflsh System** (Downstream Mitigation Installation and Modification of Screen Cleaning Backflush System). The total cost to install this system was $968,000. The cost and installation (in 1993 dollars) was spread over 3 years: $679,800 (1984), $244,600 (1985), and $43,600 (1986). Debris loading was far

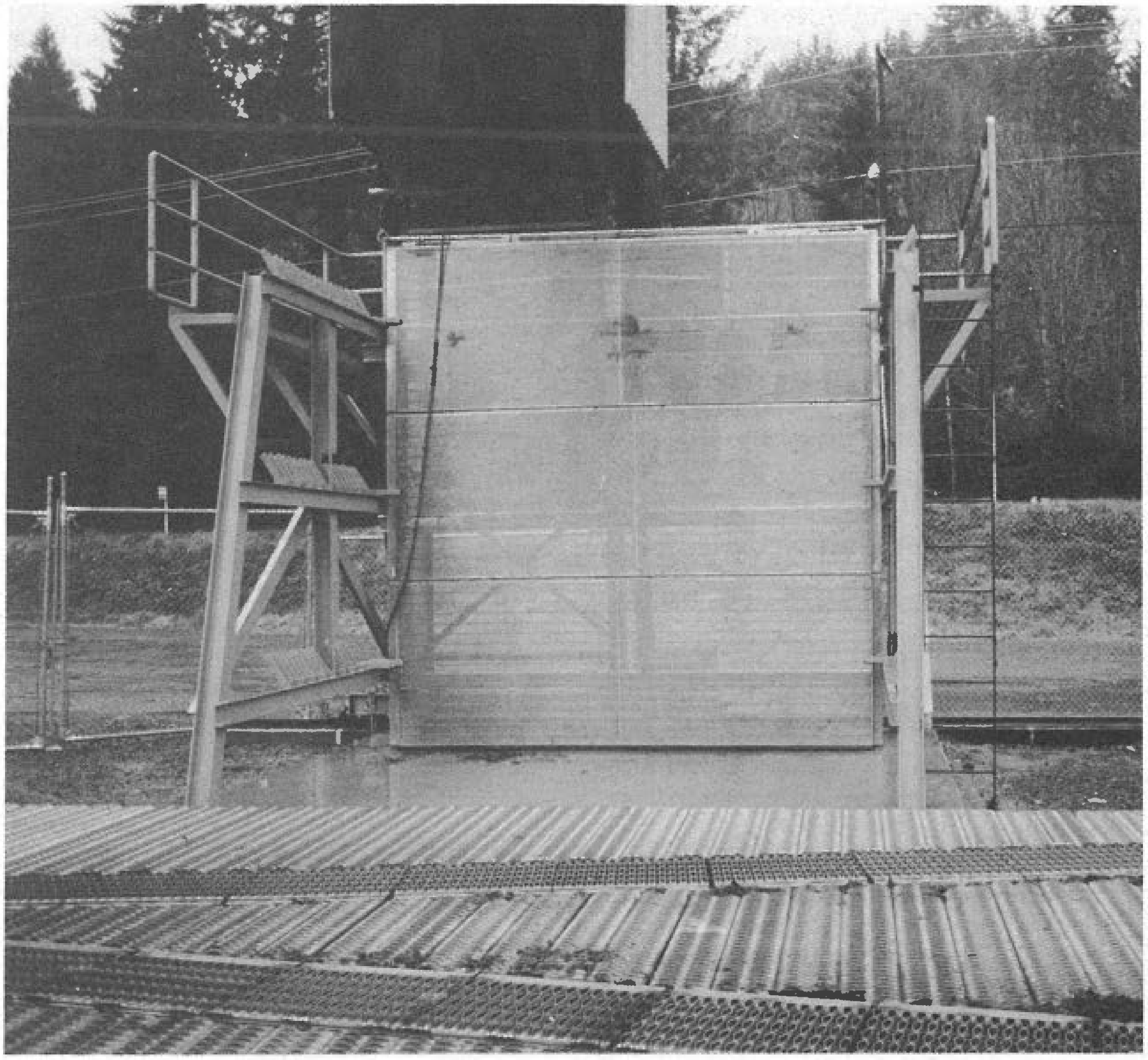


Figure 11-15. Spare 15 by 15 foot screen panel and crane hoist at Leaburg.

more severe than was originally anticipated, and the spacing and number of spray nozzles were modified to expand the screen area cleaned. In its present form, the fish screen system is equipped with a permanently mounted rotary spray backwash system that removes accumulated debris from the screen panels. Automated cleaning of the screens is triggered by detection of debris buildup on the screen surface, which is electronically measured in the form of a water level drop across the screens. The cleaning system is located on the downstream side of the screens and consists of 60 rotary spray arms, each 7 feet in diameter, with 10 spray nozzles per arm. The spray arms rotate in a propeller-like manner and direct jets of water against the canal flow to backflush through the panels. The pump pressure is sufficient to clean the screens as well as rotate the arms for maximum coverage. The cleaning method allows continuous system operation, as the screen panels are cleaned while in place.

Controlled by microprocessor-activated values, the spray arms sequentially operate from upstream to downstream to facilitate moving the loosened debris downstream. Each spray arm operates for approximately 20 seconds, then the microprocessor transfers the valve opening to the next downstream spray arm. The loosened debris, along with the fish, then continue down the bypass flume and return to the river. The supply water for the spray arm is pumped from the canal water that has already passed through the screen panels and is further filtered by a commercially available in-line filter to eliminate spray nozzle fouling.

6. **DWM—Screen Hydraulics Study.** The $71,600 (1987) hydraulics study was initiated after fish protection evaluation results indicated that salmon fry were being disproportionately impinged on the right-bank screen. The hydraulics study indicated that the shape of the subcanal bypass was influencing approach velocities.

7. **DWM—Rebuild Bypass** (Downstream Mitigation Subcanal Bypass Rebuild). $43,600 (1988) was spent to reconfigure the subcanal bypass to change the internal hydraulics, substantially leveling the approach velocities across the screens. This change resulted from the DWM Screen Hydraulics Study (Item 6 above).

8. **DWM—Install Solid Baffles.** As part of the evolution of the fish protection system, solid baffles were installed on the face of the stationary screen in 1990 ($170,200). These baffles were evaluated to be ineffective and were eventually replaced with adjustable baffles (Item 9 below).

9. **DWM—Install Adjustable Baffles.** The previously installed solid baffles (Item 8 above) were removed from the front of the screen panels and replaced during 1991 with adjustable baffles behind the screens. The $227,500 cost includes both the solid baffle removal and the adjustable baffle installation. The effect of the adjustable baffles was to level the approach velocities through all screen areas, which ultimately had dramatically positive effects on the survival of salmon fry.

10. **DWM—Modify Flume Evaluation** studies determined that some fry were "leaking" through gaps in elements of the downstream bypass system. The $31,800 cost was for dewatering the power canal, plugging these gaps, and smoothing the interior surfaces of the concrete bypass canal to further reduce fry mortality.

11.4.2 Annual Operations and Maintenance.

11. **UPM—Adult Ladder** (Upstream Mitigation Adult Ladder Operations and Maintenance). Adult ladder maintenance includes raking trash off the auxiliary attraction water screen, maintenance of the video camera and film loading, cleaning the viewing window, and the annual dewatering for cleaning out the fish ladder cells and diffuser channels. The costs include labor and materials. A mean cost of $14,000 (1993 dollars) was reported for 1989 to 1992. The 1993 dollar value is used to estimate costs from 1983 to 1988 and for 1993 and 1994. Because the right-bank ladder will be rebuilt and fully functional during 1995, adult ladder operations and maintenance costs should increase in 1995 when this second ladder is fully operational. Because some economies of scale should be present in the future ladder operations and maintenance activities, the operations and maintenance costs for 1995 and beyond are increased to 1.5 times the earlier cost to represent the operations and maintenance required by both ladders.

12. **DWM—Screen System** (Downstream Mitigation Screen System Operations and Maintenance). Normal operations and maintenance costs, including labor and material, are minimal. However, failure of pump bearings periodically results in

relatively expensive replacement activities. One maintenance person keeps the debris off the trashrack, requiring approximately 10% of his work plan. Cost data was provided by licensee for the years 1989 through 1992. These values in 1993 dollars are $3,600, $0, $98,300 and $88,000. A simple mean value of $47,500 was used to estimate future operations and maintenance costs for the downstream mitigation system. The reported operations and maintenance costs (1989–1992) have significant variations and may in fact represent anomalies. However, because both extreme costs are included ($0 and $98,294), the mean should reflect future aberrations. High water flow years will bring an increase in debris loading with corresponding higher operations and maintenance costs, while low water conditions may repeat the minimal operations and maintenance costs experienced in 1990. Future water, debris, and operation and maintenance conditions are all difficult to predict. The analysis simply assumes that past costs will be repeated in the future. The screens have operated since 1984, but operations and maintenance costs are available only from 1989 onward. Over $2 million was spent to install and modify the screens and backwash system prior to 1989. It is assumed that any operations and maintenance prior to 1989 was conducted in conjunction with these other ($2 million) activities and costs.

11.4.3 Annual Monitoring.

13. **UPM—Passage Counting.** The Oregon Department of Fish and Wildlife has maintained the upstream migrant fish counts as an additional activity associated with the contract for evaluation of the downstream migrant facility. The upstream fish count facility is basically a small concrete room with a window for viewing passage via the left-bank ladder. Access is gained by descending a ladder through a hatch opening at ground level into the viewing room, which is approximately 8 feet below ground level. A single window allows viewing and videotaping. Upstream migrant fish counting requires about 27 labor-hours per month to read the videotape and prepare monthly, yearly, and 5-year fish count data. Most of this time is spent viewing the videotape, which takes about 2 hours of analysis per 48 hours of actual passage time. The daily operation of the video equipment is performed by the licensee, and the analysis is performed by the Oregon Department of Fish and Wildlife. Modernizing the equipment may reduce this analysis time in the future.

The Oregon Department of Fish and Wildlife personnel involvement includes 1 week of a supervising biologist's time, 2 months of a staff biologist's time, and 12 months of a fishery technician's time. About 15% of the contract is for support and supplies, with very little capital outlay. These personnel also perform the downstream migrant fish counting functions. The cost data for the years 1984 to 1993 is historical data that has been indexed to 1993 values. The monitoring cost has been assumed to be split between upstream and downstream mitigation through 1993. The split used is 11% for upstream mitigation and 89% for downstream. The upstream monitoring of the videos is much less labor intensive then the downstream controlled testing. The involvement of the Oregon Department of Fish and Wildlife in the monitoring process is expected to end after 1993, as it appears that the downstream passage/protection monitoring will no longer be required because the performance of the downstream system is acceptable. The upstream passage/protection system monitoring will continue in some as yet undetermined form. The actual cost for this function is not currently known with certainty. The yearly growth of the contract has historically been approximately 4.5%, so the inflation index of 4.5% was used to estimate the future upstream passage counting costs. When the left-bank ladder is reconstructed during 1995 the counting duties will increase, but it is assumed that due to video advances, the economics of scale, and a continuing sophistication of monitoring counting, the costs will not increase significantly. The licensee also funds annual aerial surveys of redds in the river. This cost ($3,500) has not been included as a mitigation cost, and it is provided only as additional information to the reader.

14. **DWM Passage Counting.** The Oregon Department of Fish and Wildlife has maintained the upstream migrant fish counts as an additional activity associated with the contract for evaluation of the downstream migrant facility. The downstream passage counting functions performed by the Oregon Department of Fish and Wildlife include mortality studies and weekly sampling of downstream migrants at the screen evaluator. The Oregon Department of Fish and Wildlife personnel involvement includes 1 week of a supervising biologist's time, 2 months of staff biologist's time, and 12 months of a fishery technician's time. About 15% of the contract is for support and supplies, with very little capital outlay. Activities include minor maintenance associated with the screen and evaluator, analysis and reporting of evaluation results, recommendations for needed facility modifications, and a review of progress at an annual coordination meeting between the Oregon Department of Fish and Wildlife, the licensee, and the Federal fishery agencies. Because of the labor requirements of the controlled testing used to monitor downstream passage rates compared to the upstream labor requirements, the cost has been split 11% for upstream and 89% for downstream. This ratio was recommended by the licensee. The cost data for the years 1984 to 1993 is historical data that has been indexed to 1993 values. The involvement of the Oregon Department of Fish and Wildlife in the downstream monitoring process is expected to end after 1993, as it appears that the downstream passage monitoring will no longer be required because the performance of the downstream system is now acceptable.

11.4.4 Annual Reporting and Administrative Costs.

15. **UPM—Annual Reporting.** The annual reporting requirements are estimated to require 40 hours per year. An average personnel value of $30/hour is used to estimate an annual cost of $1,200. One-half ($600) of the annual reporting costs have been assumed to be for upstream mitigation issues.

16. **DWM—Annual Reporting.** The other half of the estimated annual reporting costs is assumed for downstream mitigation related issues. (Item 15 above.)

17. **UPM—Administrative.** It has been estimated that mitigation activities such as staff time spent at meetings with other agencies, coordination of operations, reacting to fishery contingencies, and other events have required administrative costs in the $10,000 to $20,000 range. A value of $15,000 has been used as an estimate. One-half ($7,500) of the administrative costs have been assumed to be for upstream mitigation issues.

18. **DWM—Administrative.** The other half of the estimated administrative costs is assumed for downstream mitigation issues. (Item 17 above.)

11.4.5 Lost Generation Costs.

19. **Estimated Generation Losses.** Historical generation losses were obtained for the years 1983 through 1991. The years 1987 to 1991 were used to estimate a mean value ($130,300) of future generation losses. The years 1983 through 1986 were not included in the average because the magnitude of generation losses was heavily influenced by plant shutdowns resulting from the installation of and modification to the downstream fish screen system. These types are shutdowns are not anticipated to occur again.

The exact percentage of generation losses resulting from either upstream or downstream mitigation is not available. As a result, the generation losses are not assigned as an upstream or downstream mitigation cost; instead they are discussed as a separate cost item. The estimate of generation lost as a result of upstream and downstream mitigation efforts includes:

- Power canal closures to effect upstream and downstream passage/protection facility modifications

- Reductions in power canal flows for reduced screen velocities required to meet fry survival criteria (10% reduction in canal flow required January to April to achieve fry survival rates greater than 95%)

- Canal closures to release adults from the trailrace of the powerhouse (returning adults to the river to continue travel to upstream ladders past the powerhouse and dam)

- The downstream fish screens have resulted in a lower flow into the power canal, resulting in a loss of an estimated 1 megawatt capacity.

Power canal closures were frequently used to perform needed repair and maintenance to generation facilities. These closures were often used to supplant a later requirement for powerhouse downtime. The percent of canal closures used for powerhouse generation-related activities is estimated by the licensee at 10% to 50%. A value of 30% has been applied to the lost generation. As a result, the lost generation for upstream and downstream mitigation is estimated at 70% of the generation losses.

Short-term canal flow reductions that permit higher bypass flows in the river allow the Oregon Department of Fish and Wildlife to navigate this stretch of stream with a deep draft "planting boat" that releases legal-size hatchery trout for anglers. Generation losses from this activity are included in the estimate of generation losses, but these losses are estimated to be small percentage of the total losses.

Early high costs were associated with long-term power canal closures needed to make major facility modifications; the more recent high costs are related to small daily canal flow reductions over extended periods. These generation losses do not include lost generation resulting from instream minimum flows.

Table 11-7. Leaburg mitigation costs.

Leaburg Project—Mitigation Cost Analysis—All Values in 1993 Dollars

9/09/93	–10	–9	–8	–7	–6	–5	–4	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	TOTALS
Capital & Study Costs—(Non Annual)																					
1) UPM—Left Fish Ladder ('69)	$445,700																				$445,700
2) UPM—Right Fish Ladder (Est)													$604,400								$604,400
3) DWM—Screen Panels	$776,500																				$776,500
4) DWM—Screen Const\Frames\Trashrack	$1,486,700																				$1,486,700
5) DWM—Instl\Mod Bckflsh System		$679,800	$244,600	$43,600																	$968,000
6) DWM—Screen Hydraulics Study					$71,600																$71,600
7) DWM—Rebuild Bypass						$43,600															$43,600
8) DWM—Install Solid Baffles								$170,200													$170,200
9) DWM—Install Adjustable Baffles									$227,500												$227,500
10) DWM—Modify Flume										$31,800											$31,800
Annual Operations & Maintenance																					
11) UPM—Adult Ladder	$14,000	$14,000	$14,000	$14,000	$14,000	$14,000	$14,000	$14,000	$14,000	$14,000	$14,000	$14,000	$21,000	$21,000	$21,000	$21,000	$21,000	$21,000	$21,000	$21,000	$336,000
12) DWM—Screen System							$3,600	$0	$98,300	$88,000	$47,500	$47,500	$47,500	$47,500	$47,500	$47,500	$47,500	$47,500	$47,500	$47,500	$664,900
Annual Monitoring																					
13) UPM—Passage Counting		$5,100	$5,200	$5,400	$6,900	$6,500	$6,900	$7,000	$7,600	$7,700	$7,700	$8,000	$8,400	$8,800	$9,200	$9,600	$10,000	$10,500	$11,000	$11,400	$152,900
14) DWM—Passage Counting		$41,300	$41,800	$43,400	$55,500	$52,700	$55,500	$57,000	$61,400	$62,100	$62,300										$533,000
Annual Reporting & Admin Costs																					
15) UPM—Annual Reporting	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$12,000
16) DWM—Annual Reporting	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$600	$12,000
17) UPM—Administrative	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$150,000
18) DWM—Administrative	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$150,000
Annual Generation Losses																					
19) Estimated Generation Losses	$357,100	$378,400	$374,200	$118,200	$14,100	$7,900	$10,700	$279,200	$339,800	$130,300	$130,300	$130,300	$130,300	$130,300	$130,300	$130,300	$130,300	$130,300	$130,300	$130,300	$3,312,900
Subtotal UPM Capital & Study Costs	$445,700	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$604,400	$0	$0	$0	$0	$0	$0	$0	$1,050,100
Subtotal UPM Annual Costs	$22,100	$27,200	$27,300	$27,500	$29,000	$28,600	$29,000	$29,100	$29,700	$29,800	$29,800	$30,100	$37,500	$37,900	$38,300	$38,700	$39,100	$39,600	$40,100	$40,500	$650,900
Subtotal UPM (Excludes Generation)	$467,800	$27,200	$27,300	$27,500	$29,000	$28,600	$29,000	$29,100	$29,700	$29,800	$29,800	$30,100	$641,900	$37,900	$38,300	$38,700	$39,100	$39,600	$40,100	$40,500	$1,701,000
Subtotal DWM Capital Costs	$2,263,200	$679,800	$244,600	$43,600	$71,600	$43,600	$0	$170,200	$227,500	$31,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$3,775,900
Subtotal DWM Annual Costs	$8,100	$49,400	$49,900	$51,500	$63,600	$60,800	$67,200	$65,100	$167,800	$158,200	$117,900	$55,600	$55,600	$55,600	$55,600	$55,600	$55,600	$55,600	$55,600	$55,600	$1,359,900
Subtotal DWM (Excludes Generation)	$2,271,300	$729,200	$294,500	$95,100	$135,200	$104,400	$67,200	$235,300	$395,300	$190,000	$117,900	$55,600	$55,600	$55,600	$55,600	$55,600	$55,600	$55,600	$55,600	$55,600	$5,135,800
Total Expenses (Includes Generation)	$3,096,200	$1,134,800	$696,000	$240,800	$178,300	$140,900	$106,900	$543,600	$764,800	$350,100	$278,000	$216,000	$827,800	$223,800	$224,200	$224,600	$225,000	$225,500	$226,000	$226,400	$10,149,700

Notes: 4.5% Index rate used to present values as 1993 dollars
DWM = Downstream Mitigation
UPM = Upstream Mitigation
Some costs are estimated, see mitigation cost text for details
Subtotal UPM Capital Costs includes items: 1, 2
Subtotal UPM Annual Costs includes items: 11, 13, 15, 17
Subtotal DWM Capital Costs includes items: 3, 4, 5, 6, 7, 8, 9 & 10
Subtotal DWM Annual Costs includes items: 12, 14, 16 & 18

12. LITTLE FALLS CASE STUDY

12.1 Description

The Little Falls project (FERC number 03509) diverts water from a New York State Department of Transportation barge canal, which in turn diverts water from the Mohawk River near Albany, New York (Figures 12-1 and 12-2). The Department of Transportation barge canal and navigation lock have been in operation since about 1914. The Little Falls project began operation in 1987 and has a total installed capacity of 13.6 megawatts.

Because the canal diverts the majority of flow from the Mohawk River, many downstream migrating anadromous blueback herring pass into the canal and are subject to turbine entrainment. The following mitigative measures were employed at the Little Falls project in 1990 in order to reduce turbine entrainment: (a) one-half-inch wire mesh screens were placed in front of the trash racks to a depth of 20 feet; (b) the ice/trash sluice was operated as a fish bypass with a minimum flow of 100 cfs; and (c) turbines were shut down when hydroacoustic monitoring indicated that excessive numbers of fish were passing into the penstocks.

12.1.1 Fish Resource Management Objectives of Mitigation. Blueback herring are not native to the Mohawk River because waterfalls at the confluence of the Mohawk River with the Hudson River near Albany prevented upstream passage of anadromous fish. Operation of the series of locks on the barge canal has enabled blueback herring to become established in the Mohawk River. An estimated 10,000 to 20,000 upstream-migrating adults pass through Lock 17 at Little Falls each spring (Little Falls Hydroelectric Association, 1991b). Because of the spawner's tendency to swim upstream against the water flow, upstream-migrating adult blueback herring avoid the intake to the plant.

Figure 12-1. Little Falls project, on the Mohawk River.

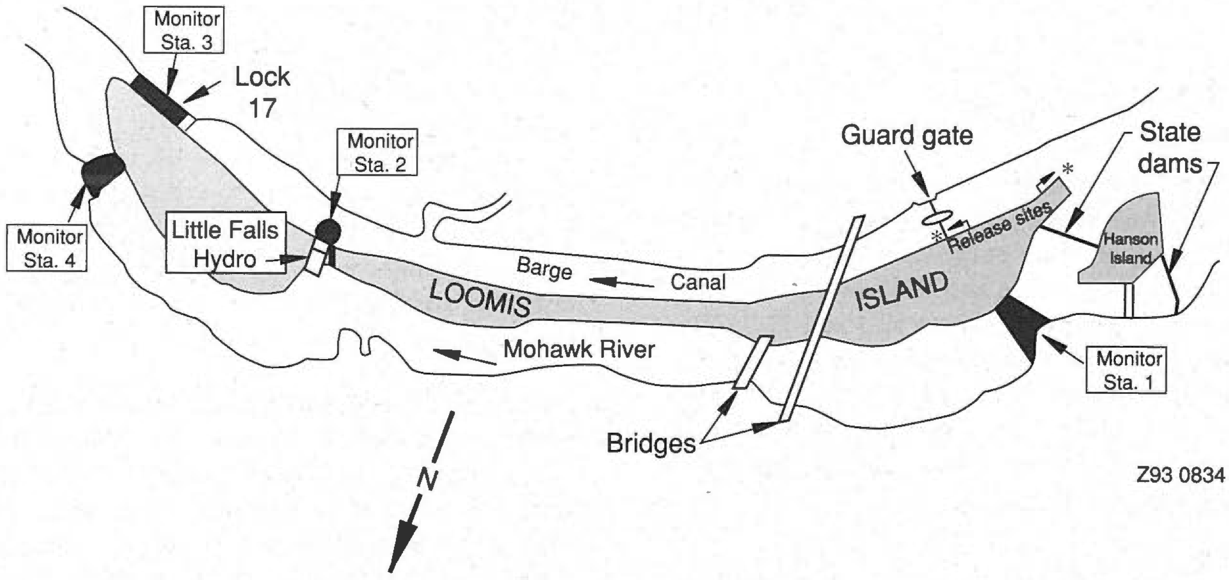


Figure 12-2. Little Falls project vicinity, showing Mohawk River, barge canal, and state dams. Source: RMC Environmental Services, Inc. (1992)

Entrainment of downstream-migrating juveniles and adults passing through the barge canal was considered to be a greater problem. During years with normal stream flows, downstream migrants prefer to move through the barge canal rather than the bypassed reach of the Mohawk River (Figure 12-3), and they are thus susceptible to being drawn into the hydroelectric project intake on the canal, 1000 feet upstream from Lock 17. Passage occurs through the lock chamber as well as through the valves and tunnels used to fill and empty the lock. Downstream migration occurs between mid-September and mid-November, with the peak in October. Migration appears to be triggered by a combination of falling water temperatures and increasing stream flows.

Blueback herring have been observed congregating in large schools in front of the project intake or near the lock; opening the locks for barge traffic passes most fish downstream. The number of downstream migrating herring passing the barge canal in the Little Falls area each year was not estimated, although based on hydroacoustic monitoring an estimated 173,100 fish (±50%) were present in the intake area and bypass sluice during a 10-day period in mid-October (Little Falls Hydroelectric Association, 1991a).

The FERC license required the licensee to develop, in cooperation with the resource agencies, a plan to determine measures necessary to mitigate adverse impacts of project operation on the upstream migration of adult and downstream migration of adult and juvenile blueback herring. Based on post-operational studies, the licensee, agencies, and FERC agreed that the existing project operation did not appear to affect the spring upstream migration of adult blueback herring. However, the potential for turbine entrainment of downstream-migrating herring has led to the installation and monitoring of intake screens.

12.1.2 Monitoring Methods. Pre- and post-operational monitoring of the Little Falls Hydroelectric project are described by the Little Falls Hydroelectric Association (1991b). Studies conducted from 1985 through 1989 were aimed at obtaining a better understanding of the fall downstream migration of blueback herring, the preferred routes (Mohawk River bypassed reach versus barge canal versus penstock intake), and the value of the ice sluice to bypass fish in the

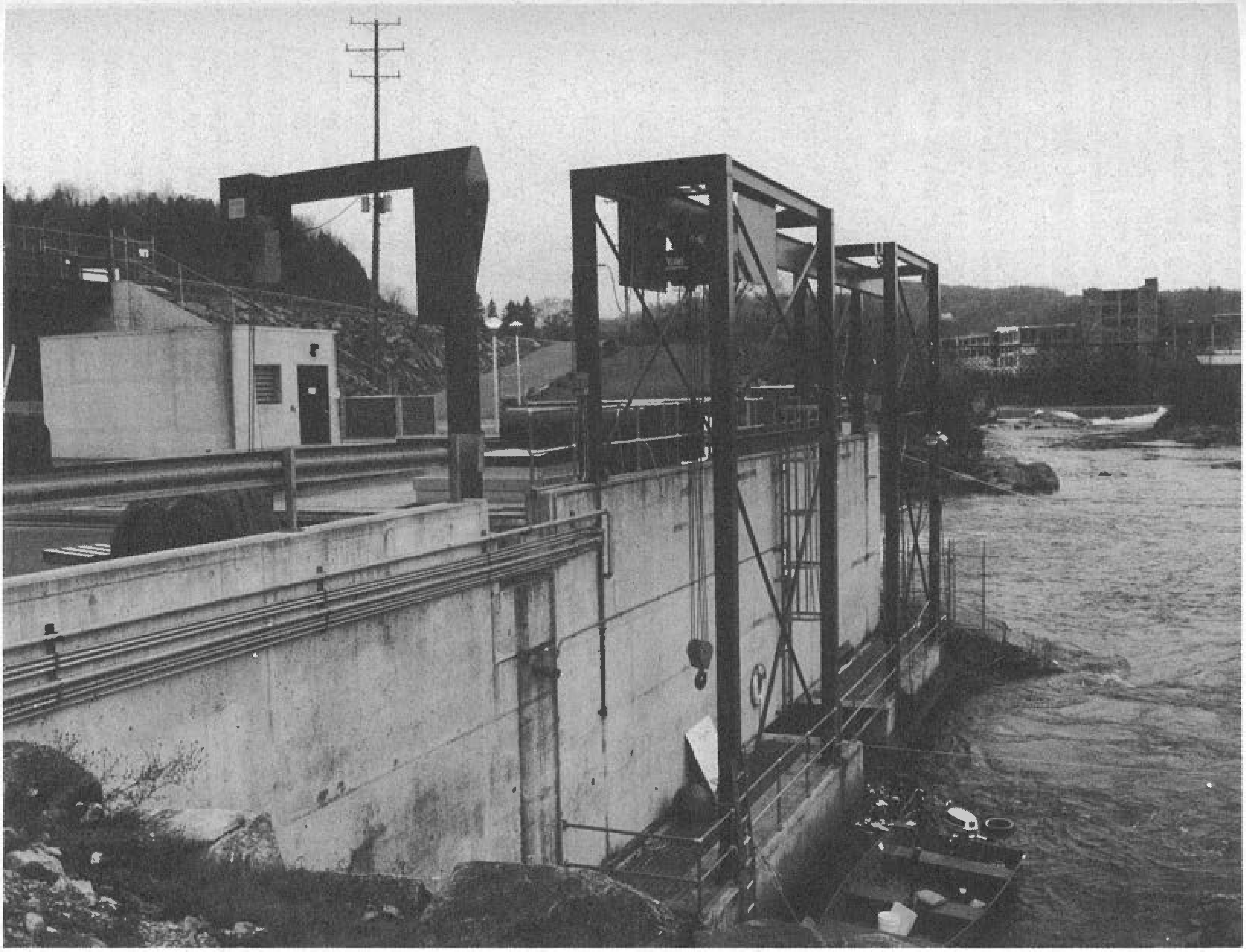


Figure 12-3. Little Falls power plant tailwater and Mohawk River.

intake area. Echo sounders and a scanning SONAR hydroacoustic system were installed in 1989.

Monitoring was increased during the 1990 downstream migration by operating a scanning SONAR at the intake/sluice entrance and high-frequency echo sounders in both penstocks immediately upstream of the turbine runners (Little Falls Hydroelectric Association, 1991a,b). The intake scanning sonar was used to determine the presence and behavior of blueback herring, whereas the penstock echo sounders were used as a gross measure of entrainment. The SONAR usually scanned the upper third of the water column near the intake and only periodically scanned the lower two-thirds. All SONAR and echo sounder outputs were videotaped. The video images were processed to estimate the volume of detected target aggregations (i.e., schools of herring). Number of fish in each aggregation were then estimated assuming that each 7- to 8-cm herring had a three-dimensional spacing of 7.5 cm.

The goals of the monitoring were to determine if there was any significant entrainment of blueback herring through the Little Falls turbines and, if required, the best procedure for preventing entrainment (Little Falls Hydroelectric Association, 1991b). Owing to these narrowly defined goals, no fish mortality studies were performed to determine the impact of turbine entrainment. Further, no monitoring was done without the 0.5-inch screens in place. Thus, while the numbers of blueback herring entrained have been estimated, neither the subsequent mortality nor the contribution of the screens in preventing entrainment was examined.

12.1.3 Performance of Mitigation. Neither the SONAR nor the echo sounders were always capable of detecting individual fish due to the tendency of fish to aggregate and the variability of spacing between fish within the aggregations. As a result, rudimentary estimates of numbers of fish were derived by estimating the size of an aggregation and making assumptions about the size and spacing of individual fish within the group. Large amounts of floating and semisubmerged debris (including leaves, grass, and brush) were trapped against the intake screens (Little Falls Hydroelectric Association, 1991a). This debris tended to clog the screens; when dislodged by vessel passage or wind-induced waves, debris was difficult to distinguish from fish on the side-scan SONAR. SONAR targets were judged to be debris aggregations rather than groups of fish if the targets changed shape and size relatively slowly, were elongated, moved in the same trajectory as local flow vectors, and did not respond to disturbance (e.g., a stone thrown into the target).

Consistent with the surface-oriented behavior of downstream-migrating blueback herring, most juveniles appeared to congregate in the upper 3 meters of water. No small target aggregations were detected in the intake area below this depth (although fewer scans were made in deeper water), and echo sounders in the penstock detected very few targets that were judged to be fish (Little Falls Hydroelectric Association, 1991a). However, considerable penstock target activity was observed, most of which was attributed to other objects with similar sound-scattering characteristics, such as leaves, small twigs, silt, turbulence, or entrained air.

Based on comparison of target activity recorded by the intake-scanning SONAR and the penstock echo sounders for seven major fish target "events" in mid-October, the licensee estimated that fewer than 1% of the blueback herring in the area of the intake were entrained through the turbines (Little Falls Hydroelectric Association, 1991a). Because of the subjectivity associated with differentiating fish from debris based on hydroacoustic recordings, and the lack of direct measurements of entrainment (e.g., tailrace netting), it is not possible to verify these estimates with the existing data. Screen clogging by debris was a common problem which, if severe enough, might result in localized areas of high through-screen velocities and increased risk of fish impingement. The potential loss of juvenile blueback herring through impingement on the intake screens was not studied.

12.2 Mitigation Benefits

12.2.1 Benefits to Fish Populations. No information is available on the effects of the intake screens on blueback herring populations in the Mohawk River.

12.2.2 Benefits to Fisheries. No information about the effects of this mitigative measure on recreational or commercial fisheries is available.

12.3 Mitigation Costs

12.3.1 Introduction. The mitigation cost analysis for the Little Falls hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; an upstream fish passage/protection system section, discussing the upstream mitigation costs; a downstream fish passage/protection system section, discussing the downstream mitigation costs; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal written correspondence and from telephone calls. A site visit greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

12.3.2 Cost Summary. The total costs of environmental mitigation at the Little Falls plant for a 20-year (1985–2004) time frame are estimated at $2,737,800 (Table 12-1). When levelized as an average cost per year for the 20-year analysis, the average annual cost is $136,890. With an average annual energy production of 49,400 megawatt-hours of electricity, the cost of the identified mitigation is 2.8 mills per kilowatt-hour. This equates to about three-tenths of a cent per kilowatt-hour of produced electricity. The largest cost item is the downstream mitigation annual costs (Figure 12-4), which are primarily driven by the size of the annual lost generation costs.

The study costs through 1992 have totaled $749,660 (Figure 12-5), which is 54% of all mitigation costs incurred through 1992. This is six times the incurred capital costs for mitigation during the same period.

12.3.3 Upstream Fish Passage/ Protection.

12.3.3.1 Capital and Study Costs. To date no upstream mitigation practices have been employed at Little Falls, and there is no reason to expect future upstream mitigation requirements. The project is unique in that upstream migrants travel through the navigation locks and canal as well as the river.

A 4-year study (1985–1988) examined the upstream movements of adult blueback herring in relationship to the siting and operations of the plant. A total of $190,600 was spent over the 4 years. An additional upstream mitigation study expense was the purchase of a fixed beam echo sounder ($28,440). The 20-year total for upstream nonannual costs is $219,040. The levelized annual cost is $10,950, and, using the annual average power production of 49,400 megawatt-hours, the cost per kilowatt-hour is 0.2 mills (Table 12-2).

Table 12-1. Twenty-year costs for upstream and downstream mitigation at Little Falls.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Upstream mitigation	270,520	13,530	0.3
Downstream mitigation	2,467,280	123,360	2.5
Total costs	2,737,800	136,890	2.8

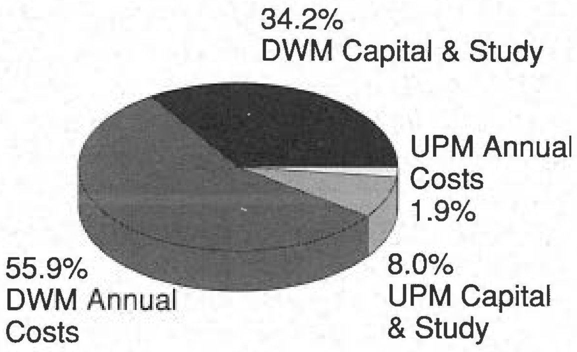


Figure 12-4. Upstream (UPM) and downstream (DWM) mitigation costs at the Little Falls project.

12.3.3.2 Annual Costs. The annual upstream mitigation costs are expected to be zero in the future (excluding the water used for extra lock operations to facilitate upstream movement). The 20-year total cost is $51,480 and the levelized annual cost is $2,570. With an average annual energy production of 49,400 megawatt-hours, the cost per kilowatt-hour is 0.1 mills.

12.3.4 Downstream Fish Passage/ Protection.

12.3.4.1 Capital and Study Costs. The downstream mitigation capital costs include the

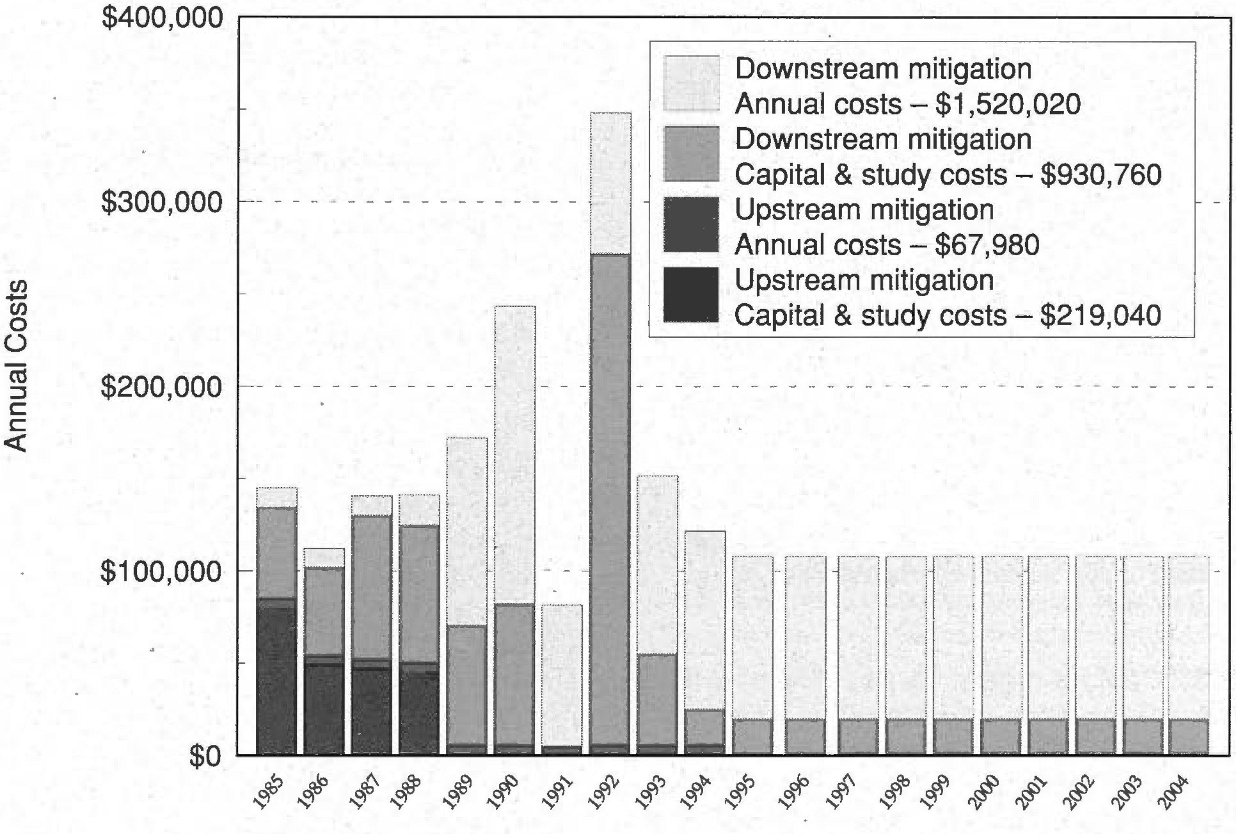


Figure 12-5. Yearly costs of upstream and downstream mitigation at the Little Falls project.

Table 12-2. Twenty-year costs incurred for upstream mitigation at Little Falls.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital costs	219,040	10,950	0.2
Annual costs	51,480	2,570	0.1
Total upstream costs	270,520	13,530	0.3

one-half-inch wire mesh screens ($2,850) placed over the turbine intakes during 1990 and 1991. The wire mesh screens proved difficult to clean, and they clogged often. The wire mesh screens were replaced in 1992 by a drilled (0.5-inch holes) plate screen ($5,230), which is in use today. It is proposed that in 1993 the fish sluice and gate be improved at a cost of $50,000. Additional costs include the turbine intake modifications ($122,060). These modifications included the reconfiguration of the concrete intakes and some concrete sluice modifications. The total cost for the modifications and screens was $180,140.

Study costs include a 4 year (1985–1988) downstream migration study that totaled $190,600. Additional downstream migration studies occurred during 1989, 1990, and 1992. These studies respectively cost $35,780, $45,650, and $261,250 (two parts). Various adult and/or juvenile downstream migrations were studied. It is proposed that starting in 1994 $20,000 be annually contributed to an agency study fund. The total cost of the downstream migration studies and the contribution to the study fund is $750,620.

The total capital and study costs for downstream mitigation were $930,760. The 20-year levelized annual cost is $46,540. With an average production of 49,400 megawatt-hours, the average cost per kilowatt-hour for the capital and study costs is 0.9 mills (Table 12-3).

12.3.4.2 Annual Costs. The costs comprising the annual downstream mitigation costs include two-thirds of the mitigation management costs through 1994 and all after, operations and management ($72,000), plant shutdowns in 1989 and 1990 ($170,000) required by downstream migration studies, and lost generation from 100 cfs spills over the sluiceway from 1990 on ($1,140,000). The proposed mitigation plan requires 4 months per year of 100 cfs bypass flows at an annual cost of $80,000. The 20-year total for all annual costs is $1,536,520. The 20-year levelized annual cost is $76,830, and, with an average annual energy production of 49,400 megawatt-hours, the cost per kilowatt-hour for the annual costs is 1.6 mills.

12.4 Cost Descriptions and Assumptions

This section provides an explanation of the individual cost items and the assumptions and estimates required to quantify the respective items and derive totals. The item numbers correspond to the 20-year spreadsheet (Table 12-4) used to determine costs. All costs have been indexed to 1993 dollars and are discussed as such.

12.4.1 Capital Costs.

1. **1/2" Wire Mesh Screens.** In 1990 wire screens with one-inch horizontal and vertical spaces were installed to a depth of 20 feet in front of the turbine intakes. The wire mesh screen clogged quickly and acted as a solid surface. The screens were in place during 1990 and 1991, and they were replaced in 1992 (Item 2 below). The wire mesh screens were hung in front of the trash racks (Figure 12-6), and they were installed using the hoist on the trash rack rake. The costs to install the screens was reported as minimal. The manufactured cost of the wire mesh screens was $2,850.

Table 12-3. Twenty year costs incurred for downstream mitigation at Little Falls.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital and study costs	930,760	46,540	0.9
Annual costs	1,536,520	76,830	1.6
Total downstream costs	2,467,280	123,360	2.5

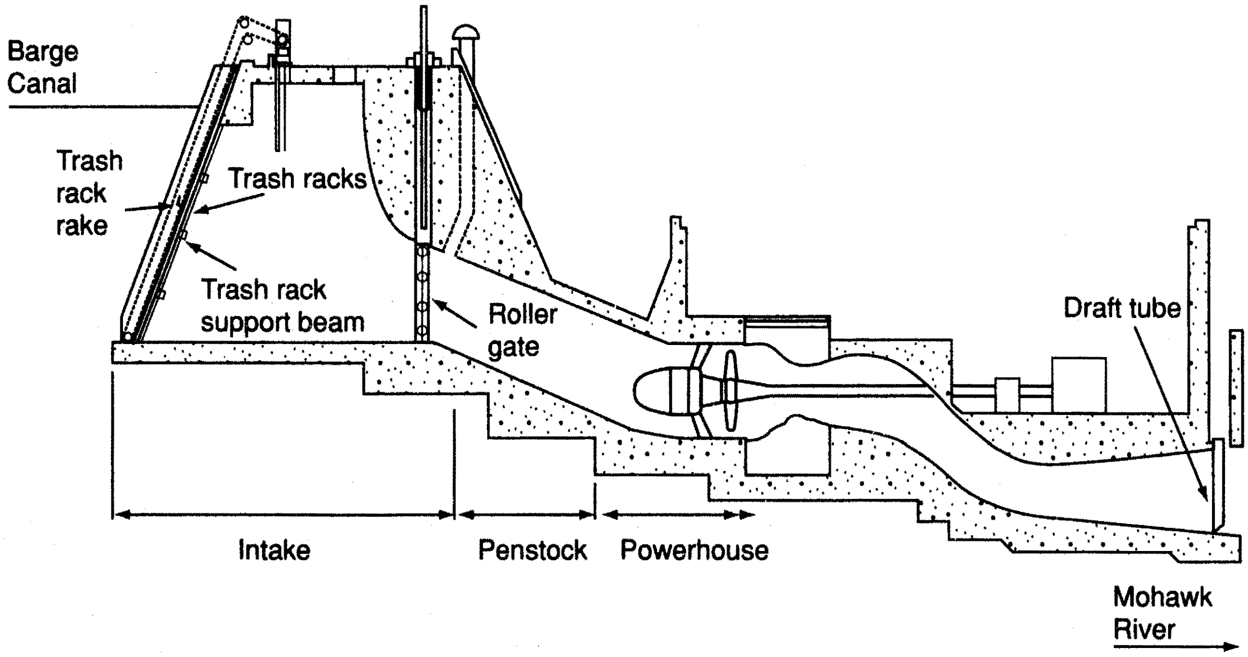


Figure 12-6. Side view of Little Falls power plant. The fish screens sit on the trash racks.

2. **Drilled Plate Screens.** In 1992 the wire mesh screens (Item 1 above) were replaced with the drilled plate screens (Figure 12-7). The drilled plates had one-half-inch holes drilled on 0.69 inch centers, resulting in 60% porosity. The major advantage of the drilled plates is that they can be cleaned with the trash rack rake. The drilled plate screens hang in front of the trash racks, and installation was performed using the installed hoist on the trash rack rake. The manufactured cost of the drilled plate screens was $5,230.

3. **Turbine Intake Modifications.** The turbine intakes and the fish sluice were modified to assist the downstream passage/protection of fish. This effort was accomplished over 4 years (1987–1990) and included the following activities: a two-foot by six-foot by three-foot section of concrete was cut out of the intake wall to ease passage from the number 1 (upstream) turbine intake to the fish sluice area; a steel "L" shaped protrusion was built at the fish sluice to guide the fish to the sluice opening; fixed beam echo sounders were purchased to monitor the passage behind the trash racks and fish screens; and concrete was added to the bottom of the fish sluice to guide the fish smoothly into the tailwater (Figure 12-8). A total 4-year cost was reported, and this cost was averaged over the 4-year time period and inflated to 1993 dollars. The total 4-year cost of this activity is $122,060. $50,000 is to be spent during 1993 to improve the sluice gate and flow dynamics.

12.4.2 Study Costs.

4. **UPM Fixed Beam Echo Sounder.** The fixed beam echo sounder was a sonar-based fish counter used to count the number of adult herring passing through Lock 17. The fixed beam echo sounder includes two dual beam transducers (4-degree beam width surrounding a 2 degree beam) set side by side on a sill immediately upstream of the upper lock gates. A third transducer was mounted for connection to a color monitor.

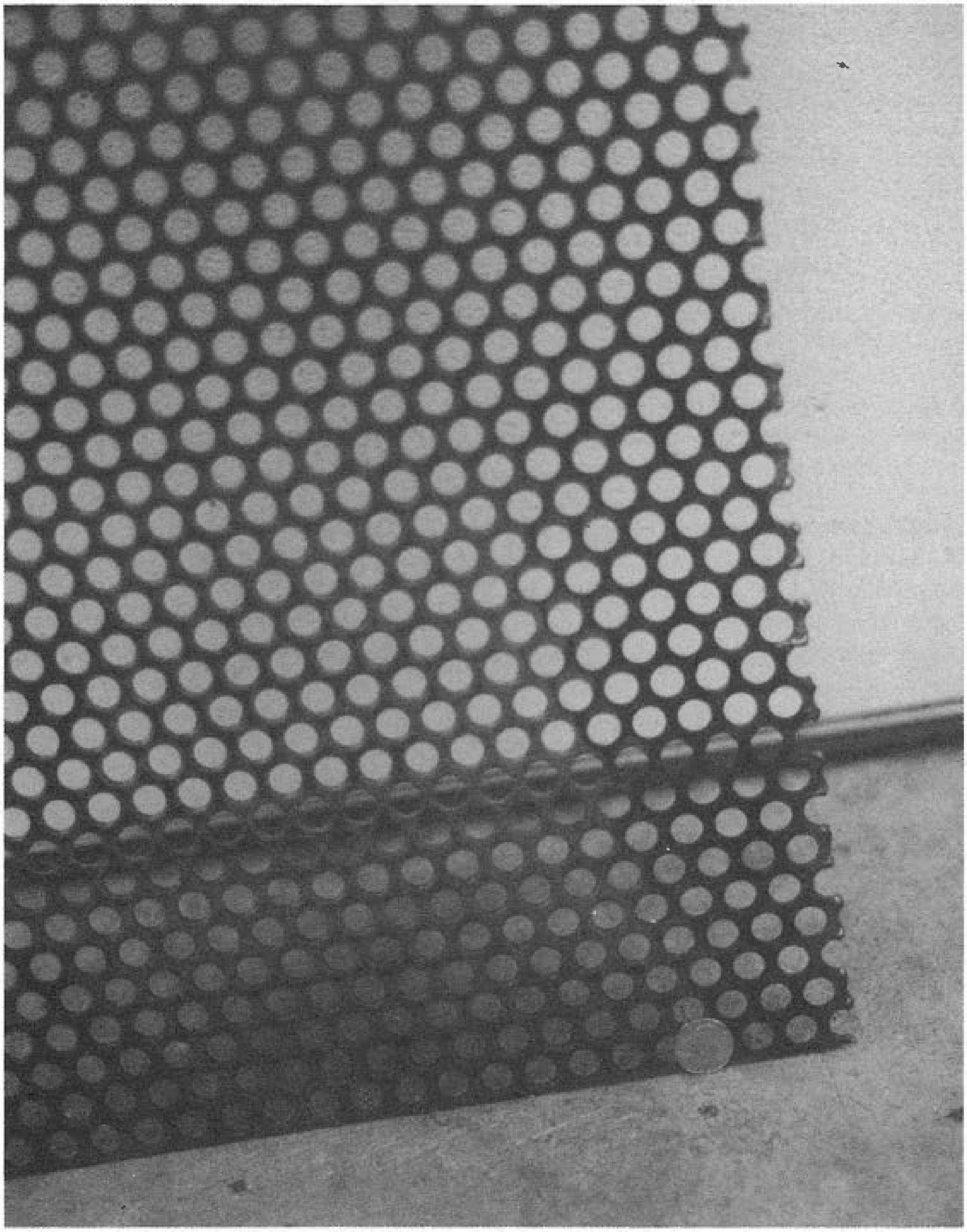


Figure 12-7. Drilled plate intake screen fitted on the Little Falls trash rack. Quarter in foreground for size reference.

The fixed beam echo sounder was used for several years of studies (Item 5 below). It was purchased in 1985 for $28,440.

5. **UPM Blueback Herring ('85–88).** A single cost was reported for all 4 years of this study. The total reported cost was averaged for the 4 years and inflated to 1993 dollars. The total cost, in 1993 dollars, for this study was $190,600. The study results were reported each year. Some of the results were reported in individual reports, others were

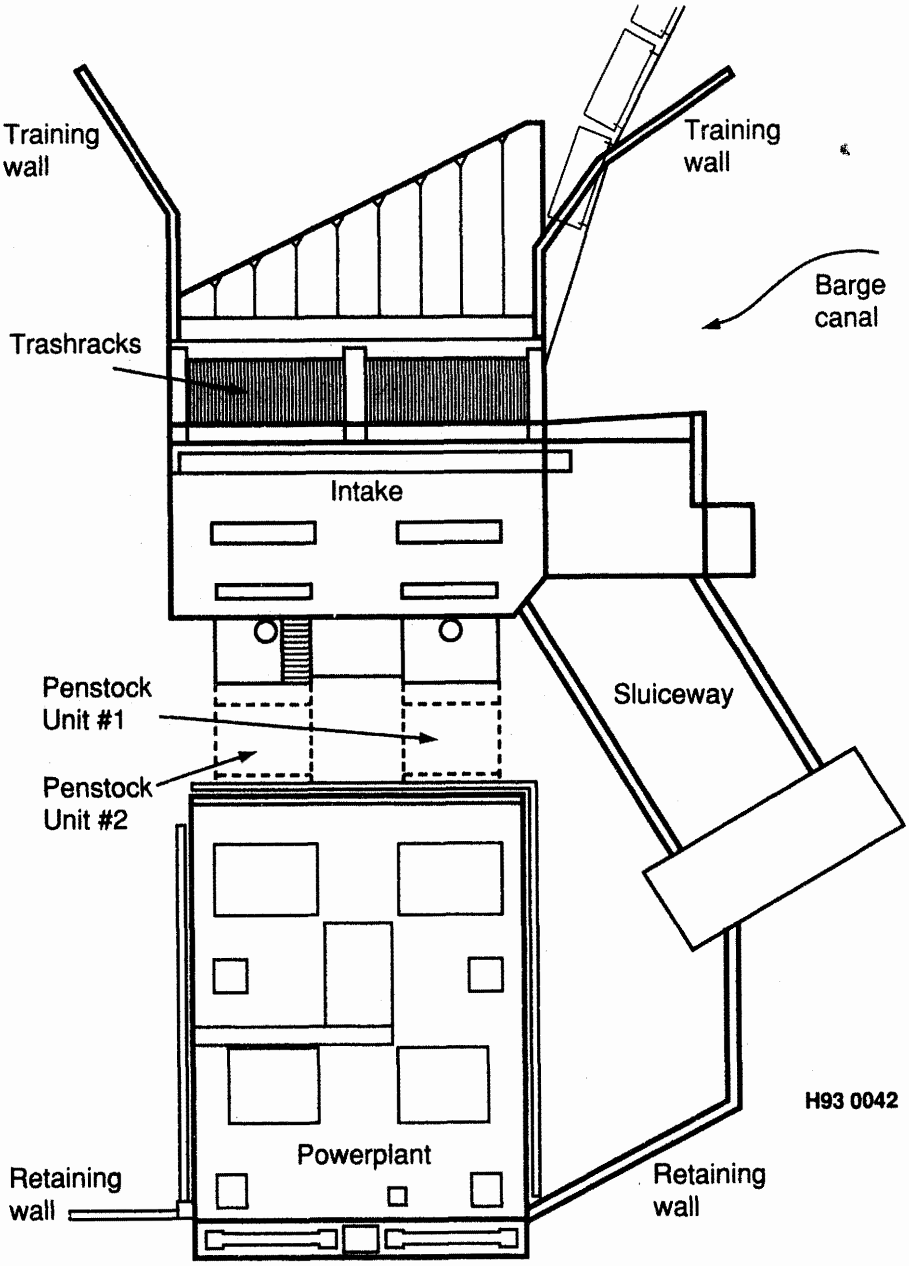


Figure 12-8. Overview of Little Falls power plant.

reported in combination with downstream mitigation results. The upstream mitigation report titles for 1985–1988 are

- "Blueback Herring Study, Upstream and Downstream Migration 1985 for Little Falls Hydroelectric Associates." This study assessed the movement patterns and total numbers of migratory blueback herring in the vicinity of the Little Falls hydroelectric development project.

- "Draft Data Report, Blueback Herring Study Upstream Migration 1986 for Little Falls Hydroelectric Associates." Adult spawning blueback herring migration patterns were examined in the vicinity of the Little Falls plant and in relation to environmental conditions such as air temperature, water temperature, discharge, and barometric pressure.

- "1987 Blueback Herring Migration Study Report." This study's objectives were to assess any changes in the established adult and juvenile migrational patterns and to determine which changes, if any, could be attributed to power generation at the Little Falls hydroelectric station.

- "The Influence of the Little Falls Hydroelectric Station on Immigrating Adult Blueback Herring, June 1988." This study attempted to determine if upstream migrating blueback herring were entrained or delayed by the Little Falls hydroelectric station.

6. **DWM Blueback Herring ('85–88).** A single cost was reported for all 4 years of this study. The total reported cost was averaged for the 4 years and inflated to 1993 dollars. The total cost, in 1993 dollars, for this study was $187,940. The study results were reported each year. Some of the results were reported in separate reports, and others were reported in combination with upstream mitigation results. The downstream mitigation report titles for 1985–1988 are

   - "Blueback Herring Study, Upstream and Downstream Migration 1985 for Little Falls Hydroelectric Associates." This study assessed the movement patterns and total numbers of migratory blueback herring in the vicinity of the Little Falls hydroelectric development project.

   - "Blueback Herring Study Juvenile Downstream Migration—1986." The primary purpose of this study was to elucidate the onset and duration of juvenile blueback herring emigration, while evaluating the effect of environmental factors such as barometric pressure, discharge, and water temperature.

   - "1987 Blueback Herring Migration Study Report." This study's objectives were to assess any changes in the established adult and juvenile migrational patterns and to determine which changes, if any, could be attributed to power generation at the Little Falls hydroelectric station.

   - "The Influence of the Little Falls Hydroelectric Station on Immigrating Adult Blueback Herring, June 1988." This study attempted to determine if upstream migrating blueback herring were entrained or delayed by the Little Falls hydroelectric station.

7. **DWM Blueback Herring (1989).** This study occurred late in 1988, and the costs were incurred in 1989. Hydroacoustic monitoring equipment was used to estimate fish passage through the canal proper and the Little Falls power station. The study title is "Report on the 1988 Juvenile Blueback Herring Emigration at the Little Falls Hydroelectric Station, February 16, 1989." The cost of this study was $35,780.

8. **DWM Blueback Herring (1990).** This study occurred during the fall of 1990, and it used hydroacoustic sensors to evaluate downstream juvenile blueback herring migration at the Little Falls hydroelectric plant. The report produced by this study is titled "1990 Blueback Herring Downstream Migration Report, September 7–November 30, 1990." The total cost for this effort was $45,650.

9. **DWM Blueback Herring (1992).** This cost includes two concurrent studies, both of which examined downstream mitigation efforts. A brief description and the study titles are provided below. The total cost for these studies was $261,250.

   - "Evaluation of Mitigative Measures for Juvenile Blueback Herring at the Little Falls Hydroelectric project." This study attempted to monitor the effectiveness of the mitigative measures at ensuring the prevention of fish mortality due to entrainment.

- "Effect of Little Falls Hydro Operations on Emigration of Radio Tagged Adult Blueback Herring." This was a radio telemetry study to determine the effect, if any, of project operations on the emigration of post-spawned adult blueback herring.

10. **Annual Study Contribution.** The $20,000 cost is a donation to an agency study fund. The prevalent mitigation study issue is downstream mitigation, and the entire cost is assumed as a downstream mitigation cost.

12.4.3 Annual Personnel Costs.

11. **Mitigation Management.** The amount of management, biologist, and other support staff resources committed to mitigation at this project (as at most projects) is difficult to quantify. The licensee has reported that the equivalent of between 20% and 30% of a full-time person's time is spent on mitigation-related administration, meetings, or reporting activities. Assuming an annual labor resource use of 25% and a hourly rate of $30, the estimated commitment is $15,600 per year through 1994. It was estimated that this resource requirement commenced in 1985 along with the start of mitigation studies. It is estimated that the future duties will diminish and the licensee has estimated an annual cost of $5,000.

    Downstream mitigation has incurred greater study costs than upstream mitigation: downstream mitigation has included ~$180,000 (screens and intake modification) in capital costs, while upstream mitigation has not had any capital requirements. For these reasons, from a cost of resources perspective, it appears that mitigation management is primarily spent on downstream mitigation issues. Therefore, one-third of the mitigation management costs have been assigned to the upstream cost totals, and two-thirds have been assigned to the downstream mitigation cost totals through 1994. After 1994, it is not expected that upstream mitigation will require this resource.

12. **DWM Operations and Maintenance.** The licensee indicated that commencing in 1988 approximately 200 person-hours per year have been spent on the operations and maintenance associated with downstream mitigation. During a site visit, plant operations personnel were observed assisting consultants with the placement of study equipment. Additional duties have included the installation and cleaning of mitigation screens. A value of $30 per person-hour was assumed for the yearly total of $6,000. It is estimated by the licensee that the operation and maintenance requirements will decrease in the future to approximately 100 person-hours per year. The value ($3,000) is used for 1995 and beyond. While acknowledging that some small proportion of the annual operations and maintenance costs may represent activities in support of upstream mitigation study consultants, the entire operations and maintenance costs have been assigned to the downstream mitigation totals. It is assumed that the screens will constitute the bulk of operations and maintenance duties, and the costs are assigned accordingly.

12.4.4 Other Revenue Costs.

13. **DWM Emigration Studies Plt Shutdown** (Downstream Mitigation Emigration Studies Required Plant Shutdown 1989 and 1990). The Little Falls project was shut down as requested by resource agencies during delays in the emigration studies. A total of 1,890,000 kilowatt-hours of generation was foregone. This equates to a total value of $170,000. This was halved and assigned for each of the 2 years. It is not anticipated that the final mitigation requirements will include plant shutdowns.

14. **DWM Annual Generation Losses.** This cost relates to the water discharge through the fish sluice adjacent to the powerhouse (Figure 12-9). In 1991 and 1992, 100 cfs were discharged for 92 days, from early September through late November, for a total loss of 670,00 kilowatt-hours. The 670,000 kilowatt-hours has an annual value of $60,000. The future mitigation proposal requires 4 months of spill per year of 100 cfs, at an annual cost of $80,000.

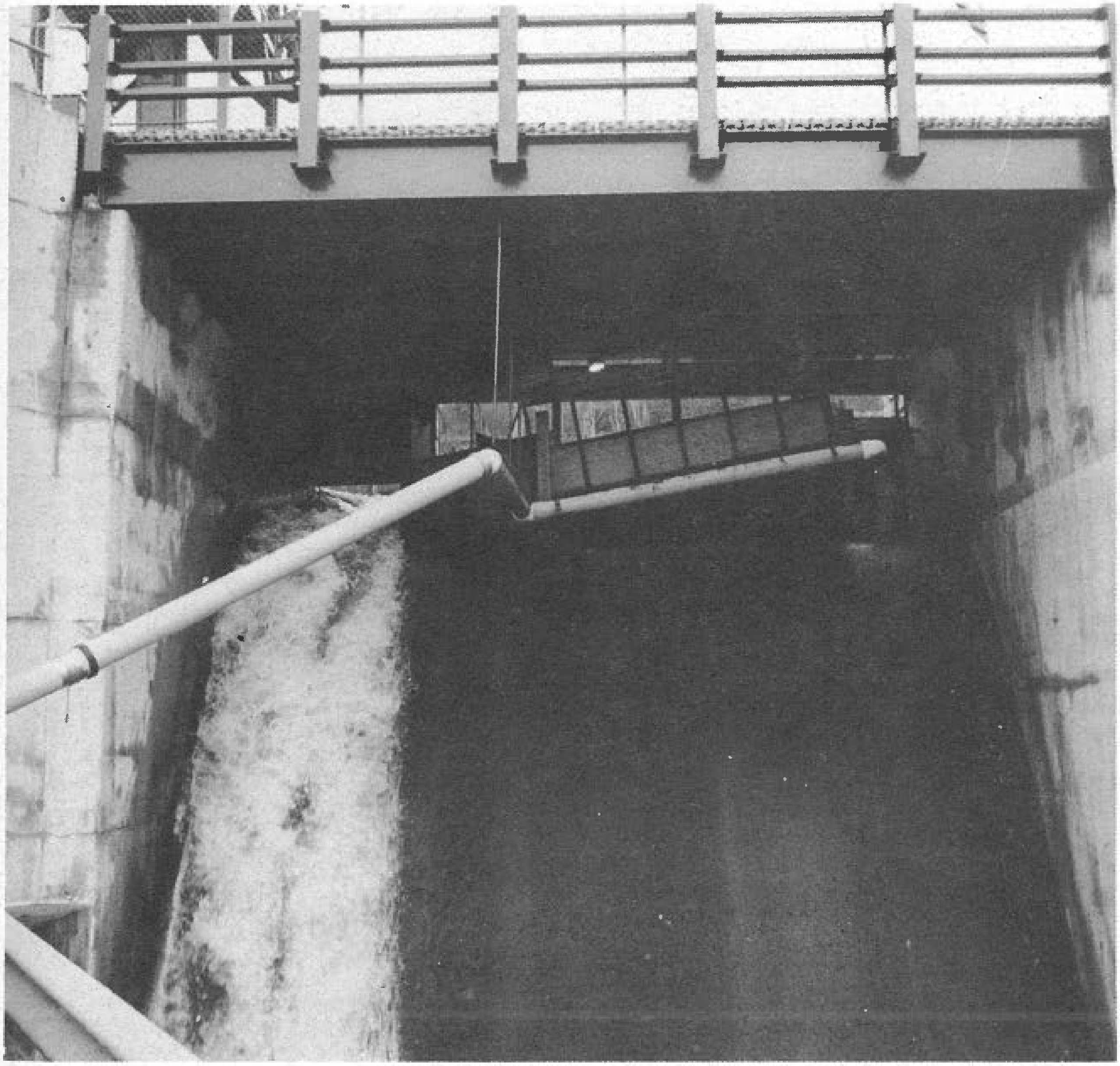


Figure 12-9. Fish sluice adjacent to the Little Falls powerhouse. A temporary fish evaluator is in the sluiceway.

Table 12-4. Little Falls mitigation costs.

Little Falls Project—Mitigation Cost Analysis—All Values in 1993 Dollars

9/09/93	–8	–7	–6	–5	–4	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	10	11	
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	TOTALS
Capital Costs—Downstream Mitigation																					
1) 1/2" Wire Mesh Screens						$2,850															$2,850
2) Drilled Plate Screens								$5,230													$5,230
3) Intake & Sluiceway Modifications			$32,560	$31,160	$29,810	$28,530			$50,000												$172,060
Study Costs																					
4) UPM Fixed Beam Echo Sounder	$28,440																				$28,440
5) UPM Blueback Herring ('85–88)	$50,840	$48,650	$46,560	$44,550																	$190,600
6) DWM Blueback Herring ('85–88)	$50,130	$47,970	$45,910	$43,930																	$187,940
7) DWM Blueback Herring (1989)					$35,780																$35,780
8) DWM Blueback Herring (1990)						$45,650															$45,650
9) DWM Blueback Herring (1992)								$261,250													$261,250
10) Annual Study Contribution										$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$220,000
Annual Personnel Cost																					
11) Mitigation Management	$15,600	$15,600	$15,600	$15,600	$15,600	$15,600	$15,600	$15,600	$15,600	$15,600	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$206,000
12) DWM Operations and Maintenance				$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$72,000
Other Revenue Losses																					
13) DWM Emigration Studies Plt Shtdn					$85,000	$85,000															$170,000
Annual Generation Losses																					
14) DWM Annual Generation Losses						$60,000	$60,000	$60,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$80,000	$1,140,000
Subtotal UPM Capital & Study Costs	$79,280	$48,650	$46,560	$44,550	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$219,040
Subtotal UPM Annual Costs	$5,148	$5,148	$5,148	$5,148	$5,148	$5,148	$5,148	$5,148	$5,148	$5,148	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$51,480
Subtotal UPM—All Costs	$84,428	$53,798	$51,708	$49,698	$5,148	$5,148	$5,148	$5,148	$5,148	$5,148	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$270,520
Subtotal DWM Capital & Study Costs	$50,130	$47,970	$78,470	$75,090	$65,590	$77,030	$0	$266,480	$50,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$930,760
Subtotal DWM Annual Costs	$10,452	$10,452	$10,452	$16,452	$101,452	$161,452	$76,452	$76,452	$96,452	$96,452	$88,000	$88,000	$88,000	$88,000	$88,000	$88,000	$88,000	$88,000	$88,000	$88,000	$1,536,520
Subtotal DWM—All Costs	$60,582	$58,422	$88,922	$91,542	$167,042	$238,482	$76,452	$342,932	$146,452	$116,452	$108,000	$108,000	$108,000	$108,000	$108,000	$108,000	$108,000	$108,000	$108,000	$108,000	$2,467,280
Total Expenses—1993 Dollars	$145,010	$112,220	$140,630	$141,240	$172,190	$243,630	$81,600	$348,080	$151,600	$121,600	$108,000	$108,000	$108,000	$108,000	$108,000	$108,000	$108,000	$108,000	$108,000	$108,000	$2,737,800

Notes: 4.5% Index rate used to present values as 1993 dollars
UPM = UPstream Mitigation
DWM = Downstream Mitigation
Subtotal UPM Capital & Study Costs includes items: 4, 5
Subtotal UPM Annual Costs includes items: 11(x0.33) through 1994
Subtotal DWM Capital & Study Costs includes items: 1, 2, 3, 6, 7, 8, 9, 10
Subtotal DWM Annual Costs includes items: 11(x0.67) through 1994 and all of 11 after, 12, 13, 14

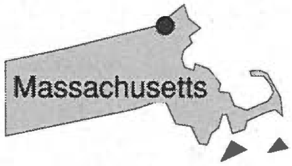
13. LOWELL CASE STUDY

13.1 Description

The Lowell Hydroelectric project (FERC number 02790), also known as the Eldred L. Field Hydroelectric project, is located on the Merrimack River (Figure 13-1) in Lowell, Massachusetts. The 15 megawatt hydroelectric project, constructed in 1985, diverts water from a canal which originates at Pawtucket Dam, and returns it to the Merrimack River downstream of Pawtucket Falls (Figure 13-2). Parts of the canal system date back to 1792, and the Northern Canal from which the Lowell project diverts water was constructed in 1846–1947 (Cunningham, 1985); hydroelectric power production originally began in 1909.

The Lowell project uses two upstream fish passage/protection facilities to transport American shad and river herring: a two-level elevator at the powerhouse (Figure 13-3) and a vertical slot fish ladder upstream at Pawtucket Dam (Figure 13-4). During peak shad migration, fish are lifted from the tailrace and released back to the Merrimack River above Pawtucket Falls, where they can swim upstream to the fish ladder (Figure 13-5). During off-peak migration, fish are released into the Northern Canal, where they can swim to the pool above Pawtucket Dam via a gatehouse. Using the canal as a release site during off-peak migration preserves water for power generation that would otherwise be needed for attraction flows to the fish ladder. Prior to the 1985 upgrade, Pawtucket Dam was a barrier to upstream fish movement. The construction of upstream fish passage/protection facilities at the Lowell project, combined with those at Lawrence, Massachusetts just downstream from Lowell, provided an opportunity to extend the range of anadromous fish in the Merrimack River.

13.1.1 Fish Resource Management Objectives of Mitigation. The Commonwealth of Massachusetts, the State of New Hampshire, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service have been working to restore anadromous fish to the Merrimack River Basin since the 1970s (Cunningham, 1985). Attention has focused on restoration of the Atlantic salmon and the American shad. Apparently because restoration of these species is at an early stage, there are only approximate quantitative goals for the operation of the fish passage/protection facilities at the Merrimack River hydroelectric projects. Objectives of the restoration activities at the present call for the return of around 1 million adult American shad and 3,000 Atlantic salmon to the Merrimack River (Stolte, personal communication). Large numbers of river herring also use the fishways, but there are no goals for this species. All Atlantic salmon in the Merrimack River are trapped at the Lawrence fishway, some



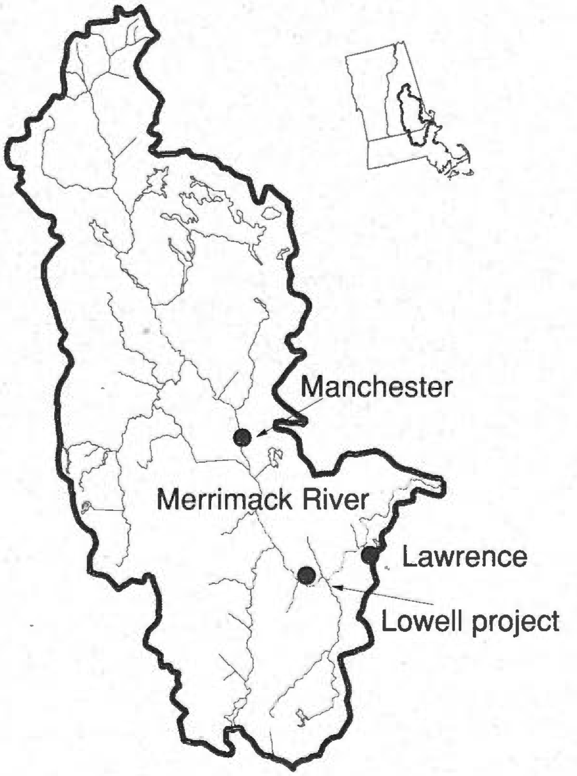


Figure 13-1. Location of the Lowell project, on the Merrimack River.

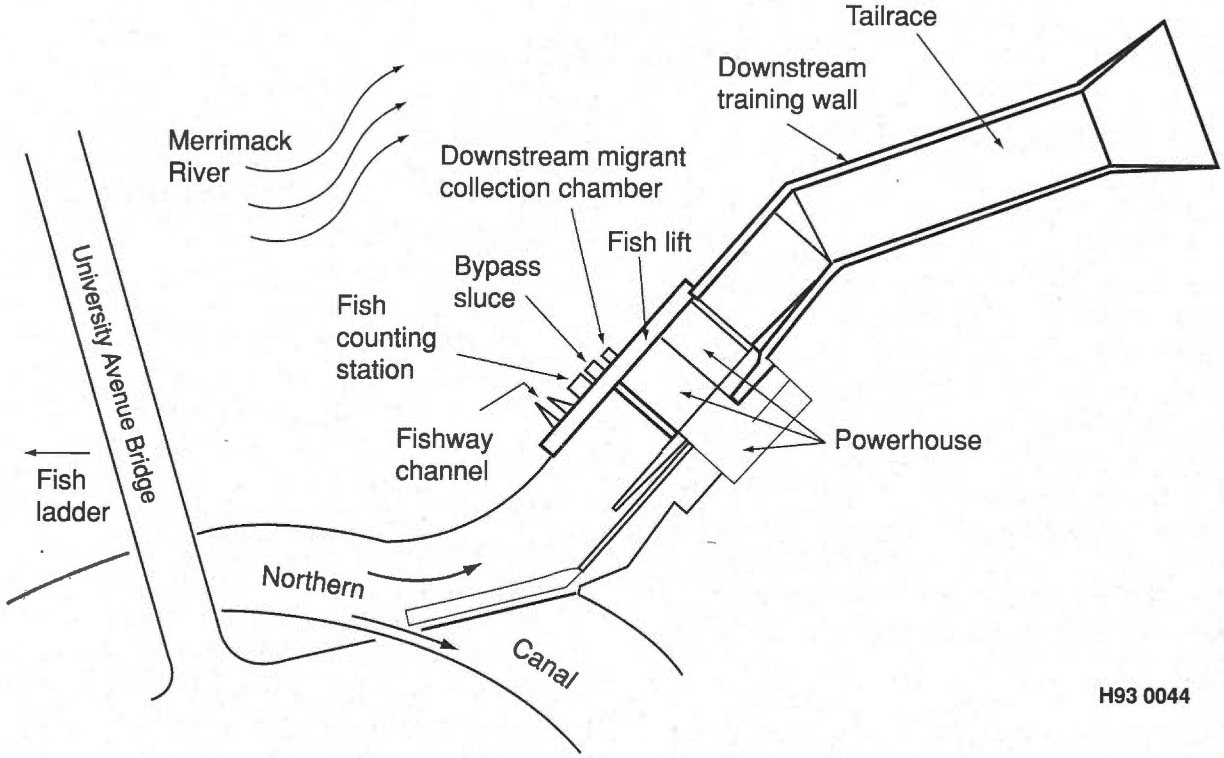


Figure 13-2. Overview of the Lowell powerhouse and fish elevator. Upstream migrants enter the tailrace and use the fish lift or travel up the Merrimack River and use the fish ladder at the Pawtucket Dam.

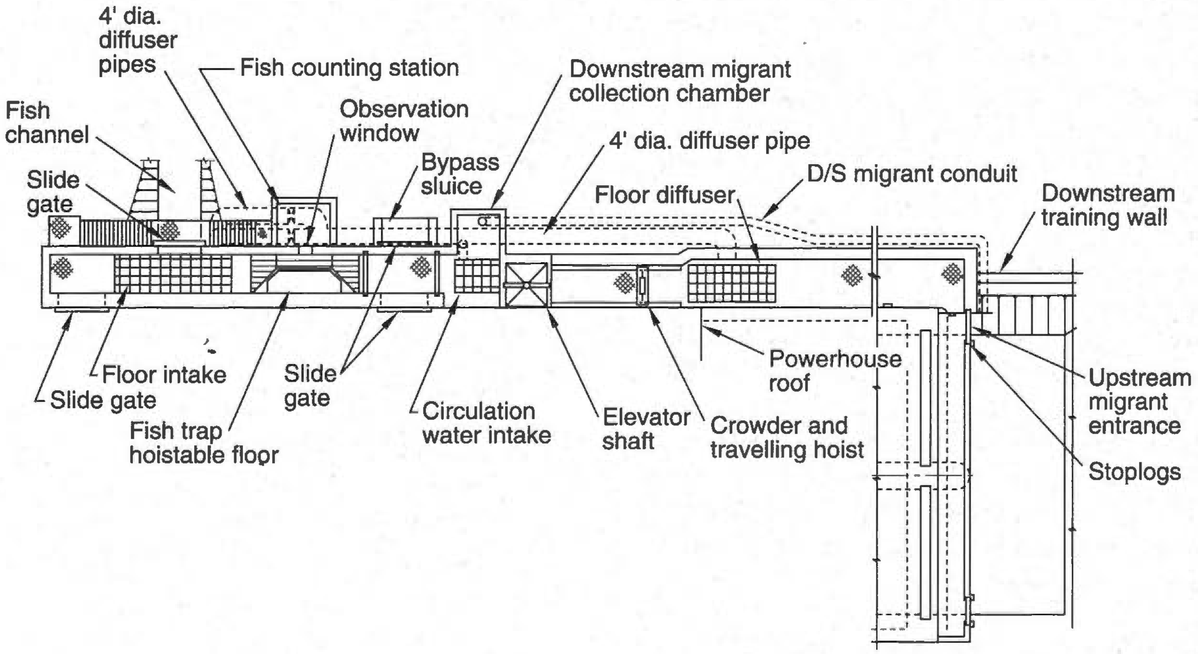


Figure 13-3. Detailed overview of the Lowell fishway at the powerhouse.

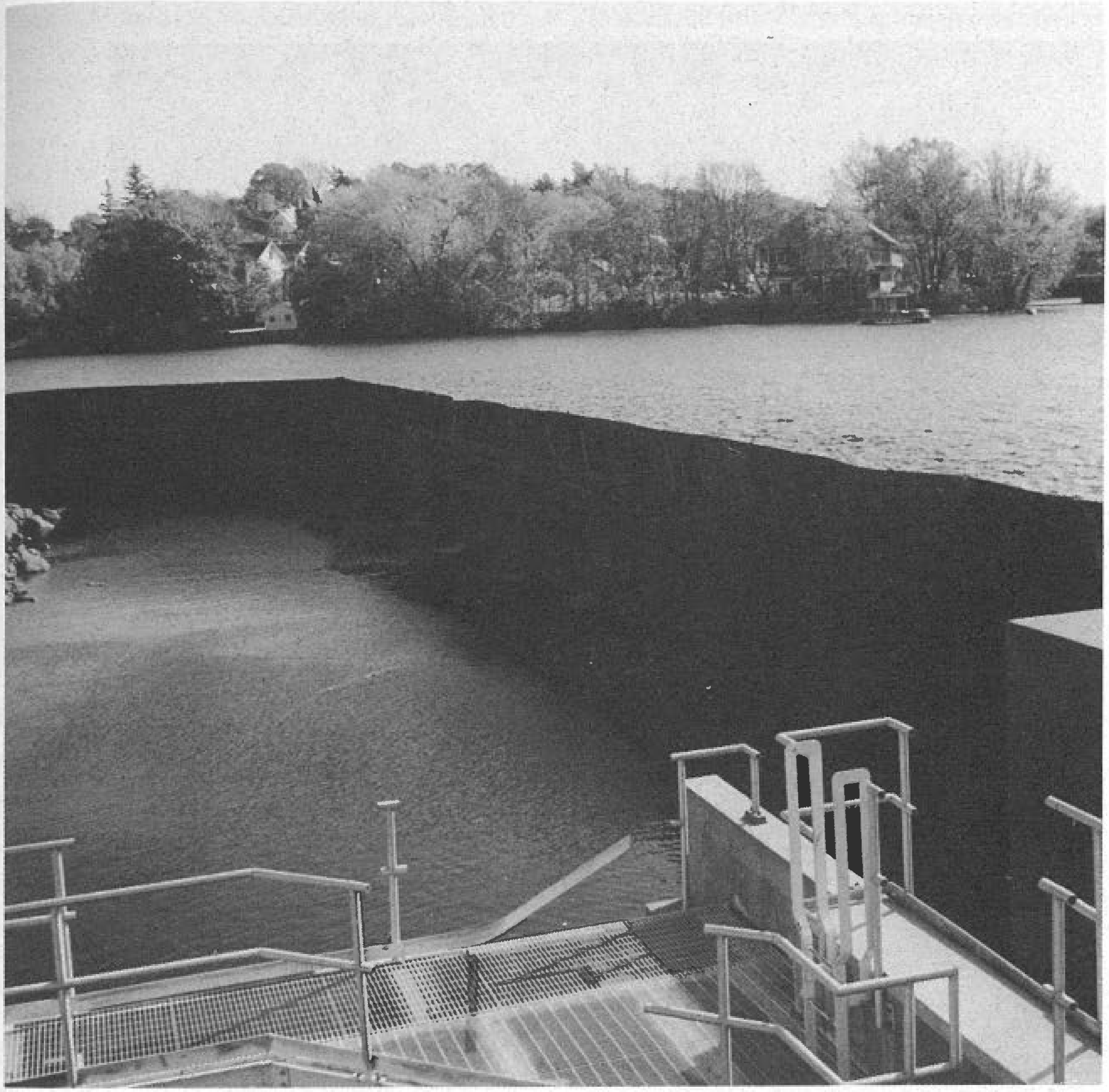


Figure 13-4. Pawtucket dam adjacent to fish ladder at the Lowell project.

10 miles downstream, and distributed upstream of the Lowell project (Stolte, personal communication). Thus, no Atlantic salmon are yet available for upstream passage at the Lowell project.

13.1.2 Monitoring Methods. Fishway counts of the numbers of Atlantic salmon, American shad, and river herring at the Lawrence and Lowell projects are made each year. The counting operations are carried out by the states and the United States Fish and Wildlife Service. As mentioned, counts are made of Atlantic salmon using the Lawrence fish lift, but all salmon are then transported upstream of the Lowell project. Also, rough counts of river herring are made at the Lawrence fish lift. American shad are counted at both the Lawrence and Lowell upstream fish passage/protection facilities.

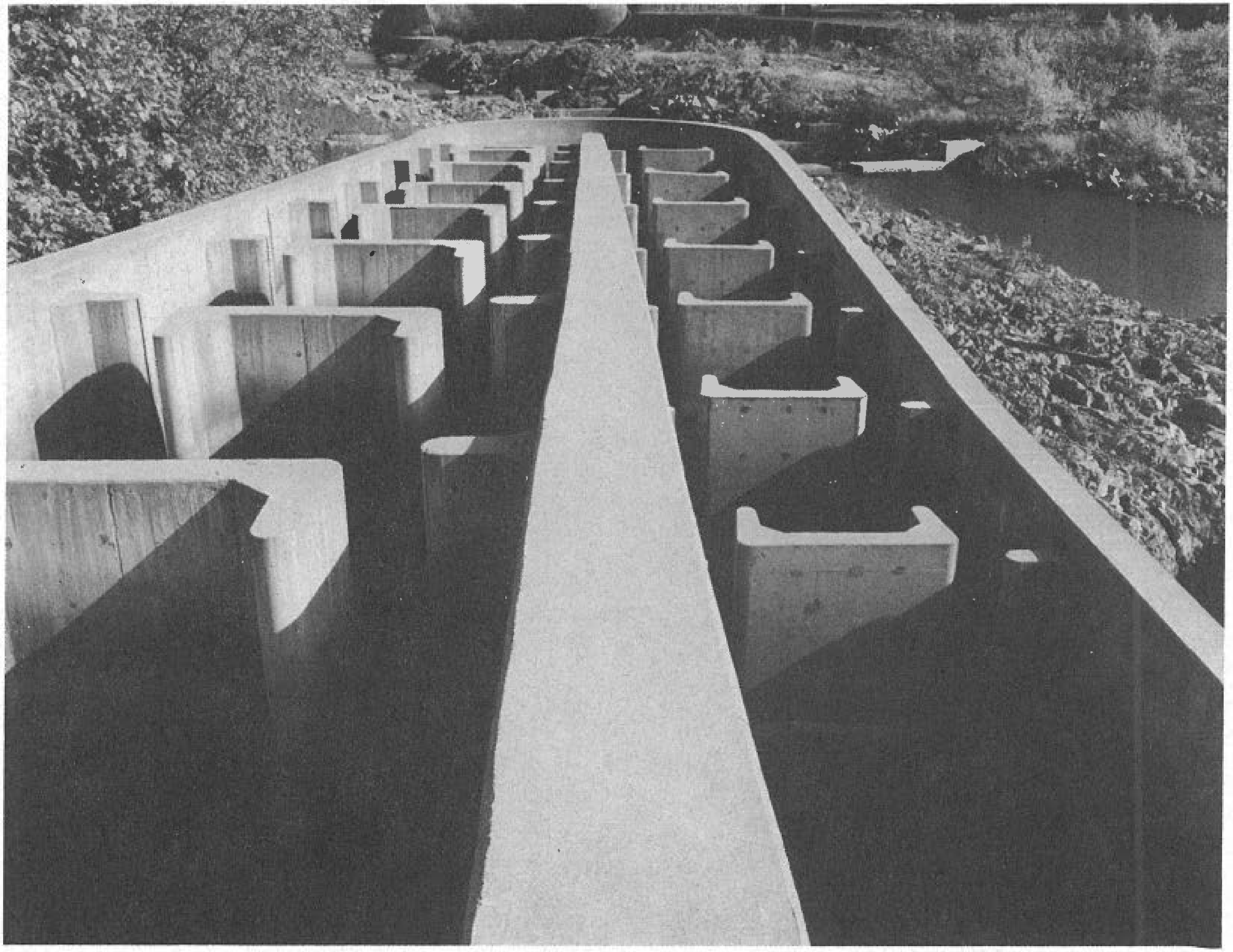


Figure 13-5. Lowell project fish ladder adjacent to Pawtucket dam.

13.1.3 Performance of Mitigation. Table 13-1 provides the numbers of fish counted at the Lowell and Lawrence upstream fish passage/protection facilities between 1983 and 1992. Counts of American shad began in 1986; numbers of shad passed upstream ranged from 6,013 to 20,796 at Lawrence and from 428 to 6,491 at Lowell. The percentage of American shad passed upstream at Lawrence that subsequently used the Lowell facility ranged from 2.7% to 31.2%. The largest number of upstream-migrating American shad and the largest percentage passing upstream at Lowell was in 1992; this occurred despite operational problems which caused the lift to be out of operation for 17 days during peak migration (Stolte, personal communication). The differences in American shad counts between Lawrence and Lowell might be due to spawning in the 10-mile-long reach of river between the dams, spawning in tributaries between the dams, or inability of shad to use the Lowell fish passage/protection facilities. There are no estimates of loss from each of these options.

13.2 Mitigation Benefits

13.2.1 Benefits to Fish Populations. The fish passage/protection facilities at the Lowell and Lawrence hydroelectric projects have successfully passed anadromous fish upstream. Large numbers of American shad used the fish ladder and lifts in 1992, although numbers are still far short of general goals at this early stage of restoration. No studies have been conducted to estimate the numbers of American shad that are lost to main stem or tributary spawning in the reach of the Merrimack River between the two dams (there is no in-river shad fishery). Consequently, neither the numbers of shad available for passage at Lowell nor the effectiveness of the Lowell fish lift and ladder can be assessed.

Protection of downstream-migrating juvenile shad and salmon is also receiving attention as part of the restoration program for the Merrimack River (Stolte, personal communication). The Lawrence project has a new downstream fish bypass that has not yet been tested. The Lowell project has an existing bypass that is ineffective, but the utility and agencies are coming to an agreement on structural methods to improve downstream fish passage/protection. In any case, measures to ensure safe downstream passage/protection for anadromous fish, which are essential complements to the upstream passage/protection facilities, have not yet been installed at Lowell. The eventual implementation and monitoring of these downstream fish passage/protection measures will allow assessment of the population-level effects of fish passage/protection mitigation at the Lowell project.

Table 13-1. Numbers of fish passed upstream at the Lowell and Lawrence projects on the Merrimack River. Data from Larry Stolte, U.S. Fish and Wildlife Service.

	American shad		Atlantic salmon	River herring
Year	Lowell	Lawrence	Lawrence	Lawrence
1983	—	—	114	5,000
1984	—	—	115	5,000
1985	—	—	213	24,000
1986	1,603	18,173	103	70,000
1987	3,926	16,909	139	>270,000
1988	1,289	12,359	65	280,000
1989	940	7,875	84	280,000
1990	443	6,013	248	250,000
1991	428	16,098	332	220,000
1992	6,491	20,796	199	100,000

13.2.2 Benefits to Fisheries. Because the Atlantic salmon and American shad restoration efforts in the Merrimack River are at an early stage, there is as yet no commercial or recreational fisheries for these stocks. Full implementation of the overall restoration effort, including bypass systems to protect downstream-migrating juveniles, should eventually result in the reestablishment of a fishery in the Merrimack River.

13.3 Mitigation Costs

13.3.1 Introduction. The mitigation cost analysis for the Lowell hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; an upstream fish passage/protection system section, discussing the upstream mitigation costs; a downstream fish passage/protection system section, discussing the downstream mitigation costs; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal written correspondents and from telephone calls. A site visit greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

13.3.2 Cost Summary. The upstream and downstream mitigation costs at the Lowell hydroelectric plant include the cost of a fish ladder at the Pawtucket Dam and the cost of a fish lift at the powerhouse. Together, the capital costs for the lift and ladder represent ~46% of all mitigation costs at Lowell (Figure 13-6). The graph of the yearly costs (Figure 13-7) highlights the magnitude of the capital costs. The first year startup costs represent 49% of all costs. The yearly costs are fairly constant with the exception of 1988 through 1993, when the studies of migrants and the cost of a modification to the downstream bypass part of the fish lift facility were incurred by the licensee. The mitigation costs at Lowell total $9,232,900 for the 20-year analysis. Leveling the costs over 20 years produces a levelized annual cost of $461,645 for upstream and downstream mitigation (Table 13-2).

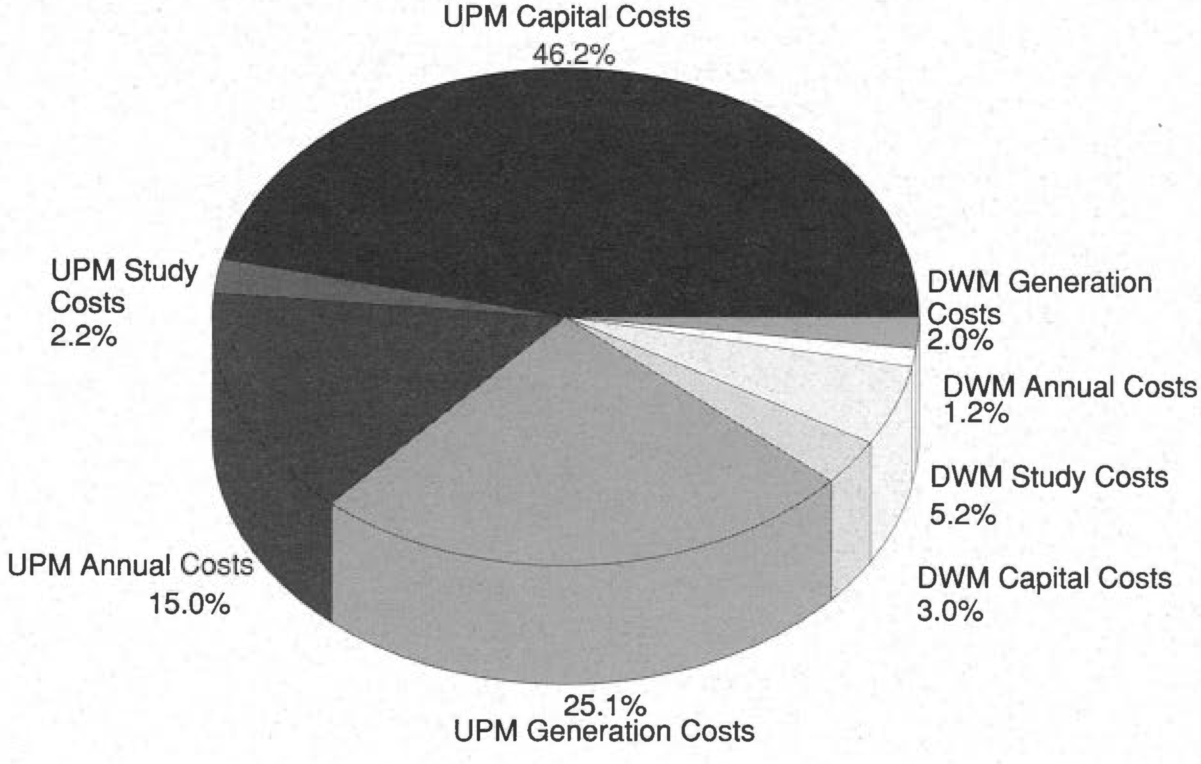


Figure 13-6. Costs of upstream (UPM) and downstream (DWM) fish passage/protection mitigation at Lowell.

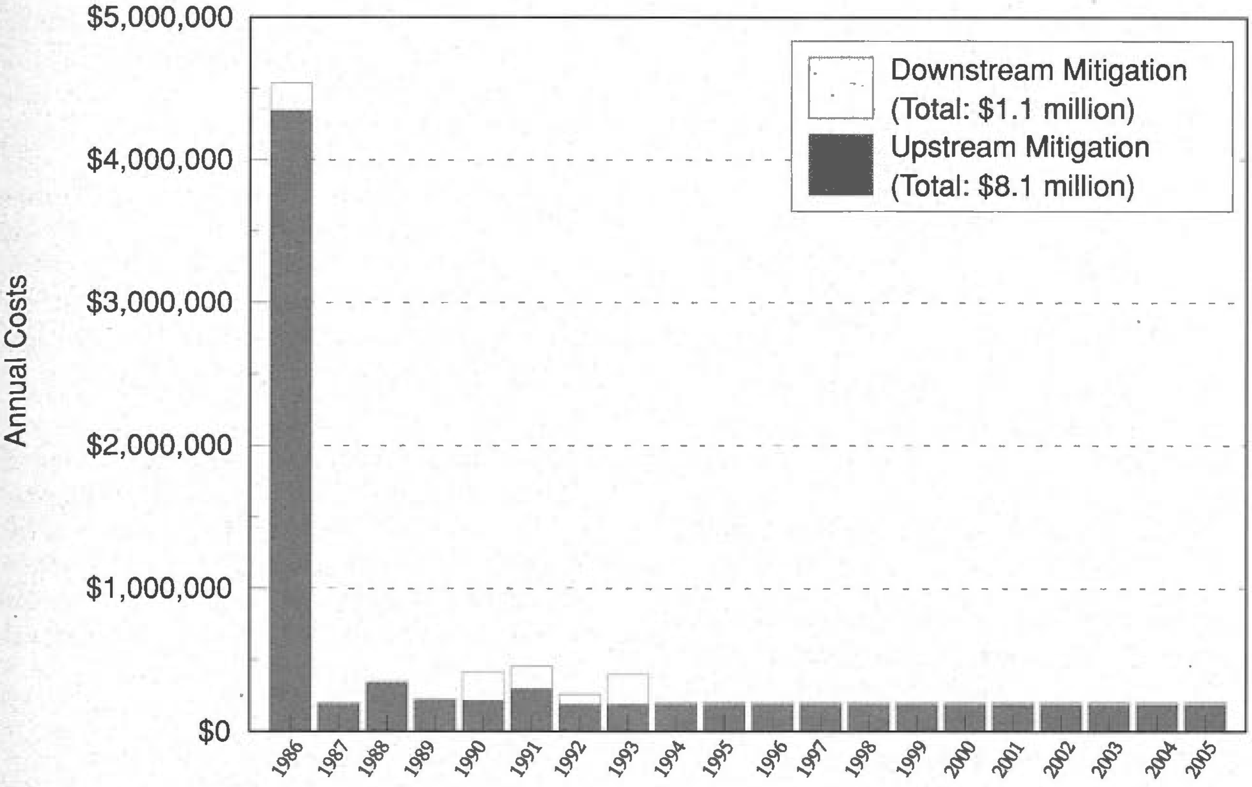


Figure 13-7. Yearly costs of upstream and downstream mitigation at Lowell.

Table 13-2. Twenty-year costs incurred at the Lowell hydroelectric plant for upstream and downstream mitigation.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Upstream	8,175,500	408,775	4.84
Downstream	1,057,400	52,870	0.63
Total costs	9,232,900	461,645	5.5

The Lowell hydroelectric plant generates an annual average of 84,500,000 kilowatt-hours of electricity. With a levelized annual mitigation cost of $461,645, the total cost for upstream and downstream mitigation is 5.5 mills per kilowatt-hour. This is the equivalent total of about one-half a cent for upstream and downstream mitigation for every kilowatt-hour of generation.

13.3.3 Upstream Fish Passage/Protection.

The magnitude of costs for upstream mitigation at the Lowell hydroelectric plant is driven by the capital cost of the fish elevator ($2,417,600), which is located immediately next to the powerhouse, and the capital cost of the fish ladder ($1,742,100), which is located at the Pawtucket Dam, ~2,000 feet upstream of the powerhouse. The total capital cost of $4,268,900 equates to a 20-year levelized annual cost of $213,450. With average annual plant generation of 84,500 megawatt-hours, the capital cost for upstream mitigation per kilowatt-hour is 2.5 mills. The upstream mitigation capital cost is the largest category of mitigation costs at this project, constituting 52% of upstream mitigation costs (Figure 13-8) and 46% of all mitigation costs. The yearly breakdown of upstream mitigation costs (Figure 13-9) clearly shows the significant contribution to

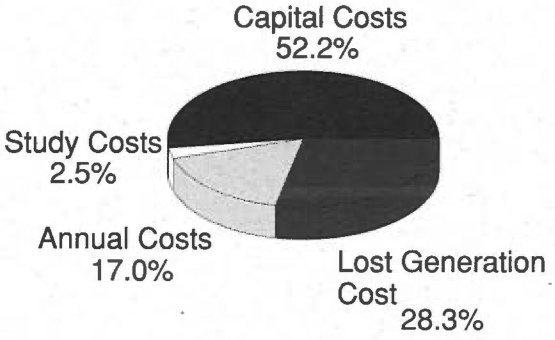


Figure 13-8. Capital, study, annual, and lost generation costs for upstream mitigation at the Lowell project.

mitigation costs that the capital-intensive ladder and lifts represent.

The upstream mitigation studies primarily examined the upstream migration of adult American shad through the fish lift and the Northern Canal. The upstream mitigation studies cost an average of $69,000. The study costs for upstream mitigation total $206,600.

The annual costs associated with upstream mitigation are primarily driven by the operation of the labor-intensive fish lift facility. Other annual costs include the operations of the ladder and the cleaning of debris out of both the lift and the ladder. Another annual cost is the administrative cost for upstream mitigation issues. The 20-year total cost for lift and ladder operations is $1,200,000 and for the administrative duties the 20-year total cost is $186,000. With a combined total of $1,386,000, the levelized annual cost is $69,300. The cost per kilowatt-hour for the annual upstream mitigation activities is 0.8 mills.

The total 20-year cost for generation losses due to upstream mitigation is $2,314,000. The generation losses result from lowered hydraulic capacity due to water releases required to operate the fish lift and ladder. The levelized annual cost is $115,700 and the cost of lost generation per kilowatt-hour is 1.4 mills.

All upstream mitigation costs over the 20 years of the analysis total $8,175,500 (Table 13-3). This equates to a levelized annual cost of $408,780 and a cost per kilowatt-hour of 4.8 mills for each kilowatt-hour of generation.

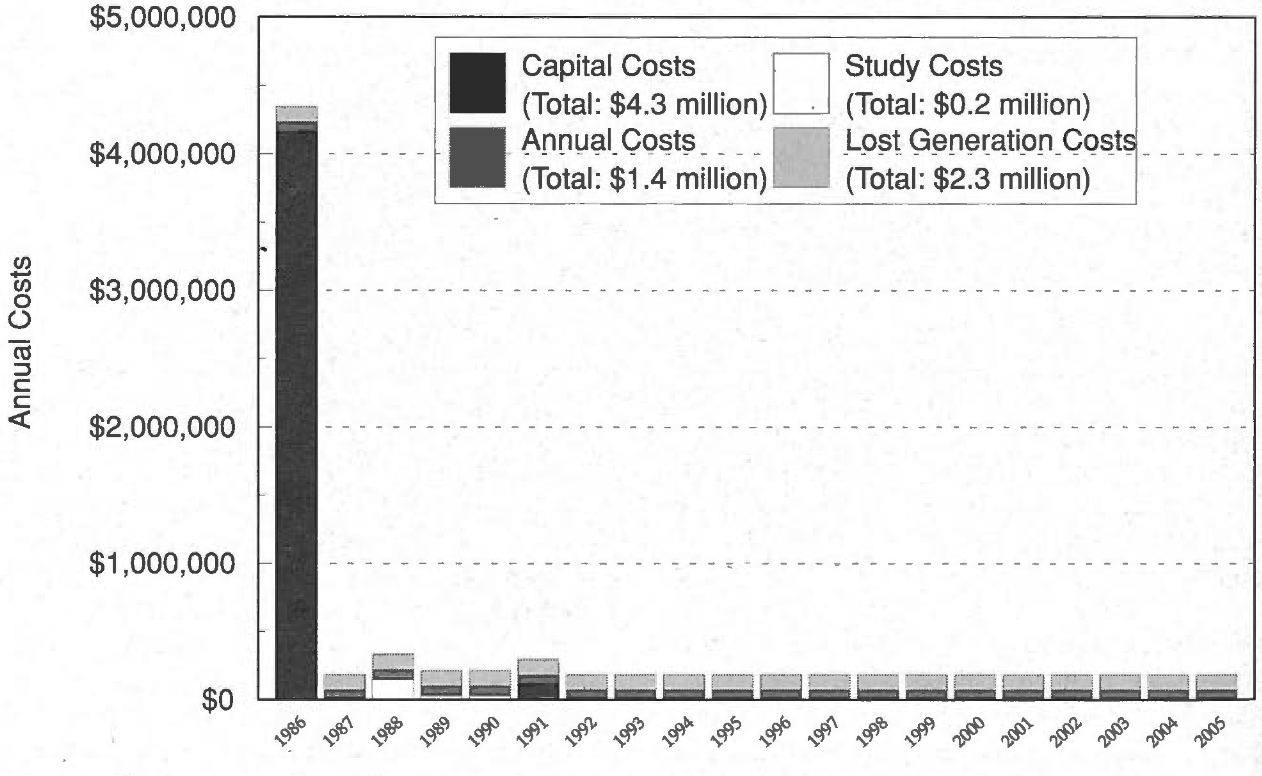


Figure 13-9. Yearly costs of upstream mitigation at the Lowell project.

Table 13-3. Twenty-year costs for upstream mitigation at Lowell.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital	4,268,900	213,450	2.53
Study	206,600	10,330	0.12
Annual costs	1,386,000	69,300	0.82
Lost generation	2,314,000	115,700	1.37
Total upstream costs	8,175,500	408,780	4.8

13.3.4 Downstream Fish Passage/Protection. Downstream fish passage/protection at the Lowell hydroelectric plant is via the downstream bypass located at the powerhouse fish lift facility. As originally constructed, the upstream fish lift elevator and the downstream migrant bypass could not operate concurrently. Over a half-dozen studies since 1990 have examined the downstream passage/protection issue. The cost of these studies have contributed a significant percentage (46%) to the 20-year total cost for downstream mitigation (Figure 13-10). From 1990 through 1993 the downstream mitigation studies totaled $483,600. With the exception of the first-year capital costs associated with construction of the downstream bypass, the studies constitute a significant amount of the costs over a few years (Figure 13-11). In light of these studies, the downstream bypass at the fish lift is being modified during 1993 to allow concurrent upstream and downstream passage.

The total 20-year capital cost for downstream mitigation is $277,800. This is the cost for the original downstream bypass component of the fish lift facility and the cost to modify the facility in 1993 to allow downstream passage while the upstream passage lift is operating. With an average annual levelized cost of $13,890 and an annual average generation of 84,500 megawatt-hours, the capital cost for downstream mitigation per kilowatt-hour is 0.16 mills (Table 13-4).

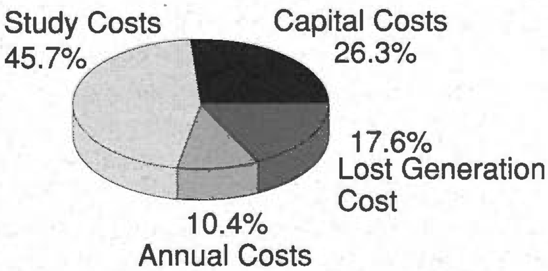


Figure 13-10. Capital, study, annual and lost generation costs for downstream mitigation at the Lowell project.

The 20-year total cost of downstream mitigation studies is $483,600, and the levelized annual cost is $24,180. Based on the average annual generation, the cost per kilowatt-hour for downstream mitigation studies is 0.29 mills. The seven studies cost an average of $69,000 each. Additional future studies (beyond 1993) have not been identified; but if they do occur, with an average of $69,000 each, they would add approximately 1 mill per year to the cost of downstream mitigation studies (assumes $69,000/84,500 MWh).

The downstream mitigation annual costs, with a 20-year total of $110,000 and a levelized annual cost of $5,500, are less than 1/10 of a mill per generated kilowatt-hour. The annual costs consist of maintenance and operations of the labor-intensive downstream bypass part of the fish facility as well as the administrative costs of downstream mitigation activities such as meetings with agencies and reporting requirements. The annual lost generation cost of $9,300 has a per kilowatt-hour cost of 0.1 mill. The lost generation cost results from spills necessary for the downstream bypass.

The total 20-year cost for downstream mitigation activities is $1,057,400, and the levelized annual cost is $52,870. With the annual average generation of 84,500 megawatt-hours, the cost of downstream mitigation at Lowell is 0.6 mills per kilowatt-hour.

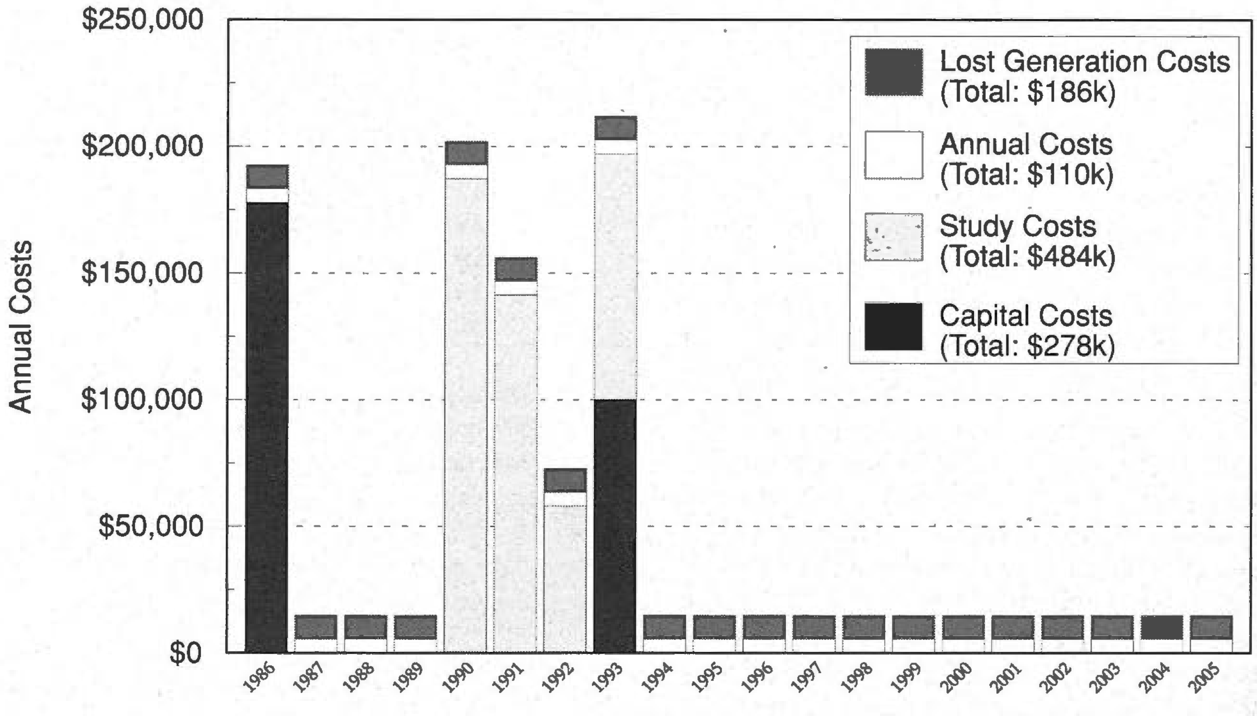


Figure 13-11. Yearly costs of downstream mitigation at the Lowell hydroelectric plant.

Table 13-4. Twenty-year costs for downstream mitigation at Lowell.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital	277,800	13,890	0.16
Study	483,600	24,180	0.29
Annual costs	110,00	5,500	0.07
Lost generation	186,000	9,300	0.11
Total downstream costs	1,057,400	52,870	0.6

13.4 Cost Descriptions and Assumptions

This section provides an explanation of the individual cost items and the assumptions and estimates required to quantify the respective items and derive cost totals. The item numbers correspond to the 20-year spreadsheet (Table 13-5) used to determine costs. All costs have been indexed to 1993 dollars and are discussed as such.

13.4.1 Capital Costs.

1. **UPM—Fish Ladder ('85).** Constructed in 1985, the fish ladder is not located in the immediate vicinity of the power house. The ladder is located 2,000 feet upstream at the Pawtucket Dam, which is used to pond the Merrimack River (Figure 13-12). The Northern Canal is used to convey water from the Pawtucket Dam, via a gatehouse and boat lock, to the powerhouse. The ladder is a concrete, double vertical slot type, with a 30 cfs internal operating flow and up to 170 cfs of entrance attraction flow. An additional 300 cfs can be provided to the river canal below the ladder as external attraction flows. The ladder operates 2 to 3 weeks per year during overflow spill periods at the dam and when the power

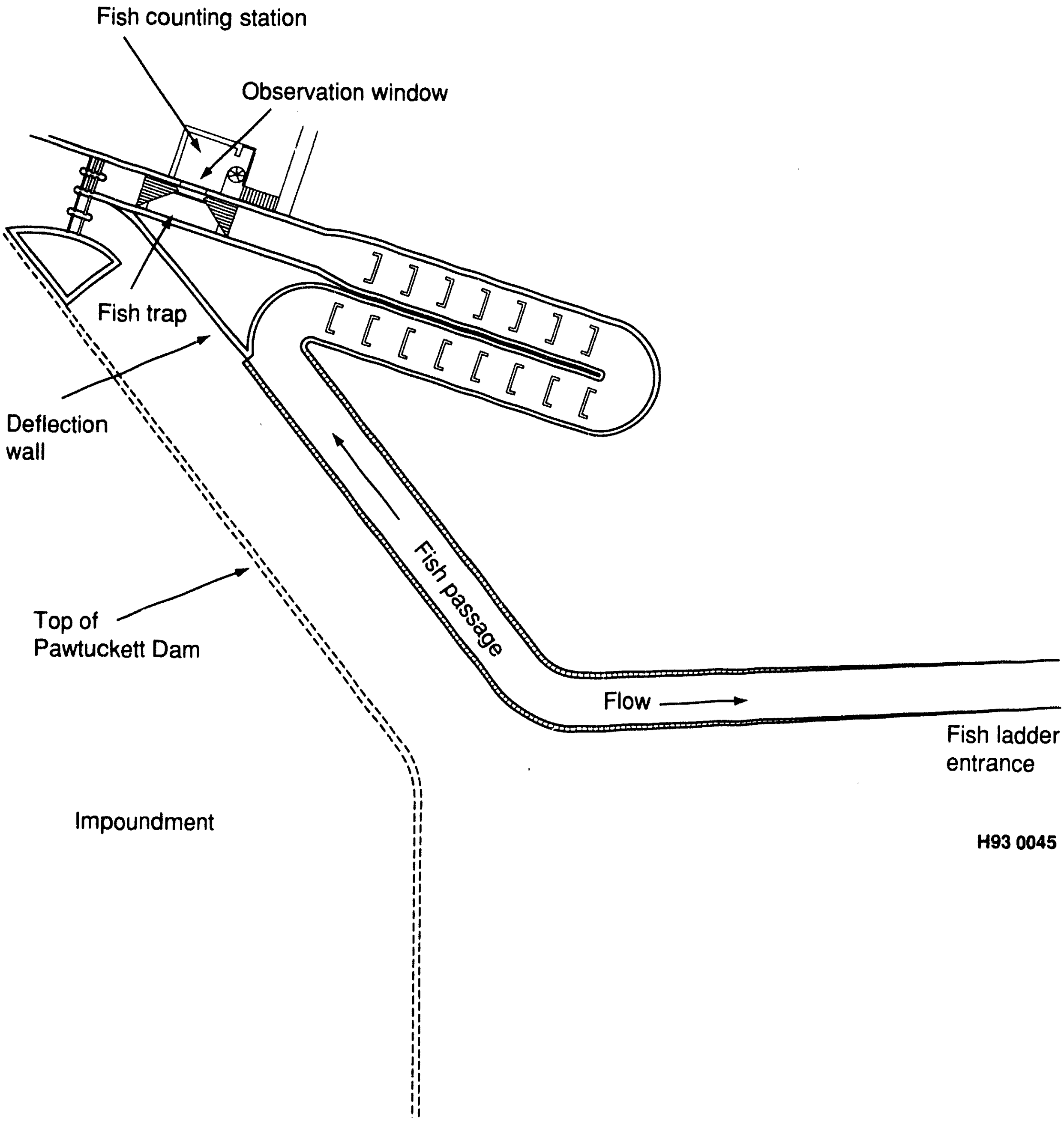


Figure 13-12. Lowell fish ladder located on the Merrimack River at the Pawtucket Dam.

house fish lift is out of service. The fish ladder construction cost was $1,742,100.

2. **UPM—Fish Lift Facility ('85).** Constructed in 1985, the powerhouse fish lift facility has both upper and lower exit canals and two fish counting rooms for each exit canal. The upper exit allows upstream migrants to pass the powerhouse into the Northern Canal and pass the gatehouse and boat lock into the Merrimack River. The lower exit, which has never been used, would pass upstream migrants into the river canal above the powerhouse tailrace, and on to the fish ladder at the Pawtucket Dam. The lift usually operates from May through late June or early July, for an average annual period of 8 to 10 weeks. The lift has a hopper capacity of 1,400 gallons, an operating

capacity of 150 cfs, and an attraction water capacity of 50 cfs (Figure 13-13).

The fish bypass for downstream passage is an integral part of the fish lift facility and is discussed below in Items 4 and 5. The licensee estimated the proportion of the total capital costs that represented the upstream and downstream segments of the lift facility. Based on this proportion, the capital cost for the upstream mitigation portion of the fish lift facility was estimated to be $2,417,600. The annual costs and generation losses have been similarly segmented based on this proportion because the annual and generation costs were not separated when obtained for upstream and downstream mitigation. These costs are discussed below as Items 16 through 21.

3. **UPM—Six Flow Control Weirs** (Upstream Mitigation Six Flow Control Weirs). The six concrete weirs were added to the river channel below the Pawtucket Dam during 1991. The weirs provide appropriate flow conditions in the river canal for upstream migrants using the fish ladder. The capital cost of the weirs was $109,200.

4. **DWM—Fish Lift Facility Bypass ('85).** First operational in 1986, the fish bypass structure is part of the fish lift facility. The bypass is typically operational from April 1 through the middle of November. The bypass was designed to pass downstream migrants from the forebay of the powerhouse (lower end of the Northern Canal), through the fish lift exit canal, to the bypassed reach of the weir adjacent to the powerhouse and tailrace. As was discussed in Item 2 above, the capital cost for the downstream mitigation bypass was estimated as a proportion of the total lift facility cost. The fish lift facility downstream bypass is estimated to have cost $177,800.

5. **DWM—Fish Lift Facility Bypass.** The fish lift facility downstream bypass (Item 4 above) was modified during 1993 to provide greater flexibility of location, depth, and width of the flows, and to allow the downstream bypass to be operated concurrently with the upstream passage fish lift. This concurrent passage (both upstream and downstream) was not a feature of the original design. The estimated 1993 modification cost is $100,000.

13.4.2 Study Costs.

6. **UPM—Radio\Telemetry Shad** (1st Year). This 1988 radio-telemetry study of adult American shad examined the shad's upstream stream passage through the Northern Canal Gatehouse at Pawtucket Dam. This was the first of a 2-year study. Items 7 and 8 below discuss the associated second-year study costs. The total cost of $149,500 includes a 1 week trial use of hydroacoustic equipment for monitoring juvenile herring at the powerhouse intakes. The additional cost of the juvenile herring hydroacoustic trial was not considered substantial enough to attempt to show it as a separate cost item.

7. **UPM—Radio\Telemetry Shad** (2nd Year). This 1989 radio-telemetry study of adult American shad was the second year of a 2-year study. The study terminated early during the upstream passage season due to failure of the contractor's radio-telemetry receivers. The cost of this partial study was $28,600.

8. **UPM—Radio\Telemetry Shad** (2nd Yr). This 1990 radio-telemetry study of adult American shad was the conclusion of a 2-year study that was only partially completed during 1989. The cost to complete the study was $28,500.

9. **DWM—Radio\Tel. PwrHs Salmon** (1st Yr). Downstream Mitigation Radio-telemetry Study of Powerhouse Salmon Passage. The first year of a 2-year study examining Atlantic salmon smolt powerhouse passage through the turbines. At the time (1990), the downstream bypass could not operate when

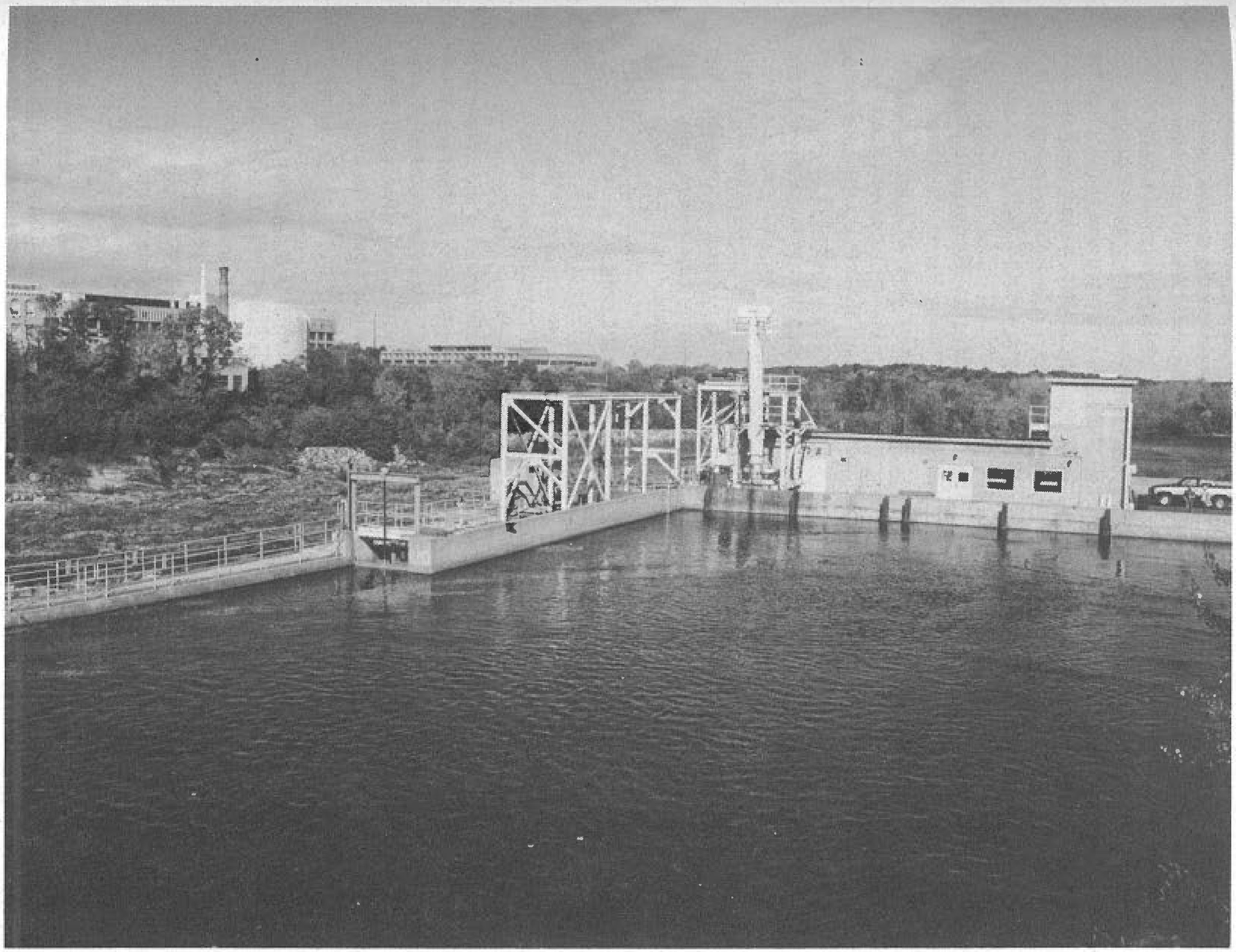


Figure 13-13. Lowell power house, fish lift facility, and forebay of Northern Canal.

the fish lift was operating. This first-year study cost was $68,500. The second-year study cost is discussed below as Item 11.

10. **DWM—Mark\Recap Shad\Herring** (1st Yr) (Downstream Mitigation Mark and Recapture Study of Shad and Herring). The first year of a 2-year study examining juvenile shad and herring downstream passage/protection at the powerhouse and bypass. The cost of $118,700 includes incline plane trapping in the Northern Canal for juvenile herring migratory periods. The second-year study cost is discussed below as Item 12.

11. **DWM—Radio\Tel. PwrHs Salmon** (2nd Yr) (Downstream Mitigation Radio-Telemetry Study of Powerhouse Salmon Passage). The second year of a two-year study examining Atlantic salmon smolt powerhouse passage/protection through the turbines. At the time (1991), the downstream bypass could not operate when the fish lift was operating. This second-year study cost was $77,000.

12. **DWM—Mark & Recapture Herring** (2nd Yr) (Downstream Mitigation Mark and Recapture Study of Shad and Herring). The second year of a 2-year study examining juvenile shad and herring downstream passage/protection at the powerhouse and bypass. The cost of $64,400 includes incline plane trapping in the Northern Canal for juvenile herring migratory periods. An additional second-year study was preformed, and that cost is discussed below as Item 13.

13. **DWM—Mark & Recapture Herring** (2nd Yr) (Downstream Mitigation Mark and Recapture Study of Shad and Herring). The completion of the second-year study (Item 12 above) of juvenile shad and herring downstream passage, using the fish lift facility exit canal as an alternative downstream bypass. This second-year study cost was $58,000.

14. **DWM—Video Camera Salmon\Shad\Herring** (Downstream Mitigation Video Camera Study of Salmon Smolt and Adult Shad and Herring). This 1993 study incorporated video camera monitoring of the fish lift facility exit canal for downstream passage utilization by the salmon smolt and post-spawned adult shad and herring. The study also incorporated radio-telemetry monitoring of adult shad approach and passage/protection through the Lowell project. The study cost was $32,000.

15. **DWM—Mark & Recapture Shad & Herring** (Downstream Mitigation Mark and Recapture Study of Juvenile Shad and Herring). This 1993 study, at a total estimated cost of $65,000, is a mark and recapture study of juvenile shad and herring on their downstream passage through the modified downstream bypass structure (Item 5 above). The original shallow bypass gate has been replaced with two full-depth gates to provide greater depths and widths for bypass flows.

13.4.3 Annual Costs.

A single cost was obtained for the operations and maintenance costs for both upstream and downstream mitigation. A single cost was also obtained for the administration and management costs associated with the upstream and downstream mitigation. It both cases, the costs were proportionally split into upstream and downstream mitigation costs based the method discussed above in Item 2.

16. **UPM—Fish Lift & Ladder** (Upstream Mitigation Fish Lift and Ladder Annual Operations and Maintenance Costs). The fish lift is responsible for the majority of the annual cost of $60,000, as it is labor intensive. Other duties include the removal of trash from both the lift and the ladder.

17. **UPM—Admin & Man.—Ladder\Lifts** (Upstream Mitigation Administration and Management of the Fish Ladder and Fish Lift). The estimated annual cost of $9,300 is for the administration and management of environmental and regulatory license and

permit requirements associated with these facilities. Activities include communications, planning, and meetings.

18. **DWM—Fish Lift Bypass** (Downstream Mitigation Fish Lift Facility Downstream Bypass Annual Operations and Maintenance Costs). The fish lift downstream bypass annual operations and maintenance cost is estimated at $4,800. The operation of the bypass is labor-intensive. Other duties include the removal of trash from the lift.

19. **DWM—Admin & Man. Bypass** (Downstream Mitigation Administration and Management of the Fish Lift Facility Downstream Bypass). The estimated annual cost of $700 is for the administration and management of mitigation requirements associated with these facilities. Activities include communications, planning, and meetings.

13.4.4 Lost Generation Costs.

A single cost was obtained for the value of lost generation associated with all fish passage/protection operations at the project. In order to best represent the separate upstream and downstream mitigation related generation losses, the costs were proportionally split into upstream and downstream mitigation costs based the method discussed above in Item 2.

20. **UPM—Fish Passage Operations.** The flows used for upstream migrant passage through the lift and the ladder, as well as the associated attraction flows, have been estimated to have an annual value of $115,700.

21. **DWM—Fish Passage Operations.** The flows used for downstream migrant passage through the fish lift facility downstream bypass have been estimated to have an annual value of $9,300.

Table 13-5. Lowell mitigation costs.

9/09/93

Lowell Project—Mitigation Cost Analysis—All Values in 1993 Dollars

	–7	–6	–5	–4	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	10	11	12	
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	TOTALS
Capital Costs																					
1) UPM—Fish Ladder ('85)	$1,742,100																				$1,742,100
2) UPM—Fish Lift Facility ('85)	$2,417,600																				$2,417,600
3) UPM—Six Flow Control Weirs						$109,200															$109,200
4) DWM—Fish Lift Facility Bypass ('85)	$177,800																				$177,800
5) DWM—Fish Lift Facility Bypass								$100,000													$100,000
Study Costs																					
6) UPM—Radio\Telemetry Shad (1st Year)			$149,500																		$149,500
7) UPM—Radio\Telemetry Shad (2nd Year)				$28,600																	$28,600
8) UPM—Radio\Telemetry Shad (2nd Year)					$28,500																$28,500
9) DWM—Radio\Tel. PwrHs Salmon (1st Yr)					$68,500																$68,500
10) DWM—Mark\Recap Shad\Herring (1st Yr)					$118,700																$118,700
11) DWM—Radio\Tel. PwrHs Salmon (2nd Yr)						$77,000															$77,000
12) DWM—Mark & Recapture Herring (2nd Yr)						$64,400															$64,400
13) DWM—Mark & Recapture Herring (2nd Yr)							$58,000														$58,000
14) DWM—Video Camera Salmon\Shad\Herring								$32,000													$32,000
15) DWM—Mark & Recapture Shad\Herring								$65,000													$65,000
Annual Costs																					
16) UPM—Fish Lift & Ladder	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$1,200,000
17) UPM—Admin & Man.—Ladder/Lifts	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$186,000
18) DWM—Fish Lift Downstream Bypass	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$4,800	$96,000
19) DWM—Admin & Man. Downstream Bypass	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$700	$14,000
Annual Generation Losses																					
20) UPM—Fish Passage Operations	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$2,314,000
21) DWM—Fish Passage Operations	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$186,000
Subtotal UPM Capital Costs	$4,159,700	$0	$0	$0	$0	$109,200	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$4,268,900
Subtotal UPM Study Costs	$0	$0	$149,500	$28,600	$28,500	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$206,600
Subtotal UPM Annual Costs	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$69,300	$1,386,000
Subtotal UPM Annual Lost Generation Costs	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$115,700	$2,314,000
Subtotal UPM—All Costs	$4,344,700	$185,000	$334,500	$213,600	$213,500	$294,200	$185,000	$185,000	$185,000	$185,000	$185,000	$185,000	$185,000	$185,000	$185,000	$185,000	$185,000	$185,000	$185,000	$185,000	$8,175,500
Subtotal DWM Capital Costs	$177,800	$0	$0	$0	$0	$0	$0	$100,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$277,800
Subtotal DWM Study Costs	$0	$0	$0	$0	$187,200	$141,400	$58,000	$97,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$483,600
Subtotal DWM Annual Costs	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$5,500	$110,000
Subtotal DWM Annual Lost Generation Costs	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$9,300	$186,000
Subtotal DWM—All Costs	$192,600	$14,800	$14,800	$14,800	$202,000	$156,200	$72,800	$211,800	$14,800	$14,800	$14,800	$14,800	$14,800	$14,800	$14,800	$14,800	$14,800	$14,800	$14,800	$14,800	$1,057,400
Total Expenses—1993 Dollars	$4,537,300	$199,800	$349,300	$228,400	$415,500	$450,400	$257,800	$396,800	$199,800	$199,800	$199,800	$199,800	$199,800	$199,800	$199,800	$199,800	$199,800	$199,800	$199,800	$199,800	$9,232,900

Notes: 4.5% Index rate used to present values as 1993 dollars

UPM = Upstream Mitigation
Subtotal UPM Capital Costs includes items: 1, 2 & 3
Subtotal UPM Study Costs includes items: 6, 7 & 8
Subtotal UPM Annual Costs includes items: 16 & 17
Subtotal UPM Annual Lost Generation Costs includes items: 20

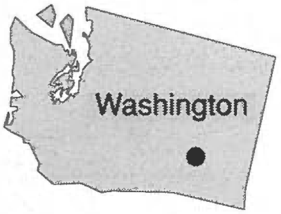
DWM = Downstream Mitigation
Subtotal DWM Capital Costs includes items: 4 & 5
Subtotal DWM Study Costs includes items: 9, 10, 11, 12, 13, 14 & 15
Subtotal DWM Annual Costs includes items: 18 & 19
Subtotal DWM Annual Lost Generation Costs includes items: 21

14. LOWER MONUMENTAL CASE STUDY

14.1 Description

The Lower Monumental Dam is located on the Snake River in southeastern Washington at river mile 41.6 (Figure 14-1). It was constructed by the U.S. Army Corps of Engineers and began operating in 1969. The project has six generators and a capacity of 810 megawatts.

Fish ladders. Adult fish passage/protection facilities at the Lower Monumental Dam include two fish ladders and a collection canal across the powerhouse (Figure 14-2). The spillway fish ladder (left-bank ladder) is located on the south side of the dam between the spillway and the navigation lock. The powerhouse ladder (right-bank ladder) is located on the north shore adjacent to the powerhouse. Both ladders are 16 feet wide with a one-on-ten slope. The fish ladders use an overflow weir design in combination with submerged orifices. Fish can enter the upstream passage/protection facilities through several entrances at the bases of the ladders and through entrances along the powerhouse. Detailed descriptions of the Lower Monumental fish ladders and operating criteria are provided in Corps of Engineers (1988a).



Fish screens. Turbine entrainment of downstream-migrating salmon and steelhead is mitigated at the Lower Monumental Dam by the use of submerged traveling screens, also known as gatewell screens (Figure 14-3). The submerged traveling screen is lowered through the intake

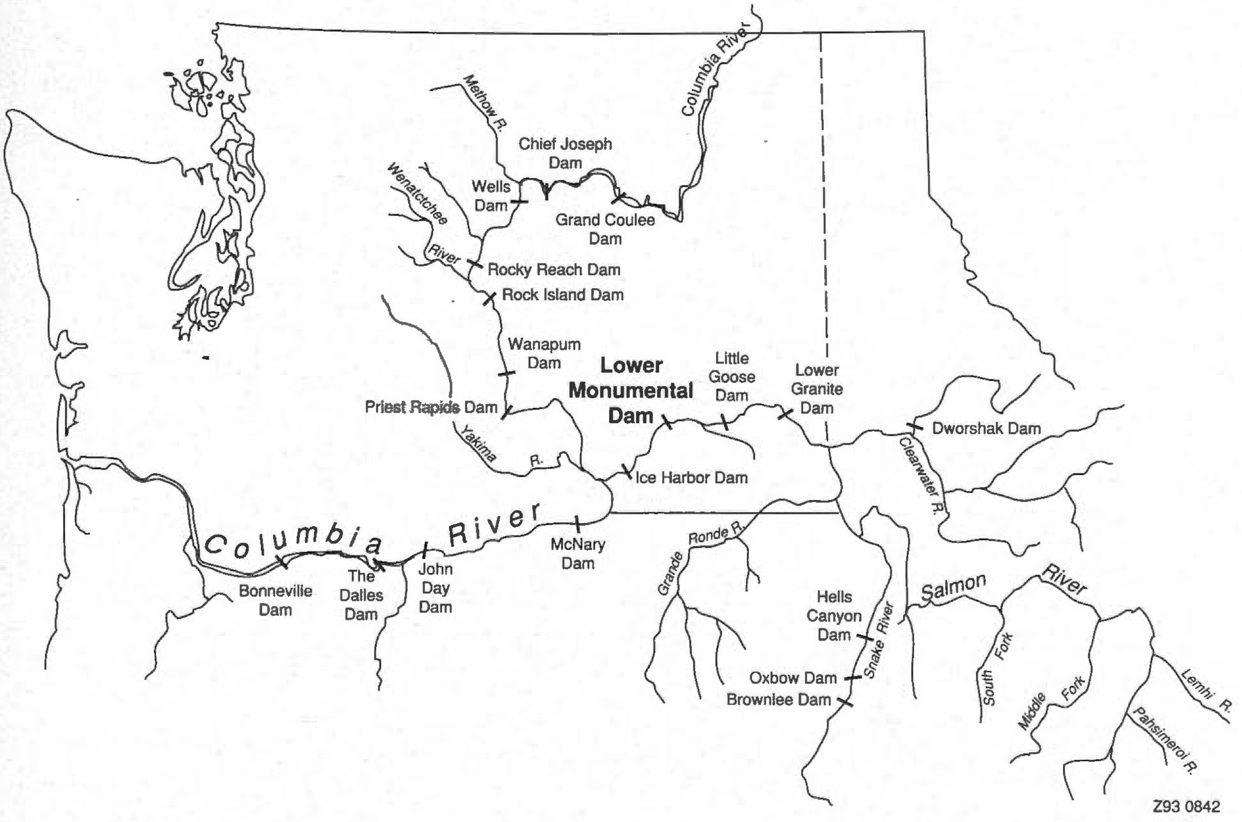


Figure 14-1. Location of Lower Monumental Dam in the Columbia River basin. Lower Monumental is located on the Snake River near the confluence of the Snake and Columbia Rivers (Raymond, 1979).

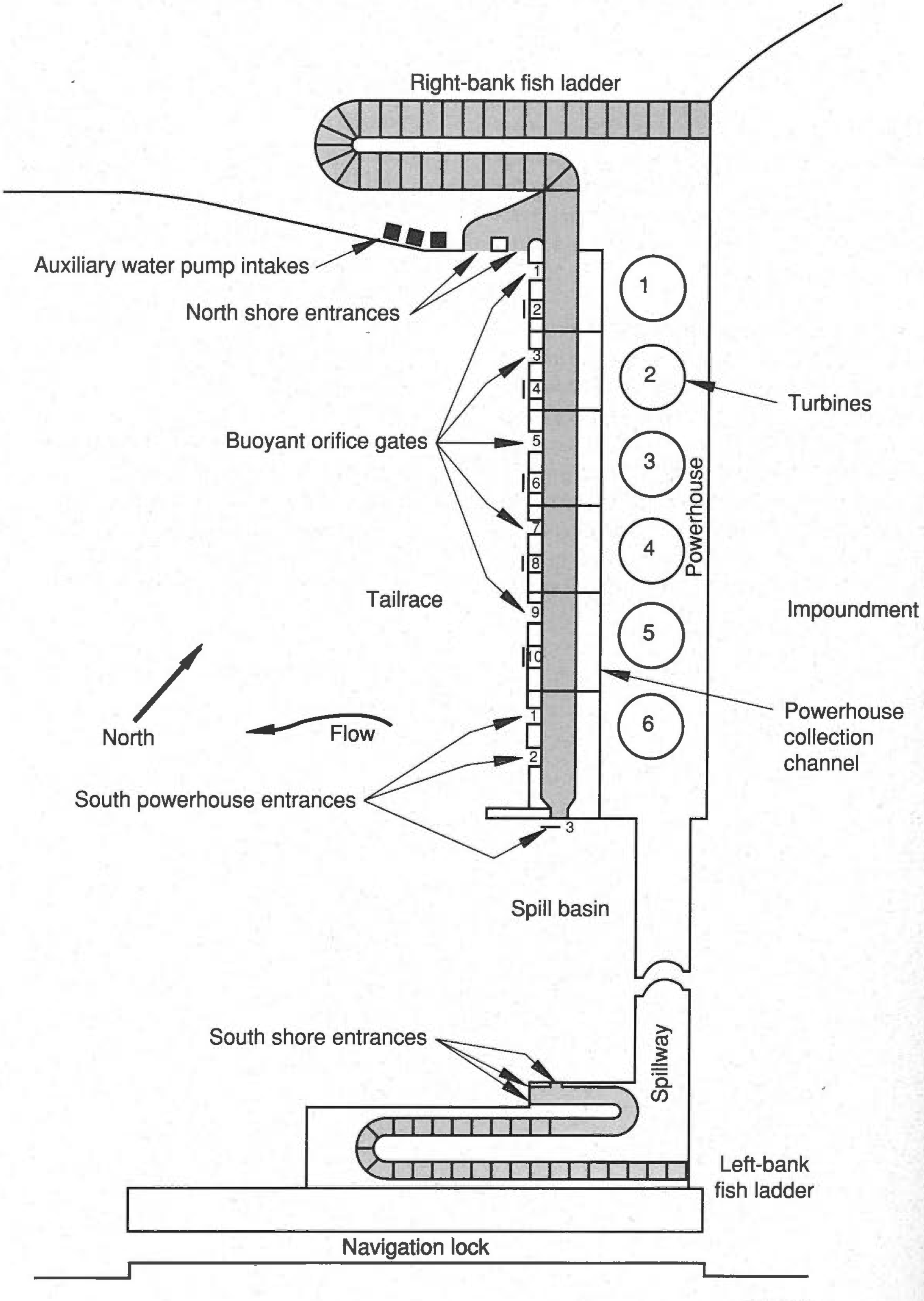


Figure 14-2. Overview of the Lower Monumental upstream fish collection and passage/protection system. Includes powerhouse, navigation lock, and the left-bank and right-bank fish ladders.

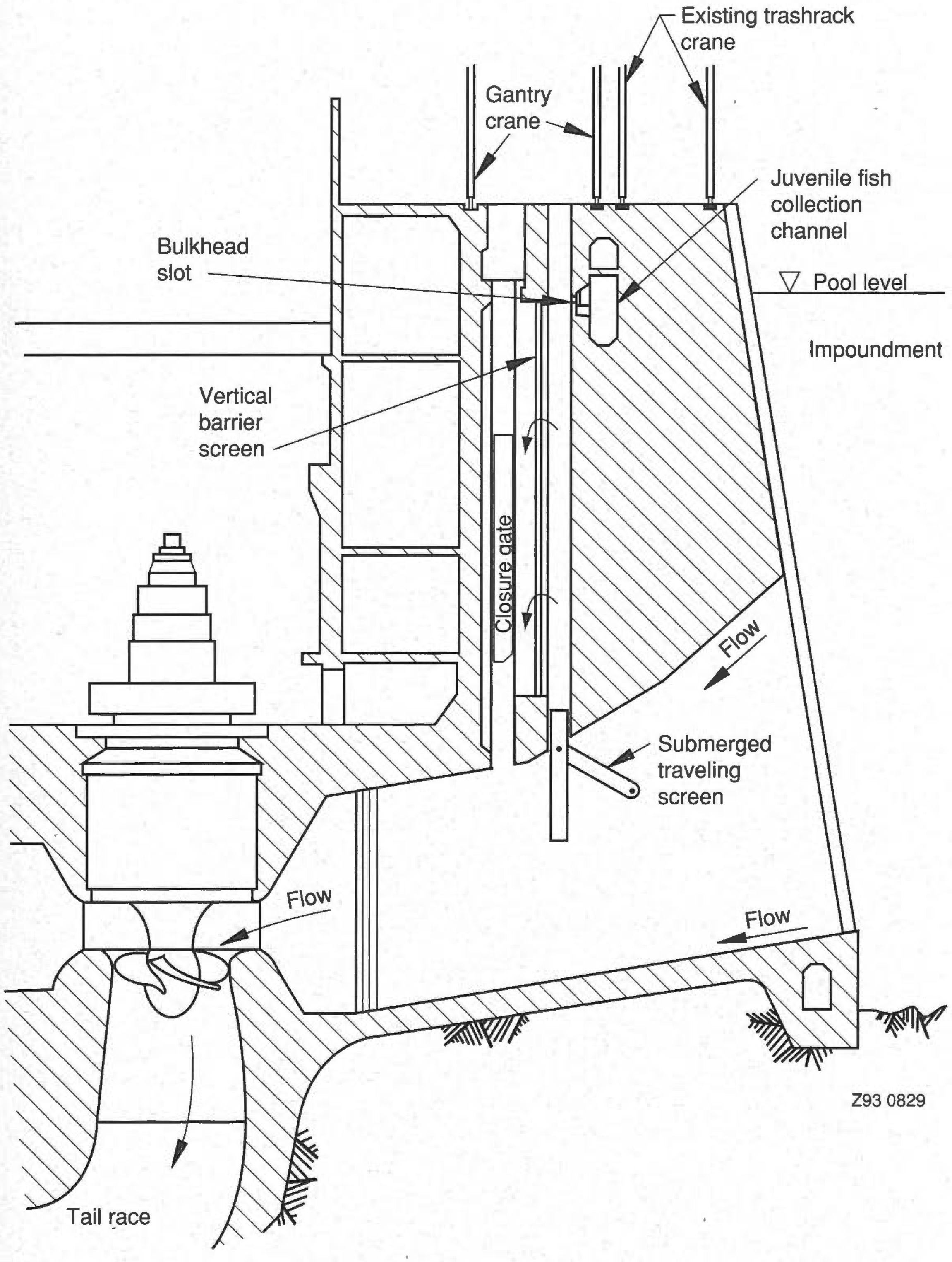


Figure 14-3. Lower Monumental downstream fish collection and passage/protection system. The submerged traveling screens direct the downstream migrants into the gatewell slot, to the right of the vertical barrier screen and into the juvenile fish collection channel. Excess water flows through the vertical barrier screen.

bulkhead slot into the turbine intake water passageway and, once inside, is extended upstream at a 55-degree angle (measured from the vertical). Each submerged traveling screen is over 34 feet long and 23 feet wide; the Lower Monumental powerhouse contains a submerged traveling screen for each of the 18 bulkhead slots. The mesh screen rotates like a conveyor belt at a speed of approximately 0.3 fps (Figures 14-4 and 14-5).

Juvenile fish are directed by the submerged traveling screens into the intake bulkhead slot where fish entrance orifices to the collection gallery are located. Fish are conveyed by gravity through the 12-inch-diameter, tube-type orifices into the collection gallery. Each of the 36 orifices is provided with a gate and attraction lighting. The collection gallery is a mined canal, sized to transport fish at velocities between 3 and 9 fps to the fish collection and transportation system at the base of the dam. A holding, loading, and bypass system and truck and barge loading facilities allow bypassed fish to be released directly to the river below the dam or transported to a point downstream of the Bonneville Dam on the Columbia River.

Detailed descriptions of the Lower Monumental juvenile fish facilities and operating criteria are provided in Corps of Engineers (1989).

14.1.1 Fish Resource Management Objectives of Mitigation. Historical runs of salmon and steelhead in the Snake River have been diminished by a variety of factors, including overfishing, habitat loss, and construction of dams. Significant numbers of coho salmon and sockeye salmon previously entered the Snake River each year; the former has been declared extinct, and the latter are so rare that the Snake River stock has been listed as endangered under the Endangered Species Act (Bjornn and Peery, 1992). Two groups of summer steelhead trout also enter the Snake River between June and October. Three runs of chinook salmon (spring, summer, and fall) enter the Snake River between late March and October. Because of declining numbers, all Snake River chinook salmon have been listed as threatened. Snake River chinook salmon stocks are adversely impacted not only by reservoir and turbine-passage mortality but also by poor ocean survival, low genetic variability, lack of stress tolerance, and a high incidence of bacterial kidney disease (Williams, 1989).

The construction of dams and the creation of storage reservoirs on the Columbia and Snake Rivers has altered the flow regime for upstream-migrating salmonids. Peak flows have been reduced in the spring, which may aid adult migration past the dams (Bjornn and Peery, 1992). On the other hand, the Snake River dams are obstacles to fish passage unless the fish can find the fishway entrances and ascend the dams without excessive delay. Considerable research has been conducted in the last decade to define the best conditions for upstream fish passage; that research is summarized in this case study.

Similarly, the Corps of Engineers recognized the need to reduce mortality of downstream-migrating juvenile salmon and steelhead resulting from turbine passage, and as early as 1968 the Corps of Engineers began to implement measures to reduce mortalities (U.S. Army Corps of Engineers, 1988b). These measures included transportation, spill flows, and installation of submerged traveling screens. The Corps of Engineers' goal is to improve the level of juvenile survival with economically justifiable protection measures. The Corps of Engineers is committed to achieving by 1994 the 90% survival standard set by the Northwest Power Planning Council for the seven projects upstream of Bonneville Dam, and they have agreed to achieve the Council's interim standard on an annual basis (U.S. Army Corps of Engineers, 1988b). Based on studies at other dams and model studies, the Corps of Engineers has projected future optimum fish guiding efficiencies for the Lower Monumental juvenile fish facilities, (i.e., the percentage of entrained fish that are directed into the intake bulkhead slot and bypass collection channel) (Table 14-1).

Although the Corps of Engineers is responsible under Federal law for identifying adverse effects caused by its dams, it is not specifically required

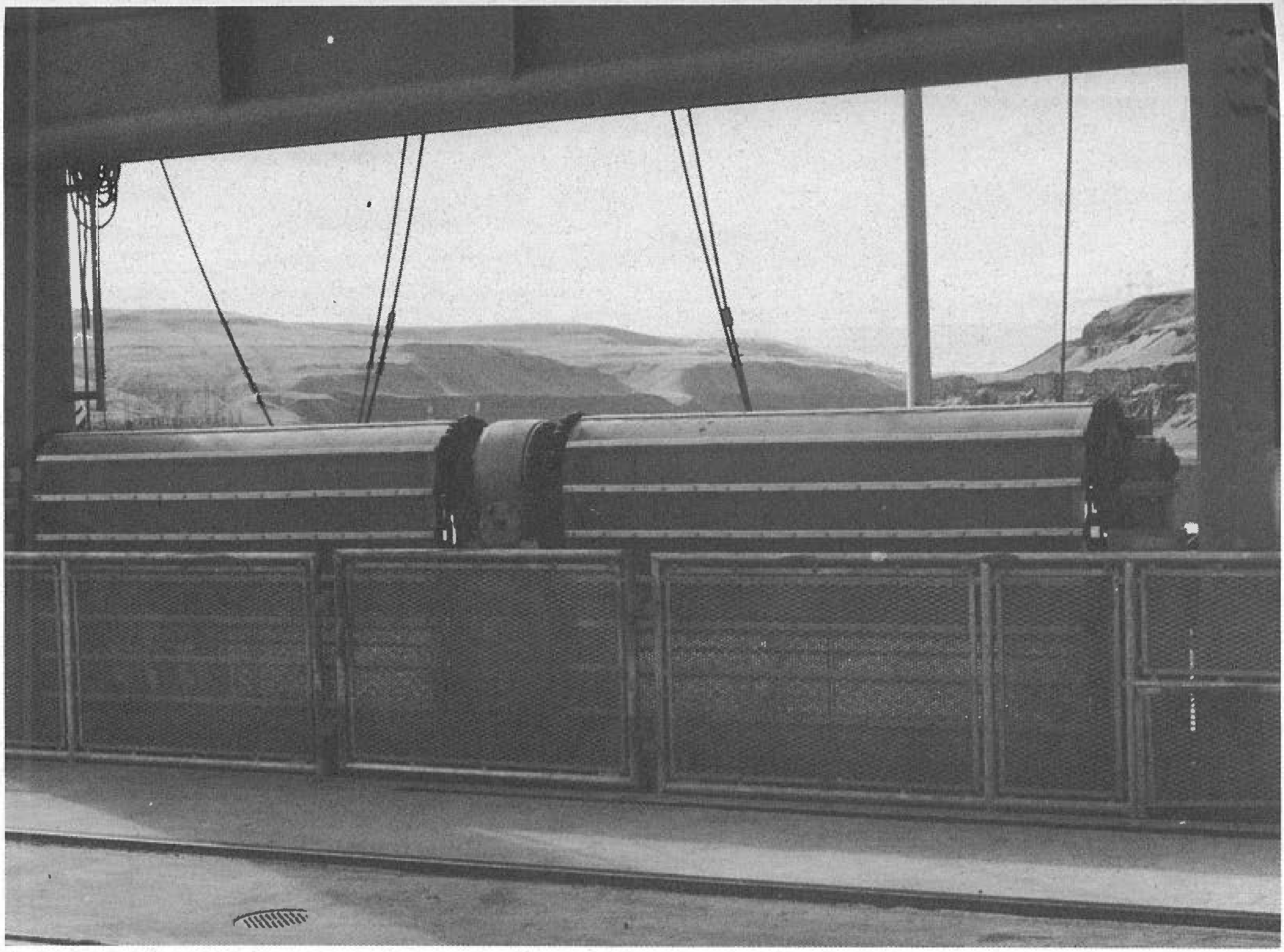


Figure 14-4. Lower Monumental submerged traveling screens in raised position.

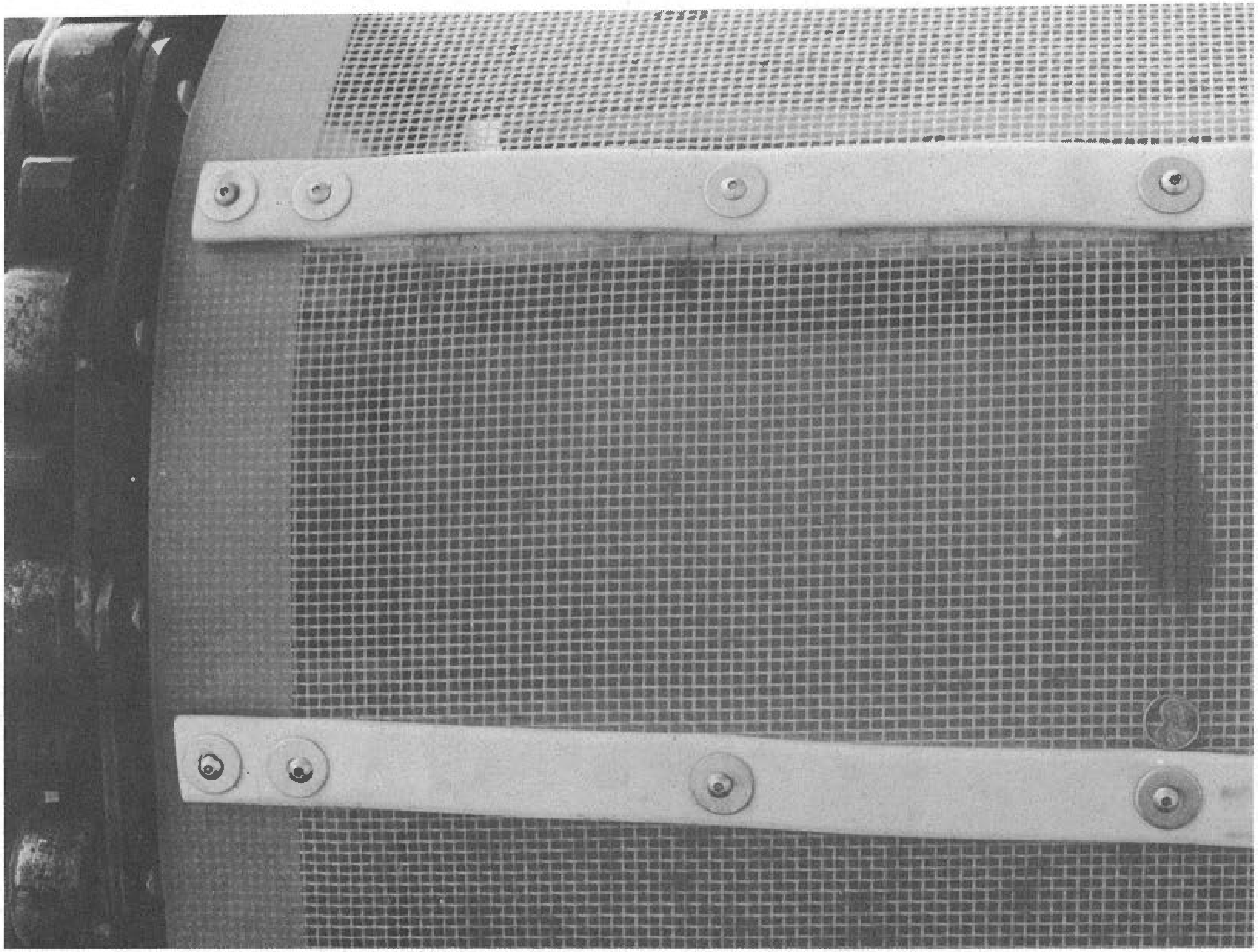


Figure 14-5. Closeup of Lower Monumental submerged traveling screen in raised position. Penny used to contrast chain and nylon screen sizes.

Table 14-1. Future optimum fish guiding efficiencies for various species at Lower Monumental.

Species	Future optimum fish guiding efficiencies (%)
Spring chinook	78
Fall chinook	40
Steelhead	80
Sockeye	55

to mitigate this damage on completed projects or to restore the numbers of migrating fish to a specific level (GAO, 1990).

14.1.2 Monitoring Methods.

Fish ladders. Adult chinook salmon passage was monitored at Lower Monumental Dam from April 12 to June 16, 1982 (Turner et al., 1984). Upstream-migrating spring chinook salmon were trapped at either the Ice Harbor fish ladder (on the Snake River downstream from Lower Monumental Dam) or at the Bonneville Dam on the Columbia River (Figure 14-1). Thirty-five fish were trapped at Ice Harbor, radio-tagged, and released either below (31) or above (4) Ice Harbor Dam. In addition, the passage of 41 salmon that were radio-tagged at Bonneville Dam was monitored at both Ice Harbor and Lower Monumental Dams.

Bjornn et al. (1992) monitored the migrations of adult chinook salmon past dams in the Snake River in 1991. Radio transmitters were attached to 531 spring and summer chinook, and 728 steelhead. These tagged fish were then released near Ice Harbor dam to continue their upstream migrations.

Fish screens. Preliminary tests of submerged traveling screens at Lower Monumental were conducted in 1986 using screens borrowed from the John Day Dam (Ledgerwood et al., 1987). Nets were lowered into the intake of Turbine Unit 4, located centrally in the powerhouse, to assess the fish guidance and vertical distribution of downstream migrating steelhead and yearling and subyearling chinook salmon. Based on this information, theoretical fish guiding efficiencies were estimated for a submerged traveling screen that intercepts the upper 16 feet of the intake. Subsequently, the submerged traveling screens and associated nets were lowered into the Turbine Unit 4 intake to estimate the true fish guiding efficiency of the test screen. Tests were conducted between April and June 1986 using native steelhead and yearling chinook salmon, as well as subyearling chinook salmon that had been released from an upstream hatchery.

14.1.3 Performance of Mitigation.

Fish ladders. Of the 35 adult spring chinook salmon that were radio-tagged and released in the vicinity of Ice Harbor Dam, 34 were available for passage at Lower Monumental; one tagged fish was found dead below Ice Harbor Dam (Turner et al., 1984). Twenty-eight of the 34 salmon ascended the fish ladders at Lower Monumental, resulting in an 82.4% passage. Of the 41 chinook salmon tagged at Bonneville Dam, seven ascended the Ice Harbor ladders. All seven of these fish subsequently ascended the Lower Monumental ladders, resulting in 100% passage at Lower Monumental for this group of fish. Chinook salmon preferred the powerhouse ladder to the spillway ladder (63% versus 37%).

Fallback immediately after ascending the dam was observed in four of the 35 salmon that used the Lower Monumental ladders. Turner et al. (1984) attributed this to the large amount of spill that occurred throughout their study and noted that all four fish subsequently reascended. Eleven of the 35 fish backed down the fish ladders after ascending various distances. All of these fish successfully reascended, but the delays in upstream migration resulting from backing down the ladders ranged from a few hours to 9 days.

Chinook salmon were delayed a median of 44.8 hours at the Lower Monumental Dam during periods of high spills (Turner et al., 1984), although there was considerable variability in passage times. Passage times over Lower Monumental for fish released near Ice Harbor Dam ranged from 22.1 to 618.5 hours. Median travel time from the Ice Harbor release point to the Lower Monumental tailrace (31.9 miles upstream) was 21.4 hours. Median travel time from the Lower Monumental tailrace to the Lower Monumental fish ladder exits was 41.1 hours. Among the seven fish tagged near Bonneville Dam, median travel time between the Lower Monumental tailrace and the ladder exits was 58.2 hours.

Probable causes for the delays included fish holding in tailrace eddies several hundred feet downstream from the dam, fallout at the south end of the fishway, salmon backing down fish ladders or falling back over dams, holding and extensive movement in the collection channels, and recovery from handling and tagging stress. Turner et al. (1984) believed that the passage times were delayed by the high and severely fluctuating spill levels that occurred during the 1982 sampling season. High spills, and high spill-to-powerhouse-discharge ratios, created slack water areas and eddies in the Lower Monumental tailrace. Fish in the vicinity of these eddies exhibited relatively undirected movements, such as circular swimming, back-and-forth movements along the shore, and holding.

Passage monitoring of radio-tagged spring and summer chinook at all four lower Snake River dams was begun in 1991 (first year of a 4 year study) by Bjornn et al. (1992). Of the 435 tagged salmon that were recorded in the Lower Monumental tailrace, 391 were subsequently detected in the Little Goose Dam tailrace, 28.8 miles upstream. This represents a passage efficiency of 90%. An estimated 87% of radio-tagged salmon ascended all four dams on the lower Snake River (Ice Harbor, Lower Monumental, Little Goose, and Lower Granite). Median passage time for the Lower Monumental fish ladders was 16.8 hours; individual passage times ranged from 1.2 to 811.2 hours. Fallback of chinook salmon over the dams was uncommon in 1991 because of low river flows and lack of spill (Bjornn et al., 1992). These two factors, when coupled with low turbidities in spring and early summer, may have contributed to the relatively rapid passage rates of chinook salmon throughout the lower Snake River system in 1991.

Fish screens. Because downstream-migrating salmonids are surface oriented, entrained migrants tend to be localized in the upper regions of turbine intakes. Based on vertical distribution data of salmon and steelheads entrained at Lower Monumental Dam, Ledgerwood et al. (1987) estimated that 91, 61, and 87% of the yearling and subyearling chinook salmon, and steelhead, respectively, were located in the water column that could potentially be intercepted with a submerged traveling screen (Table 14-2). Studies with a test submerged traveling screen in place showed a lower fish guiding efficiency. Fish guiding efficiency for steelhead averaged 74%, whereas fish guiding efficiencies for yearling and subyearling chinook salmon averaged 73% and 35%, respectively (Table 14-2). The authors believed that the actual fish guiding efficiencies were smaller than the theoretical fish guiding efficiencies (which were estimated from fish distribution without a submerged traveling screen in the intake) because the submerged traveling screen changes the flow patterns in the intake. Flow is restricted in the screened portion of the intake, which tends to divert some of the water (and fish) deeper into the intake below the screen (Ledgerwood et al., 1987).

Tests carried out to determine the vertical distribution of entrained salmon and steelhead noted that some fish were diverted into the gatewell slots (bypass) even in the absence of a submerged traveling screen. These fish guiding efficiencies varied with age and species, but were as high as 20% for steelhead (Table 14-2). If the fish guiding efficiencies that were observed without a screen are subtracted from those observed with a submerged traveling screen in the intake, the net fish guiding efficiencies that can be attributed to the presence of the submerged traveling screen ranged from 29% to 55%. That is, the submerged traveling screen allowed between 29% and 55% of the entrained salmonids to be bypassed around the turbines. Descaling rates of bypassed fish were less than 10%, and were not significantly different between groups of fish that were bypassed with or without the submerged traveling screens.

Table 14-2. Fish guiding efficiency (FGE) of a submerged traveling screen (STS) tested at the Lower Monumental Dam in 1986. All values are in percent. Source: Ledgerwood et al. (1987).

Species	Mean theoretical FGE[a]	Mean FGE with STS in intake[b]	Mean FGE without STS in intake[c]	Net FGE[d]	Percent descaled[e]
Yearling chinook salmon	91	73	18	55	5.0
Steelhead	87	74	20	54	2.1
Subyearling chinook salmon	61	35	6	29	0.3

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a. Estimated percent of fish entering the intake that would be diverted to a bypass by an STS that extends 16 feet down from the top of the intake, based on vertical distribution of entrained fish.

b. Mean percent of entrained fish that were diverted into a turbine bypass with the test STS in place.

c. Mean percent of entrained fish that were diverted into a turbine bypass without the test STS in place. Value may be as low as 2 to 4% (text).

d. Mean FGE with the STS minus mean FGE without the STS. This is the percentage of entrained fish that were diverted into the bypass by the STS.

e. Average percent of bypassed fish that showed loss of scales when STS was in place. These values were not significantly different from descaling percentages of fish that were bypassed without the STS in place.

The actual percentage of fish bypassed without a submerged traveling screen may be lower than indicated in Table 14-2 because fish are free to swim back out of the gatewell slots and pass through the turbine. Presumably, the presence of a submerged traveling screen would prevent fish initially diverted into the gatewell slots from reentering the intake. In addition, the presence of the fyke net frame in the turbine intake during these tests may have diverted additional flow and fish into the bulkhead slot. Studies at other projects suggest that more accurate values for fish guidance efficiency without a submerged traveling screen may be 2 to 4% (Hurson, personal communication).

Although a large percentage of entrained smolts can be diverted by the submerged traveling screen, the original bypass system was inadequate to collect and remove these diverted fish from the gatewell. The original bypass consisted of an embedded collection pipeline that extended from the north face of the powerhouse to the south face. Because of its small size and limited flow capacity, it was estimated that only 2% of the smolts passing through the powerhouse were intercepted by the collection pipe system, the remainder passing through the turbines or over the spillway (COE, 1989). Consequently, modifications associated with installing the submerged traveling screen at Lower Monumental also included expansion of the juvenile fish collection system.

14.2 Mitigation Benefits

For anadromous fishes, success of a juvenile fish protection measure would best be measured by increases in the numbers of adults that return to the Snake River years later. Because the downstream fish passage/protection facilities have only recently been installed at Lower Monumental, results of monitoring studies are not yet available to evaluate the overall effect on salmonid populations. The Corps of Engineers (1988b) modeled the responses of anadromous fish populations of various fish guiding efficiency improvement alternatives in an attempt to predict the consequent fishery benefits. This model analyzed the sources of mortality to juvenile fish as they migrate downstream by the various passage routes (through reservoirs, over spillways, through turbines, through bypass and collection systems, and by transportation) then calculated the numbers of returning adults based on the number of surviving smolts. The model then computed potential sport and commercial catches in the Columbia and Snake River systems by subtracting the required escapement from the number of adults returning to the Columbia River fishery. Two juvenile fish guiding efficiency levels were modeled: (a) the existing conditions in 1985 and (b) a Future Optimum Facility Level, which reflected the expected high fish guiding efficiency levels when the system was fully implemented in the Snake and Columbia Rivers. In addition, two fish transportation levels were modeled: one option had all of the bypassed smolts collected at Lower Granite, Little Goose, and McNary Dams transported to a point below Bonneville Dam ("full transportation"), whereas the other option calls for some fish to be transported downstream and others to be released into the tailwaters of the Snake River dams ("existing transportation").

In all, the effects of 24 conditions on anadromous fish populations were modeled (COE, 1988b). Some of these results are presented in Table 14-3 to illustrate the effects of different mitigative options. In general, all modifications to the base condition (installation of submerged traveling screen, augmentation of truck/barge transportation for both wild and hatchery juveniles) were projected to increase the numbers of adult fish subsequently returning to the Snake River. For example, installation of a submerged traveling screen with no other enhancements (Scenario 2) would increase the numbers of adult wild spring chinook salmon by 1.2%. Augmenting the transportation of bypassed and hatchery-raised salmon combined with submerged traveling screen installation (Scenario 4) would be expected to increase the number of returning adult wild spring chinook salmon by 5.1%.

While the model is valuable for selecting the most effective (and cost-effective) mitigation options, the predicted benefits must be verified by operational monitoring. The importance of monitoring the numbers of returning adults as a measure of the effectiveness of juvenile protection facilities is underscored by a study of a submerged traveling screen installation at the second powerhouse at the Bonneville Dam on the Columbia River (Ferguson, 1991). Several years of data on the survival of subyearling chinook salmon indicated that diversion by the submerged traveling screen and passage through the bypass system was actually detrimental to the short-term survival of the juvenile salmon tested. When compared to passage through the turbines, bypassed salmon suffered from 2.5% to 13.6% greater mortality. Further, preliminary data (returns of adults from the first year's test group) indicated that there were no significant differences between the long-term survivals of bypassed and turbine-passed fish. Ferguson (1991) suggested that the greater mortality among bypassed fish might have been due to predation by northern squawfish keying on the single point outfall of the Bonneville bypass system. The bypass system at Lower Monumental is different from that at Bonneville, and bypassed fish may not experience the degree of predation. However, the need to monitor long-term effectiveness is clear.

14.2.1 Conclusions. Fish ladders at the four mainstream dams on the lower Snake River all have similar designs. In a review of adult fish passage studies at Snake River dams, Bjornn and Peery (1992) concluded that once adult salmon and steelhead enter the fishways some may go out an entrance, but many pass up through the fishways in a few hours. A large proportion of the time required to pass a dam appears to be the time needed to find and enter the fish ladders. This time may be increased by either insufficient or excessive spill flows. When there is no spill, few fish are attracted to the fish ladder entrances adjacent to the spillway, whereas large spill flows may cause turbulence and eddies that confuse the fish. The studies of upstream fish passage at Lower Monumental are consistent with these generalizations. Delays in upstream migrations occur due to fallback over the dam and fish swimming back down the ladders after partially ascending. However, the delays do not appear to be excessive for most fish, and passage efficiency for different groups of tagged fish ranged from 82% to 100%.

Table 14-3. Projected total number of adult salmonids returning to the Snake River under various juvenile fish passage/protection scenarios at Lower Monumental Dam. Numbers in parentheses are the percentage increases over the base condition (Scenario 1). Source: U.S. Army Crops of Engineers, 1988b.

Species	Scenario 1[a]	Scenario 2[b]	Scenario 3[c]	Scenario 4[d]
Hatchery steelhead	570,850	575,764 (+0.9)	582,644 (+2.1)	588,887 (+3.2)
Hatchery spring chinook	519,456	525,445 (+1.2)	544,096 (+4.7)	545,568 (+5.0)
Hatchery summer chinook	58,209	58,878 (+1.1)	60,967 (+4.7)	61,131 (+5.0)
Wild steelhead trout	507,149	509,743 (+0.5)	515,468 (+1.6)	516,686 (+1.9)
Wild spring chinook	563,834	570,381 (+1.2)	590,735 (+4.8)	592,584 (+5.1)
Wild summer chinook	277,292	280,477 (+1.1)	290,428 (+4.7)	291,212 (+5.0)

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a. Base condition of no submerged traveling screen (STS), existing transportation of downstream migrants, and no transportation of hatchery-reared fall chinook salmon.

b. Standard STS, existing transportation of downstream migrants, and no transportation of hatchery-reared fall chinook salmon.

c. Standard STS, full transportation of bypassed downstream migrants, and no transportation of hatchery-reared fall chinook salmon.

d. Standard STS, full transportation of bypassed downstream migrants, and 100% transportation of hatchery-reared fall chinook salmon.

Monitoring of the recently installed juvenile fish bypass system at Lower Monumental will be especially important in view of the indication from the study of the second powerhouse at Bonneville Dam (Ferguson, 1991) that bypassed juvenile chinook salmon may suffer greater mortality than turbine-passed fish. Although there are differences between the two bypass systems, the Bonneville dam second powerhouse was designed and constructed with a state-of-the-art juvenile bypass system that incorporates many of the elements of the Lower Monumental facility; similar-sized submerged traveling screens guide downstream migrants to a vertical bulkhead slot from which fish exit to a collection gallery in the powerhouse. Initial results of the Bonneville monitoring study call into question the assumption that bypasses are better than turbine passage in all cases. If squawfish predation at the bypass outfall is in fact a significant problem at the Bonneville Dam, this loss from predation could be avoided at Lower Monumental by careful attention to downstream transportation and release of bypassed fish in a manner that will minimize predation losses.

14.3 Mitigation Costs

14.3.1 Introduction. The mitigation cost analysis for the Lower Monumental hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; an upstream fish passage/protection system section, discussing the upstream mitigation costs; a downstream fish passage/protection system section, discussing the downstream mitigation costs; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the upstream and downstream passage/protection mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal written correspondents and from telephone calls. A site visit greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

14.3.2 Cost Summary. The upstream mitigation ($36.3 million) and downstream mitigation ($96.2 million) costs totaled $132.5 million for the entire 20 years of the cost analysis period. The cost of lost generation resulting from 15 years (1978 through 1992) of spill flows for downstream migrants represents 57% of all upstream and downstream mitigation costs. The right-bank and left-bank fish ladders represent 61% of the total upstream mitigation costs and 17% of the total upstream and downstream mitigation costs (Figure 14-6).

The lost generation costs resulting from downstream mitigation-related spill flow practices ended during 1992. The submerged travling–screens and vertical gatewell screens ($5.0 million), and the collection gallery mining, dewatering structure, and associated flumes ($7.6 million), are now used (1993+) to transport downstream migrants past the dam without the use of spill flows. The total downstream mitigation capital cost ($18.4 million) also includes the juvenile holding, loading, and laboratory facilities ($5.7 million).

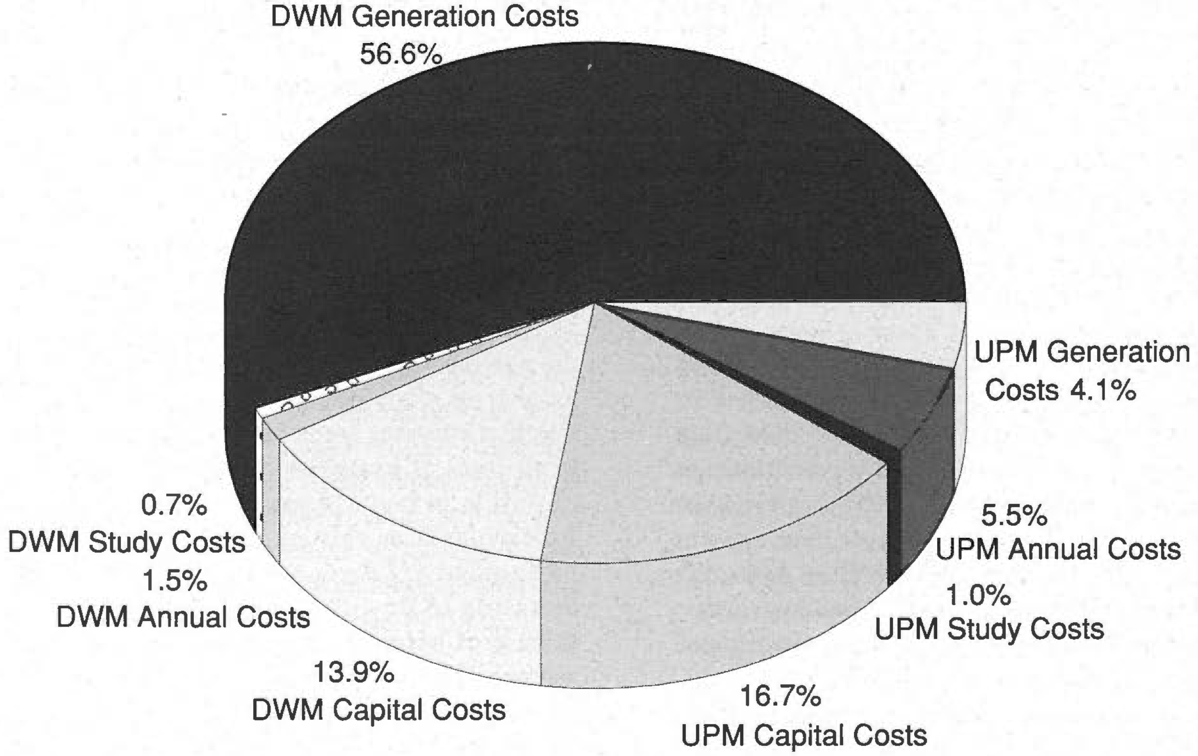

Figure 14-6. Cost of upstream (UPM) and downstream (DWM) mitigation at the Lower Monumental hydroelectric project.

The annual costs are predominantly downstream mitigation costs. The size of the 1992 downstream mitigation costs (Figure 14-7) are driven by the cost of installing the facilities for downstream migrant collection and transportation preparation. The 1994 costs decrease as spill flows will no longer be used for downstream passage mitigation. The 1978 costs contain the capital cost on constructing the fish ladders during 1969.

Normally the average annual generation as obtained from the plant operator is used to determine the mitigation costs per kilowatt-hour of generation. The project's historical generation during 1990, 1991, and 1992 was provided, and the yearly average was 1.8 million megawatt-hours (25% plant factor). Because the Pacific Northwest was mired in a drought during this period and because of the low plant factor, it is believed that this (1.8 million megawatt-hours) is an unusually low generation rate and that using it would provide an inaccurate view of mitigation costs on a per kilowatt-hour basis for the 20-year period of analysis. To more accurately demonstrate mitigation costs per kilowatt-hour, the FERC Hydropower Resource Assessment Database was used as the source for the historical average annual generation value of 2,856,000 megawatt-hours. At a plant factor of 40%, 2,856,000 megawatt-hours is believed to be a better long-term representation of average generation. Therefore, based on the levelized annual cost of $6.6 million for upstream and downstream mitigation and an average generation value of 2,856,000 megawatt-hours, the cost per kilowatt-hour is 2.3 mills (about 1/4 of a cent) for both upstream and downstream fish passage/protection mitigation. The individual cost per kilowatt-hour for upstream mitigation is 0.6 mills and mills for downstream mitigation it is 1.7 mills (Table 14-4).

14.3.3 Upstream Fish Passage/Protection. The right-bank and left-bank fish ladders are the only upstream mitigation capital cost items at Lower Monumental, with a combined total cost of $22.2 million. The ladders are the largest (61%) upstream mitigation cost component (Figure 14-8). Including daily operating inspections,

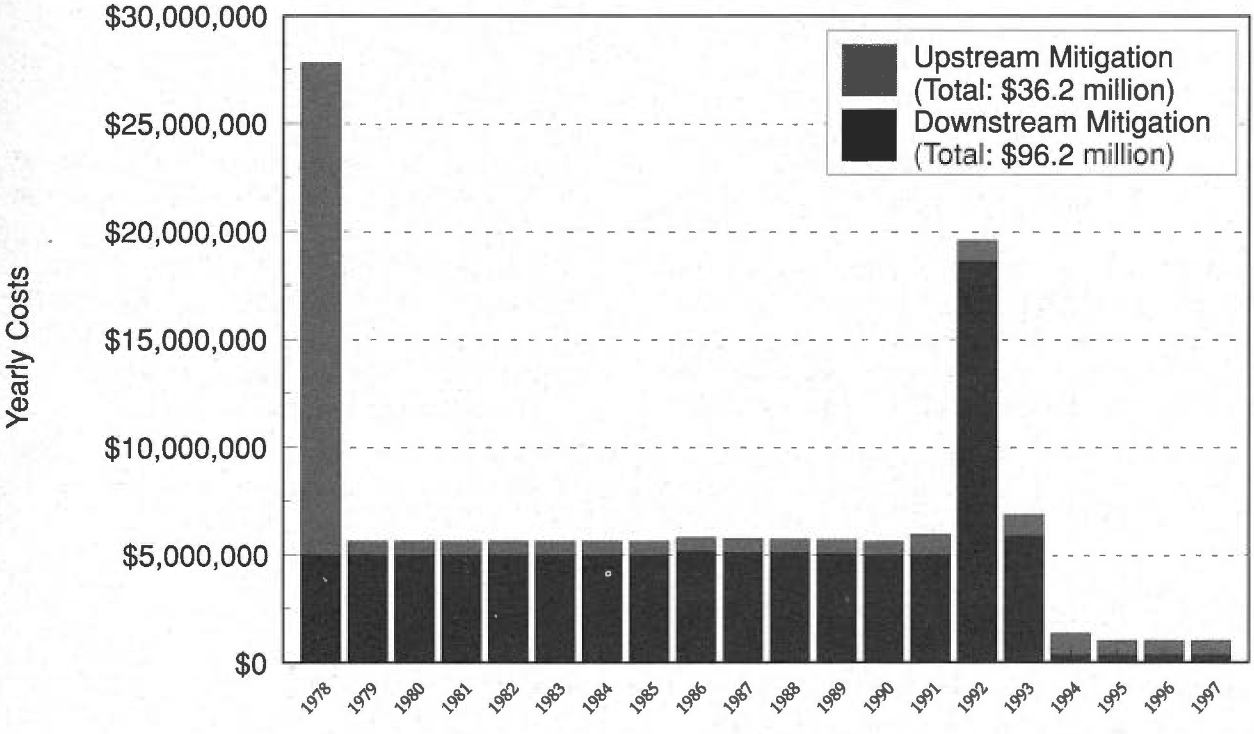

Figure 14-7. Yearly upstream and downstream mitigation costs at the Lower Monumental project.

Table 14-4. Twenty-year costs incurred at the Lower Monumental project for upstream and downstream mitigation.

	20-year total ($)	Levelized annual cost ($)	Annual cost per kWh (mills)
Upstream	36,226,000	1,811,300	0.6
Downstream	96,238,000	4,811,900	1.7
Total costs	132,464,000	6,623,200	2.3

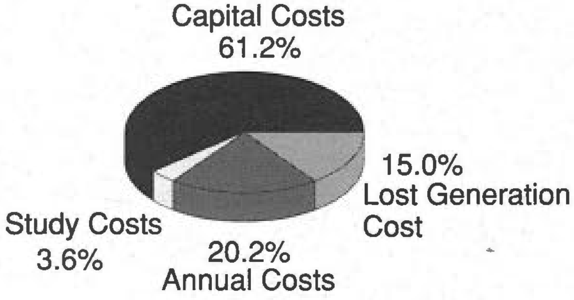

Figure 14-8. Capital, study, annual and lost generation costs of upstream mitigation at the Lower Monumental project.

the operations and maintenance costs for the two ladders is estimated at $250,000 annually. The fish counting at the two ladders costs a total of $100,000 annually. A 4-year study (1991–1994) of adult passage habits will cost a total of $1.3 million. Upstream mitigation related generation losses are estimated to cost an average of $271,000 annually. The generation losses result from flows through the ladders and for ladder attraction flows.

The 20-year total cost of upstream mitigation is $36.2 million (Table 14-5). The levelized annual cost for upstream mitigation is $1.8 million, and the cost per kilowatt-hour of generation is 0.6 mills. The future annual costs for upstream mitigation are expected to continue relatively unchanged (Figure 14-9).

14.3.4 Downstream Fish Passage/Protection. The magnitude of downstream mitigation-costs from 1978 through 1992 have been driven by the amount of lost generation incurred. During the 15-year period of generation losses resulting from spill flows, the total cost of downstream mitigation was $89.1 million, while lost generation cost a total of $75.0 million. This is 84% of the total downstream mitigation cost during this period. Over the last 5 years (1993 through 1997) of the 20-year cost analysis, zero generation losses are anticipated. The installation of the submerged traveling screens and the collection gallery downstream migrant system, at a cost of $12.6 million, eliminates the need for downstream migration spill flows and the corresponding lost generation capabilities. Other downstream mitigation related capital costsinclude the construction of the holding, loading, and laboratory facility, and the bypass pipe outfall sampling facility at a total cost of $5.7 million. Additional downstream mitigation costs include total study costs of $885,200, the total fisheries biologists cost of $324,600, and the estimated annual cost of $274,800 to operate the downstream migration passage/protection facilities.

Table 14-5. Twenty-year costs incurred for upstream mitigation at the Lower Monumental project. Columns may not total exactly due to individual rounding.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital costs	22,185,400	1,109,300	0.39
Study costs	1,300,000	65,000	0.02
Annual costs	7,320,600	366,000	0.13
Lost generation	5,420,000	271,000	0.09
Total upstream costs	36,226,000	1,811,300	0.6

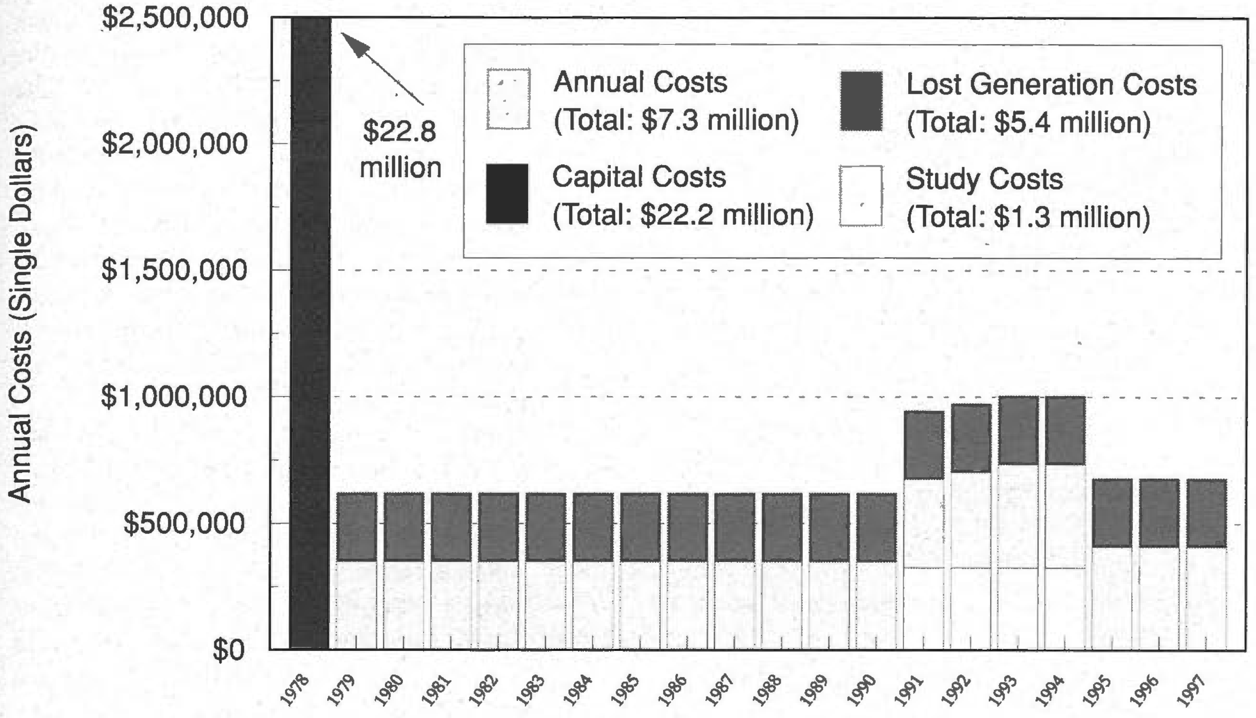

Figure 14-9. Yearly costs of upstream mitigation at the Lower Monumental project.

The 20-year total cost for downstream mitigation is estimated at $96.2 million (Table 14-6). This equates to a levelized annual cost of $4.8 million, and based on the average annual generation value of 2,856,000 megawatt-hours, the cost of downstream mitigation is 1.7 mills per kilowatt-hour of generation. The cost of downstream mitigation, excluding lost generation costs, is $21.2 million. This equates to a levelized annual cost of $1.1 million for the costs other than the downstream mitigation lost generation costs. The cost of lost generation, at 78% of total downstream mitigation costs, has historically been the most expensive downstream mitigation cost element (Figure 14-10). However, with the use of the submerged traveling screens, the average annual future cost of downstream mitigation should average below $1.0 million annually (Figure 14-11).

14.4 Cost Descriptions and Assumptions

This section provides an explanation of the individual cost items, assumptions, and estimates required to quantify the respective items and derive totals. The item numbers correspond to the 20-year analysis (Table 14-7) used to estimate total and levelized mitigation costs, as well as

Table 14-6. Twenty-year costs incurred for downstream mitigation at the Lower Monumental project. The columns may not total exactly due to individual rounding.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital costs	18,379,400	919,000	0.32
Study costs	885,200	44,300	0.02
Annual costs	1,973,400	98,700	0.03
Lost generation	75,000,000	3,750,000	1.31
Total downstream costs	96,238,000	4,811,900	1.7

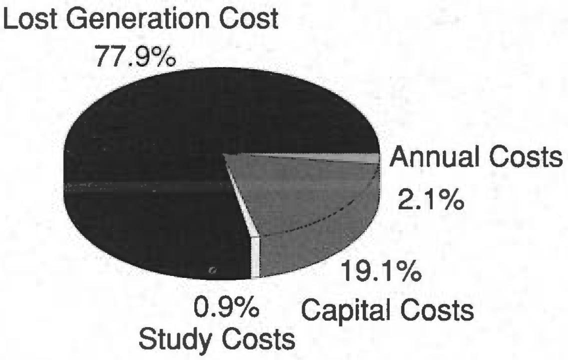

Figure 14-10. Capital, study, annual and lost generation costs of downstream mitigation at the Lower Monumental project.

costs per kilowatt-hour. All costs have been converted to 1993 dollars and are discussed as such.

14.4.1 Capital Costs—Downstream Mitigation.

1. **19 STS and 18 VBS** (Screens) (19 Submerged Traveling Screens and 18 Vertical Barrier Screens). Lower Monumental has six turbine units with three intakes per turbine for a total of 18 turbine intakes. The total cost of $4,996,900 includes 18 submerged traveling screens, one spare submerged traveling screen, and 18 vertical barrier screens. The cost includes the electrical control panels, spare parts, and special inspections required during the manufacturing and installation of the submerged traveling screens. Grouting was required behind the vertical barrier screen guides to remove irregularities in the concrete walls. The submerged traveling screens and vertical barrier screens were installed in the gatewell slots with no modifications required of the gatewell slots. The screens were installed during the fall of 1991 and the spring of 1992. The total costs (incurred 1992 and 1993) was split evenly between the 2 years, and indexed to 1993 dollars.

2. **Collection Gallery/Dewatering.** The $7,608,600 cost includes the mining and

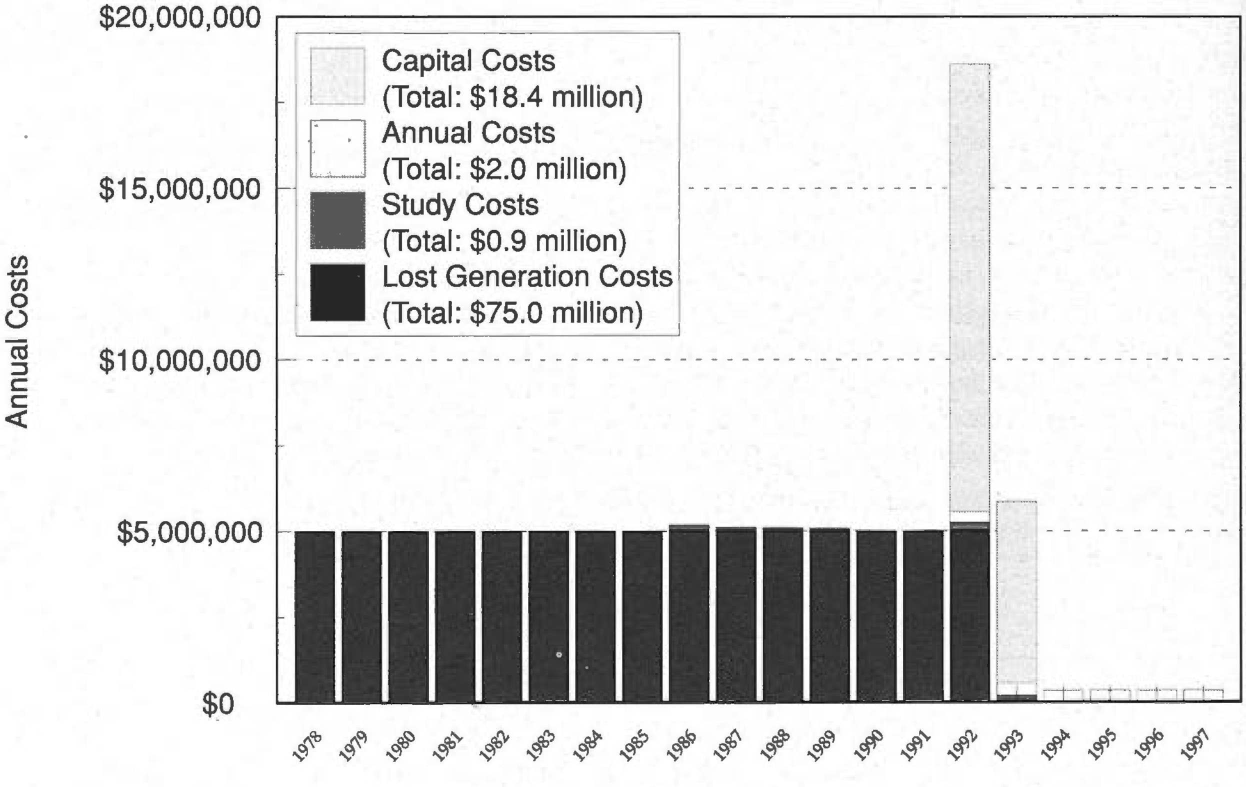

Figure 14-11. Yearly costs of downstream mitigation at the Lower Monumental project.

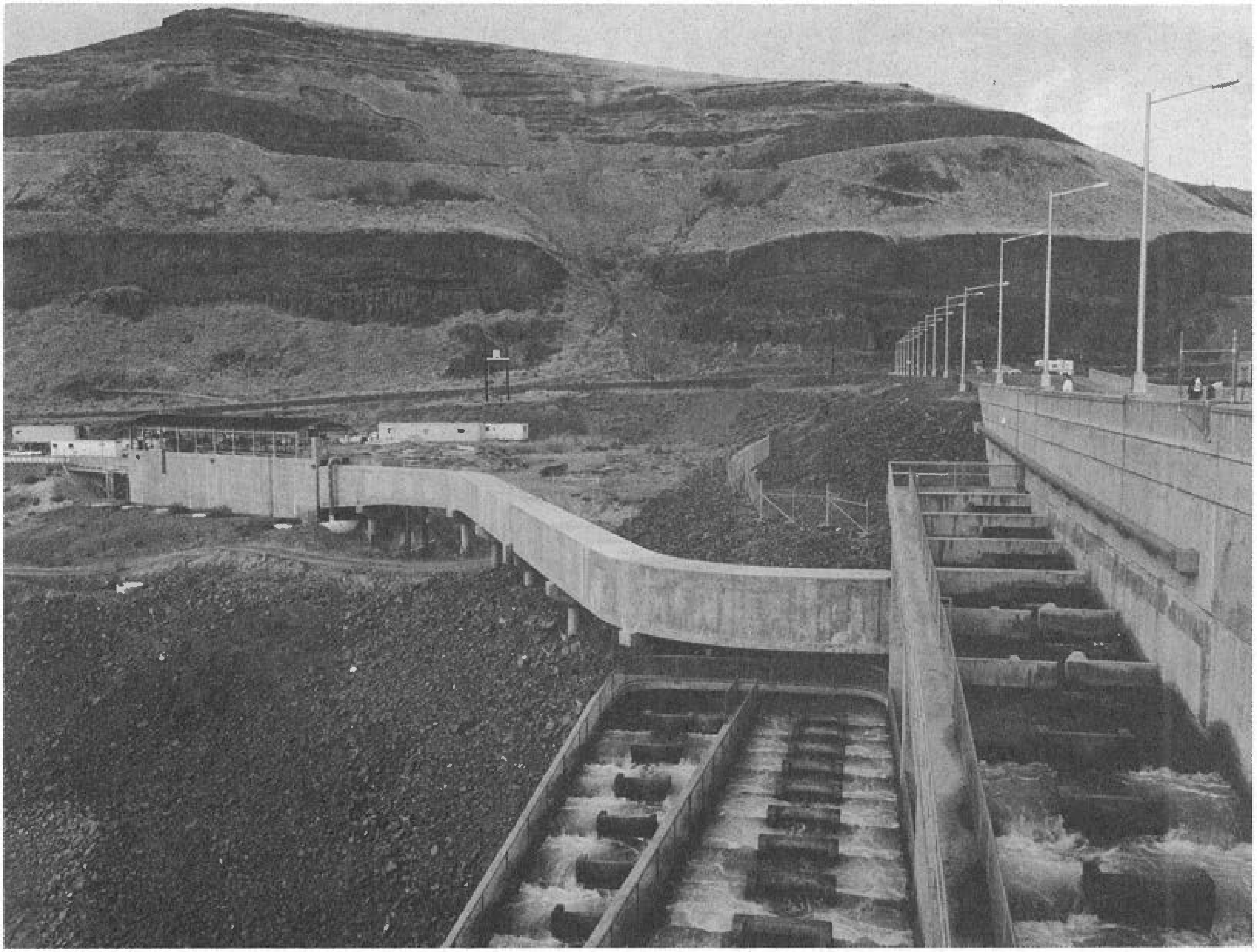

Figure 14-12. Lower Monumental juvenile bypass conduit and dewatering structure in background. Right-bank fish ladder in foreground.

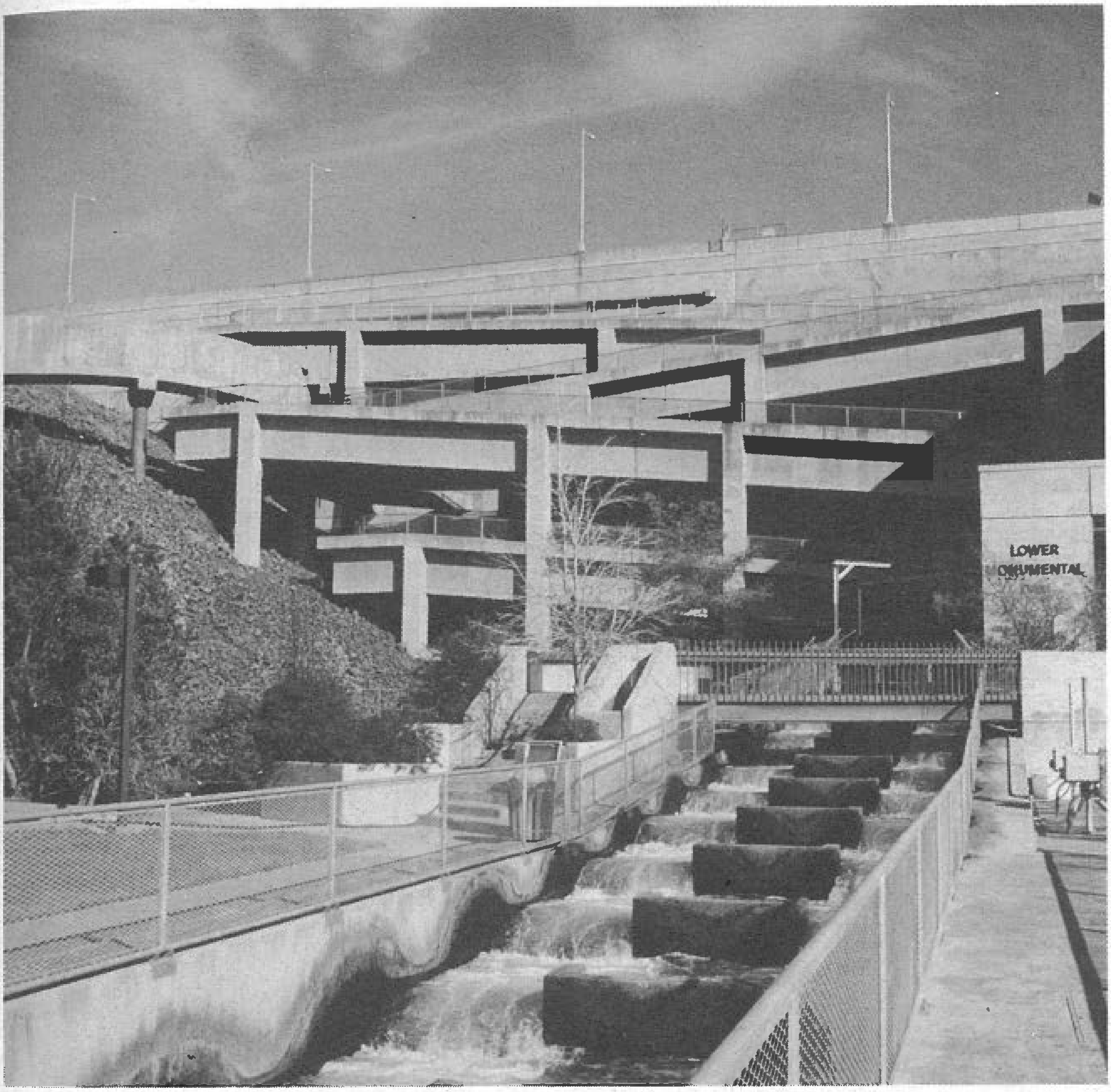

Figure 14-13. Lower Monumental right-bank fish ladder. Ladder is stacked on itself.

8. **DWM Juv Hydroacoustic Studies** (Downstream Mitigation Juvenile Fish Passage Hydroacoustic Studies). Hydroacoustic evaluations have been conducted of juvenile fish passage at Lower Monumental to provide real-time inseason information on juvenile fish passage. This information was used for managing nightly spill flows for bypassing juvenile salmonids. This activity occurred from 1986 through 1989. No cost information was obtained for 1987, so the 1986, 1988, and 1989 costs were averaged and assigned to 1987. The 4-year estimated total cost was $446,500.

9. **UPM Adult Fish Passage.** This 4-year study on adult fish passage at the four lower Snake River hydroelectric projects is currently in its third year. A single cost for 1993 was provided for all four projects. To

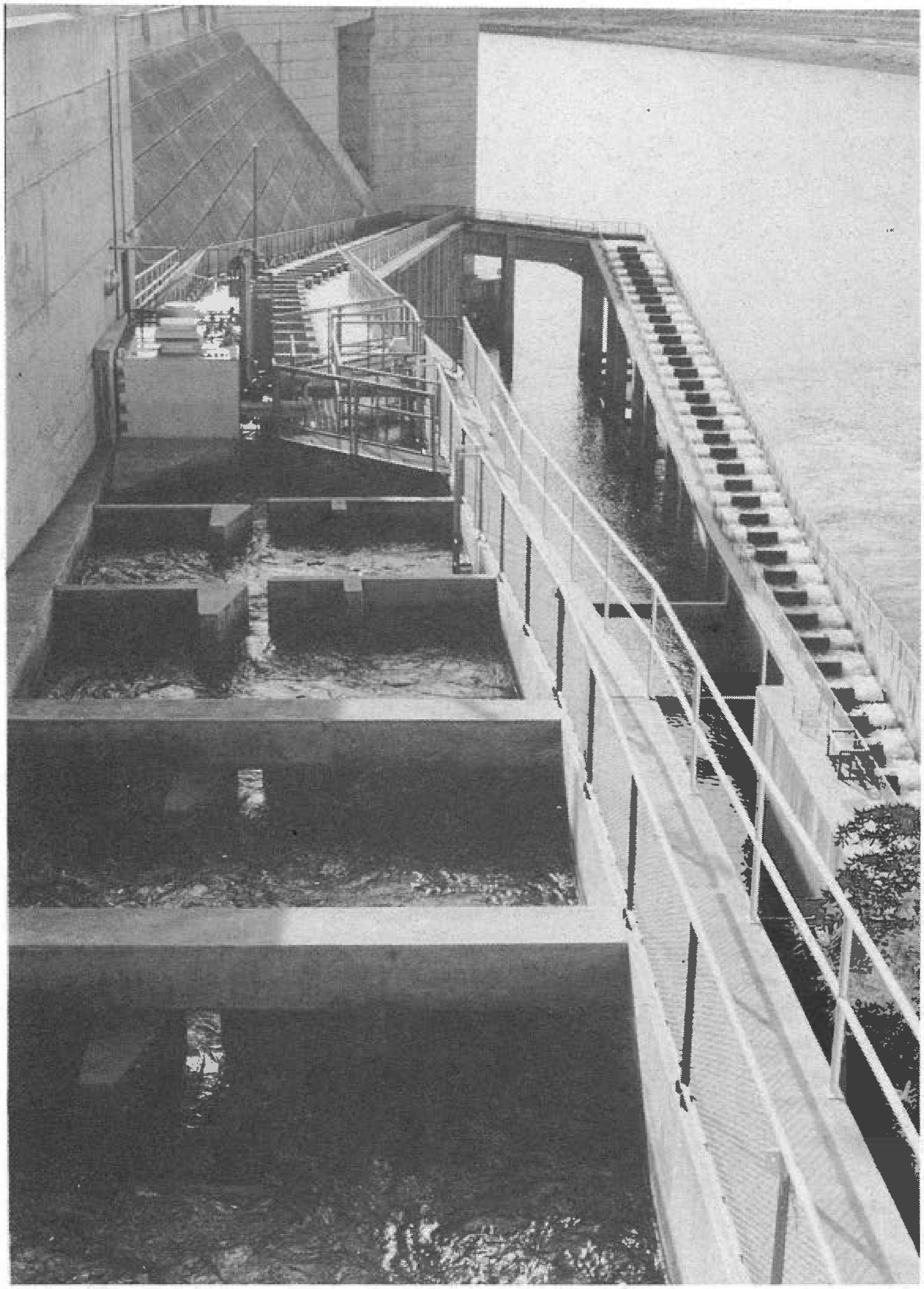

Figure 14-14. Lower Monumental left-bank fish ladder, with fish counting station. Taken from ladder top.

estimate the study cost that should be assigned to Lower Monumental, the 1993 total study cost was assigned at a rate of 25% to Lower Monumental (split between four projects). This 1993 cost of $325,000 was used to estimate the study costs for 1991, 1992, and 1994. The estimated 4-year study cost total of $1,300,000 is assigned as a upstream mitigation cost at Lower Monumental.

14.4.4 Annual Costs—Upstream Facilities.

10. **Operations and Maintenance.** The 1992 cost for the operations and maintenance of the adult fish passage/protection facilities totaled $249,800 (1993 dollars). The operator indicated that 1992 was a normal operations and maintenance year, and this cost was used for all 20 years. The cost includes normal operations of the facilities, including daily inspections, corrective actions to keep the facilities operating within established fish criteria, periodic maintenance of facilities during the operating season, and annual maintenance during the winter outage period.

11. **Fish Counting.** The adult fish counting is conducted from April 1 through October 31. The counting has been performed since 1968, but only the costs incurred during the 20 years of the cost analysis have been included. The estimated annual fish counting cost is $100,000.

14.4.5 Annual Costs—Downstream Facilities.

12. **O & M (Est. Little Goose).** The new juvenile fish passage/protection facilities at Lower Monumental have not operated a long enough period of time to adequately evaluate operations and maintenance costs. The Little Goose Dam's downstream mitigation facilities are similar to the Lower Monumental facilities and the Little Goose costs have been used to estimate the operations and maintenance costs of the Lower Monumental juvenile fish passage/protection facilities. Normal activities at Lower Monumental include daily inspections, maintenance of the submerged traveling screens during the operating season, and annual maintenance of the facilities during the winter nonuse period. The estimated annul cost is $274,800.

14.4.6 Annual Personnel Costs.

13. **UPM—Fishery Biologists.** Two fishery biologists work full time on fishery programs at five Corps of Engineers-operated hydroelectric projects. The specific amount of time spent on Lower Monumental issues is unknown, so it was assumed to be one-fifth of their combined time. The method diagramed below was used to estimate the yearly cost at Lower Monumental:

    2 (biologists) × $30 (labor rate) × 40 (hours/week) × 52 (weeks/year) × 0.20 = $25,000.

    In addition to the two biologists indicated above, a full-time biologist oversees project fishery activities at Lower Monumental and a second hydroelectric facility. One-half of this person's time is assigned as a cost to Lower Monumental by the following method:

    1 (biologist) × $30 (rate) × 40 (hours/week) × 52 (weeks/year) × 0.50 = $31,200.

    The above annual costs for biologists assigned to Lower Monumental is $56,200 ($25,000 + $31,200). This cost ($56,200) is assumed to commence during 1992 for the sake of the cost analysis. While acknowledging that fishery biologists performed fish passage/protection related functions at Lower Monumental prior to 1992, the magnitude is unknown and no costs have been assigned. Additionally, a full-time assistant biologist was assigned exclusively to Lower Monumental starting 1993. This person's cost is assigned to Lower Monumental by the following method:

    1 (biologist) $30 (rate) × 40 (hours/week) × 52 (weeks/year) = $62,400.

The $56,200 cost and the additional $62,400 cost are included for fishery biologists at Lower Monumental starting in 1993, at an annual rate of $118,600. In order to estimate separate upstream and downstream mitigation costs, the annual fishery biologists cost of $118,600 is evenly split ($59,300) between upstream and downstream mitigation.

14. **DWM—Fishery Biologists.** The costs described above under Item 13 are split evenly between upstream and downstream mitigation. Thus, the annual cost for this item beginning in 1993 is $59,300.

14.4.7 Lost Generation Costs.

15. **UPM—Ladders/Attraction Flows.** The fish ladders' attraction water is provided by three Francis turbine-driven pumps. Each turbine requires 65 cfs (195 cfs total), obtained from the forebay through penstocks. The excess water (200 cfs) from the juvenile bypass system dewatering structure is added to the adult auxiliary water supply system. This is done for two reasons: to provide additional attraction flows, and to avoid having an outfall pipe below the adult fishway entrances providing false attraction for the adult fish. Additional flows for the two fish ladders are estimated to total 200 cfs. The total estimated flows for the ladders and attraction flows are estimated at 495 cfs. To estimate lost generation for upstream mitigation, the following assumptions are employed: past energy values have ranged from 7 to 24 mills per kilowatt-hour, and an average of 15 mills is assumed; an energy production value of 5 kilowatts per 1 cfs is assumed; and the ladders operate for 10 months per year:

    15 mills × 5 (kW/cfs) × 495 (cfs) × 24 (hours/day) × 365 (days/year) × 10/12 (10 months) = $271,000.

    The fish ladders and attraction flows have been in operation since project inception, and the costs are limited to the 20-year analysis.

16. **DWM—Juvenile Fish Spills** (Downstream Mitigation—Juvenile Fish Spills) Juvenile fish passage spills have been conducted at Lower Monumental since 1978. The operator estimates that the annual spill flow costs to be ~$5 million during 1989. The amount of water spilled each year has varied tremendously, and the cost was based on the daily rate at which the Bonneville Power Administration was selling power. The power value averaged between 7 and 24 mills per kilowatt-hour. The 1993 downstream juvenile fish passage/protection system is anticipated to eliminate the need for spill flows after 1992. No other data were obtained documenting the cost of spill flows for downstream mitigation.

14.4.8 Other Cost Considerations. The Corps of Engineers has constructed 10 fish hatchery complexes in the states of Idaho, Oregon, and Washington to mitigate for fish passage/protection system losses associated with turbine passage and inundated spawning areas in addition to the upstream and downstream mitigation for fish passage/protection at the Lower Monumental Dam. These hatcheries total ~$170,000,000 in construction costs, and it is estimated that one-quarter ($42,500,000) of the total cost can be assigned to Lower Monumental Dam. This cost has not been added to the 20-year cost analysis because it is assumed to represent an off-site mitigation issue cost. If the $42,500,000 is levelized over 20 years it would add 1.5 mills to the cost of mitigation per every kilowatt-hour of generated electricity. Additional costs are incurred for the yearly operation of these 10 hatcheries.

Other fish passage-costs not added to the cost analysis include the cost of the juvenile barge transportation system. This is a cost that would be assigned to the whole system, not a single facility. Acknowledgement of the barge transportation costs does not include acceptance of the effectiveness of the system. Rather, it simply recognizes that the costs are incurred. Other costs of passage/protection not included in the analysis include meetings and legal costs resulting from mitigation-related planning sessions.

Table 14-7. Lower Monumental mitigation costs.

Lower Monumental Project—Mitigation Cost Analysis—All Values in 1993 Dollars

	–15	–14	–13	–12	–11	–10	–9	–8	–7	–6	–5	–4	–3	–2	–1	0	1	2	3	4	
9/09/93	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	TOTALS
Costs—Downstream Mitigation																					
STS & 18 VBS (Screens)															$2,554,400	$2,442,500					$4,996,900
2) Collection Gallery/Dewatering															$7,608,600						$7,608,600
3) ding/Loading/Laboratory Facility															$2,899,400	$2,774,500					$5,673,900
4) iver Post–bypass																$100,000					$100,000
Costs—Upstream Mitigation																					
/South Fish Ladders (1969)	$22,185,400																				$22,185,400
Costs—Up– & Down–stream																					
DWM Fish Passage/FGE Research															$244,700						$244,700
7) DWM Juvenile Facility Evaluation																$194,000					$194,000
8) DWM Juv Hydroacoustic Studies									$170,300	$111,600	$94,100	$70,500									$446,500
9) UPM Adult Fish Passage														$325,000	$325,000	$325,000	$325,000				$1,300,000
Costs—Upstream Facilities																					
Operations & Maintenance	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$249,800	$4,996,000
11) Fish Counting	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$100,000	$2,000,000
Annual Costs—Downstream Facilities																					
O & M (Est. Little Goose)															$274,800	$274,800	$274,800	$274,800	$274,800	$274,800	$1,648,800
Annual Personnel Costs																					
UPM—Fishery Biologists															$28,100	$59,300	$59,300	$59,300	$59,300	$59,300	$324,600
14) DWM—Fishery Biologists															$28,100	$59,300	$59,300	$59,300	$59,300	$59,300	$324,600
Annual Gen.Losses—UPM & DWM																					
UPM—Ladders/Attraction Flows	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$5,420,000
DWM—Juvenile Fish Spills	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000						$75,000,000
Subtotal UPM Capital Costs	$22,185,400	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$22,185,400
Subtotal UPM Study Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$325,000	$325,000	$325,000	$325,000	$0	$0	$0	$1,300,000
Subtotal UPM Annual Costs	$349,800	$349,800	$349,800	$349,800	$349,800	$349,800	$349,800	$349,800	$349,800	$349,800	$349,800	$349,800	$349,800	$349,800	$377,900	$409,100	$409,100	$409,100	$409,100	$409,100	$7,320,600
Subtotal UPM Lost Generation Costs	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$271,000	$5,420,000
Subtotal UPM—All Costs	$22,806,200	$620,800	$620,800	$620,800	$620,800	$620,800	$620,800	$620,800	$620,800	$620,800	$620,800	$620,800	$620,800	$945,800	$973,900	$1,005,100	$1,005,100	$680,100	$680,100	$680,100	$36,226,000
Subtotal DWM Capital Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$13,062,400	$5,317,000	$0	$0	$0	$0	$18,379,400
Subtotal DWM Study Costs	$0	$0	$0	$0	$0	$0	$0	$0	$170,300	$111,600	$94,100	$70,500	$0	$0	$244,700	$194,000	$0	$0	$0	$0	$885,200
Subtotal DWM Annual Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$302,900	$334,100	$334,100	$334,100	$334,100	$334,100	$1,973,400
Subtotal DWM Lost Generation Costs	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$0	$0	$0	$0	$0	$75,000,000
Subtotal DWM—All Costs	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,170,300	$5,111,600	$5,094,100	$5,070,500	$5,000,000	$5,000,000	$18,610,000	$5,845,100	$334,100	$334,100	$334,100	$334,100	$96,238,000
Total Expenses—1993 Dollars	$27,806,200	$5,620,800	$5,620,800	$5,620,800	$5,620,800	$5,620,800	$5,620,800	$5,620,800	$5,791,100	$5,732,400	$5,714,900	$5,691,300	$5,620,800	$5,945,800	$19,583,900	$6,850,200	$1,339,200	$1,014,200	$1,014,200	$1,014,200	$132,464,000

Notes: 4.5% Index rate used to present values as 1993 dollars

UPM = UPstream Mitigation
DWM = Downstream Mitigation
Subtotal UPM Capital Costs includes item: 5
Subtotal UPM Study Costs includes item: 9
Subtotal UPM Annual Costs includes items: 10, 11 & 13
Subtotal UPM Lost Generation Costs includes item: 15

Subtotal DWM Capital Costs includes items: 1, 2, 3 & 4
Subtotal DWM Study Costs includes items: 6, 7 & 8
Subtotal DWM Annual Costs includes items: 12 & 14
Subtotal DWM Lost Generation Costs includes item: 16

15. POTTER VALLEY CASE STUDY

15.1 Description

The Potter Valley project (FERC number 00077) diverts water from the Eel River in Mendocino County, California (Figure 15-1). The Potter Valley powerhouse discharges into the East Fork of the Russian River. Cape Horn Dam (Figure 15-2) impounds the Van Arsdale Reservoir, which provides a source of water for the Potter Valley diversion. The project began operation in 1908 and has a total installed capacity of 9.2 megawatts.

A 63-foot-high concrete pool and weir fish ladder was constructed at the Cape Horn Dam about 1910 in order to allow access of chinook salmon and steelhead trout to upstream spawning habitat (Figure 15-3). Prior to 1987, discharges over the dam produced a confusing hydrologic pattern for upstream migrating fish (SEC, 1990). Water spilled over the crest of the dam onto a stepped face and rock formations, which distracted salmon and steelhead from the ladder entrance. The fish ladder (Figure 15-4) was renovated in 1987 to correct this problem. The entrance to the ladder was repositioned with respect to the main river channel. Supplemental attraction flow, which commonly reaches 88 cfs during the salmon and steelhead migration season (SEC, 1990), is now focussed in the entrance of the fish ladder by means of a diffuser wall. The supplemental flow release is also used to provide spawning habitat in the Eel River below the dam. In addition, a velocity (guidance) barrier has been constructed that limits the movement of fish upstream of the entrance to the ladder. Both the attraction flow and velocity barrier are aimed at enhancing the ability of upstream migrants to find the entrance to the fish ladder. Other changes made in 1987 include widening weir openings between pools to accommodate higher flows and the conversion of the uppermost portion of the ladder to a submerged-orifice design.

15.1.1 Fish Resource Management Objectives of Mitigation. The objective of the Potter Valley project fish ladder is to increase the number of chinook salmon and steelhead trout that have access to spawning habitat upstream of the Cape Horn Dam. Operation of the ladder is one of a number of measures employed at the Potter Valley project to increase the salmonid populations and fishery in the upper main stem Eel River, including larger instream flow releases and greater control of the temperatures of water released from Lake Pillsbury (SEC, 1992). Although specific numerical goals for the fish ladder at Cape Horn Dam are not available, Table 15-1 shows the size of the spawning runs between 1933 and 1991 and gives some indication of the historical sizes of chinook salmon and steelhead runs in the upper Eel River.

15.1.2 Monitoring Methods. A variety of methods have been used since 1985 to evaluate the movements and fish ladder passage rates of chinook salmon and steelhead trout. Gill-netting, boat electrofishing, an Alaskan weir, a hoop trap, and a trap on the fish ladder itself have all been used to capture upstream migrants (SEC, 1990). These fish were subsequently tagged with radio transmitters and/or spaghetti tags. The movements of radio-tagged fish in the Eel River were monitored below the Cape Horn Dam by means of mobile receivers. In addition, access to and use of the fish ladder were monitored by fixed antennae located at the entrance to the pool below the dam, at the entrance to the fish ladder, and at three points in the fish ladder (Figure 15-5).

The numbers, sex, and lengths of adult salmonids that pass through the Cape Horn Dam fish ladder are documented each year. This information provides an index of the annual escapement of chinook salmon and steelhead trout to spawning habitat above the Cape Horn Dam.

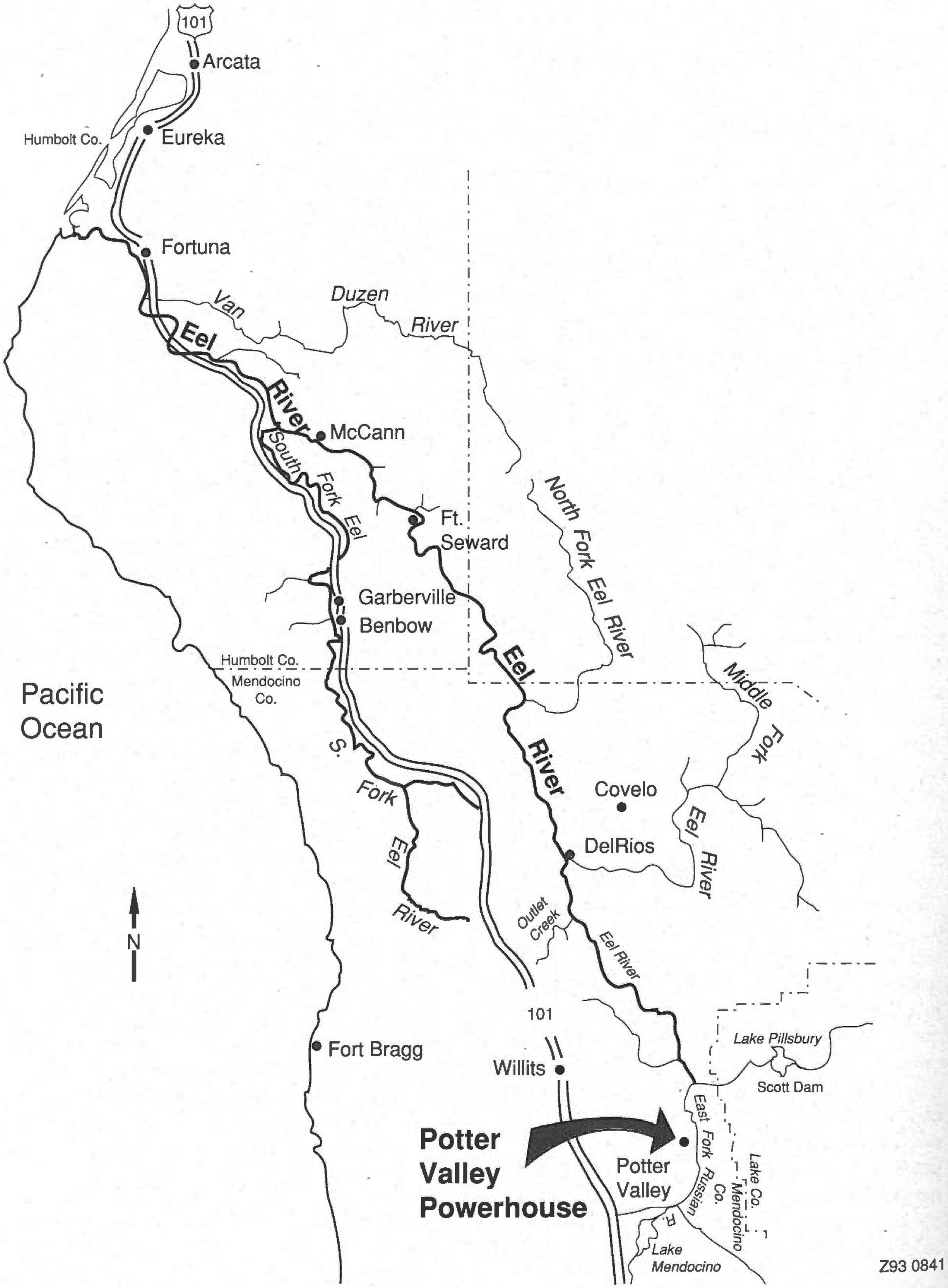

Figure 15-1. Map of the Eel River drainage and the Potter Valley powerhouse. The Potter Valley powerhouse is located at the bottom, on the East Fork of the Russian River. Source: SEC (1990).

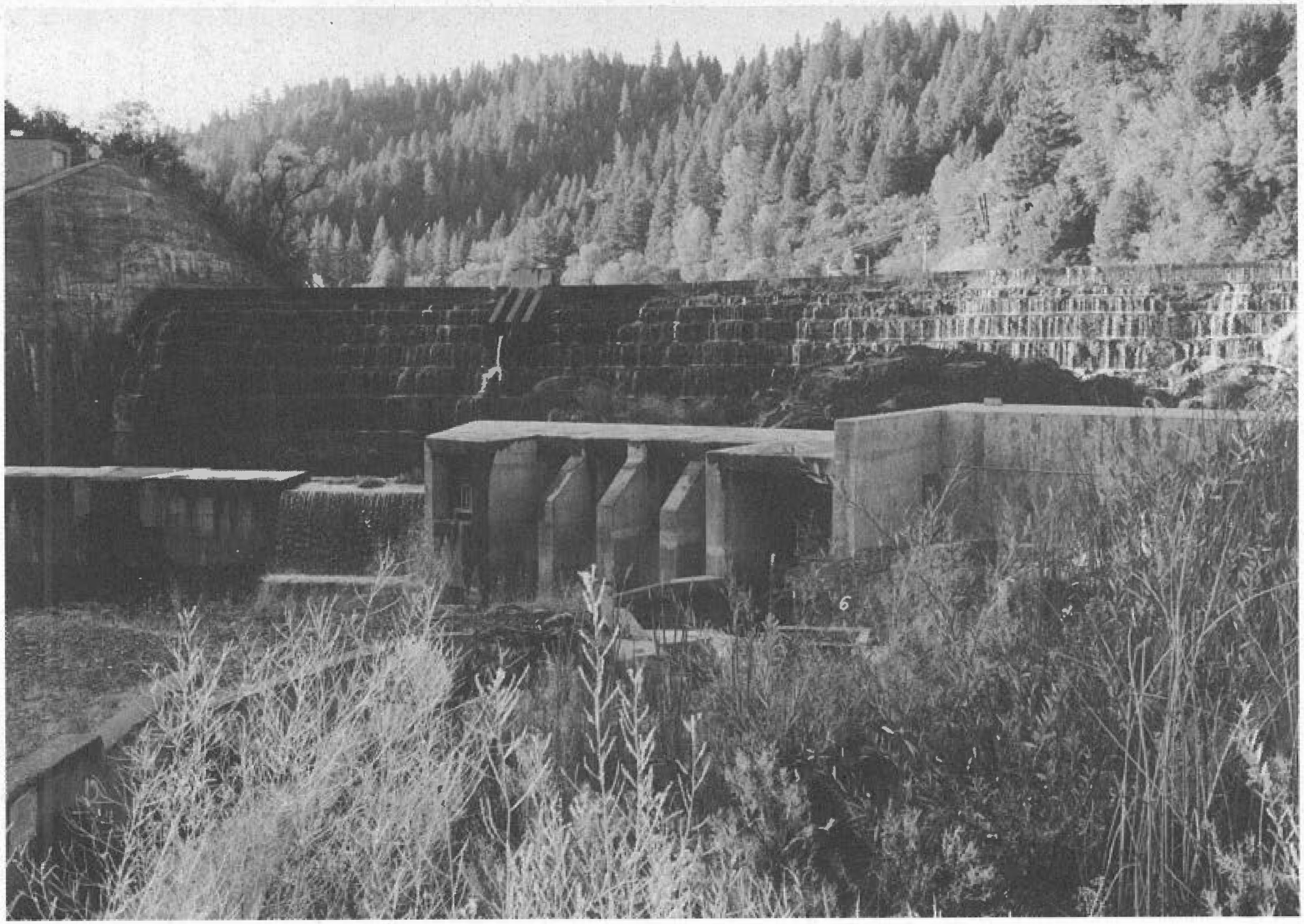

Figure 15-2. Cape Horn Dam at the Potter Valley project.

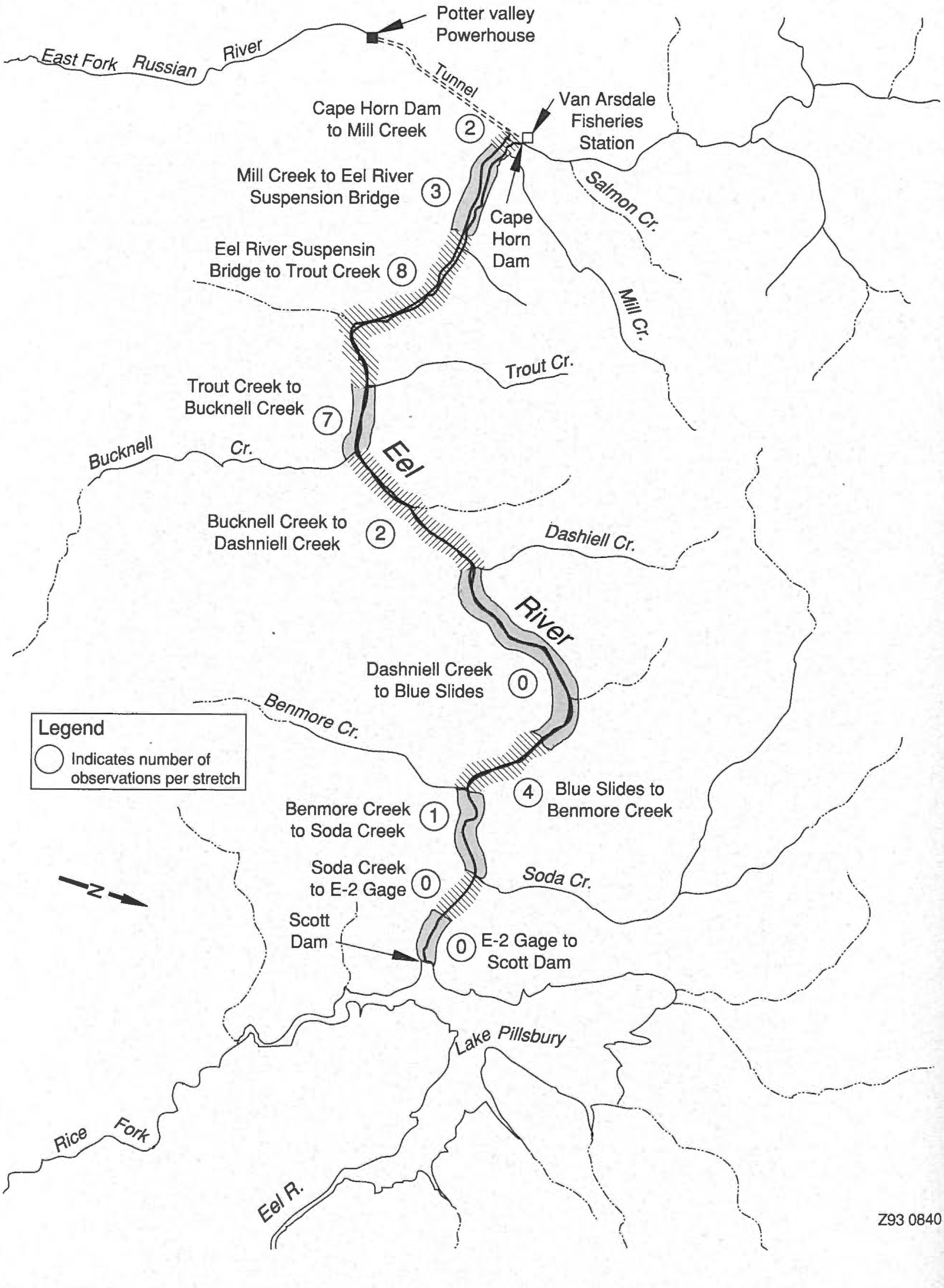

Figure 15-3. Supplemental radio tracking observation for chinook salmon above Cape Horn Dam, 1988–1989 (Potter Valley project). The circles indicate the number of fish observations per river stretch. The Potter Valley project is at the top of the map. Source: SEC (1990)

Figure 15-4. Potter Valley fish ladder.

15.1.3 Performance of Mitigation. Twelve upstream-migrating chinook salmon were collected, radio-tagged, and released below the Cape Horn Dam between December 1 and December 14, 1988 (SEC, 1990). Two salmon moved downstream from the release site, while the other 10 found the entrance to the fish ladder. Of the 10 salmon that entered the fish ladder, one ascended only as far as the fish trap (more than halfway up the ladder), three ascended the entire ladder, and six descended the ladder. Travel time between the entrance to the fish ladder and the fish trap averaged 14.8 hours and ranged from 7.5 to 25.5 hours. The three radio-tagged salmon that ascended the entire fish ladder stayed above Cape Horn Dam for the duration of the 2-month tracking period. One of them traveled as far as the reach between Benmore and Soda Creek, several miles upstream from the Cape Horn Dam (Figure 15-3).

Table 15-1. Numbers of upstream-migrating adult chinook salmon and steelhead trout trapped annually at the Van Arsdale Fisheries Station at the base of Cape Horn Dam from 1933 to 1991. (SEC, 1992). ND = Not determined.

Season	Chinook salmon	Steelhead trout	Season	Chinook salmon	Steelhead trout
1933/34	ND	3,247	1962/63	9	>2,030
1934/35	ND	2,255	1963/64	3	846
1935/36	ND	6,310	1964/65	63	>921
1936/37	ND	6,861	1965/66	93	423
1937/38	ND	3,413	1966/67	119	525
1938/39	ND	4,786	1967/68	0	531
1939/40	ND	3,889	1968/69	0	354
1940/41	ND	2,224	1969/70	15	719
1941/42	ND	ND	1970/71	34	1,863
1942/43	ND	ND	1971/72	0	696
1943/44	ND	ND	1972/73	0	586
1944/45	ND	9,528	1973/74	12	1,040
1945/46	ND	5,054	1974/75	1	1,123
1946/47	917	4,409	1975/76	2	1,078
1947/48	994	178	1976/77	0	39
1948/49	ND	2,433	1977/78	23	590
1949/50	ND	ND	1978/79	5	106
1950/51	55	1,091	1979/80	84	87
1951/52	ND	5,444	1980/81	0	1,966
1952/53	ND	2,197	1988/82	175	646
1953/54	ND	2,590	1982/83	9	369
1954/55	ND	6,131	1983/84	26	1,534
1955/56	5	3,719	1984/85	153	1,980
1956/57	0	4,109	1985/86	955	1,199
1957/58	2	5,151	1986/87	1,754	1,952
1958/59	0	3,335	1987/88	1,080	2,168
1959/60	0	2,206	1988/89	328	331
1960/61	9	1,130	1989/90	6	691
1961/62	0	1,689	1990/91	0	31

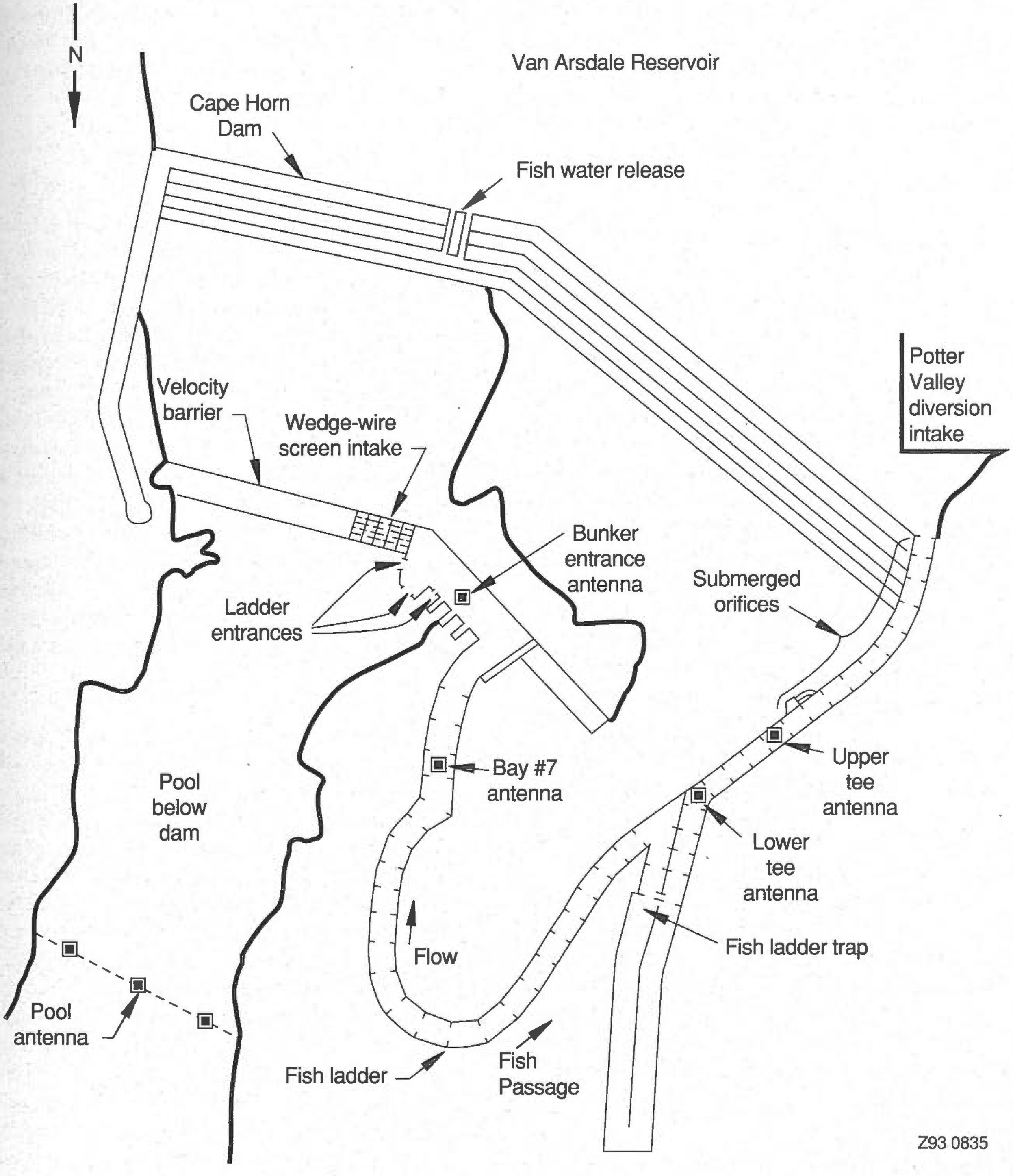

Figure 15-5. Cape Horn Dam and the Potter Valley project fish ladder, showing the location of the fixed antennae for tracking radio-tagged chinook salmon and steelhead trout. Source: SEC (1990).

No chinook salmon were counted at the Van Arsdale Fisheries Station during the 1990/91 season. This was the second year since 1980 that salmon did not use the ladder (Table 15-1), and can be attributed to the very low numbers of salmon in the river below the dam. For example, spawning and carcass surveys observed only four chinook salmon in the main stem Eel River between Outlet Creek and Cape Horn Dam (Figure 15-1), compared to an estimated 4,771 in 1986/87 and 1,354 in 1987/88 (SEC, 1992). Although there are a number of possible causes for the low numbers of chinook salmon in the river, it is believed that low stream flows in the autumn of 1990 may have delayed the run and caused salmon to spawn or be harvested in the lower portions of the Eel River (SEC, 1992).

Five steelhead trout were radio-tagged and released below the dam between January 5 and November 28, 1989. Two steelhead did not move upstream from the capture site, whereas the other three radio-tagged steelhead reached the fish ladder entrance. Two of these three ascended more than halfway up the ladder to the fish trap (Figure 15-5). Times spent within the fish ladder were very different for the two steelhead; transit times from first ladder entry to the ladder trap were 3.0 and 1,239.5 hours, respectively. It is believed that radio-tagged steelhead were very stressed by handling and tagging; this, in combination with the small sample size, preclude drawing conclusions from these data (SEC 1990).

As with salmon, the numbers of steelhead trout counted in the fish ladder in 1990/91 were unusually low compared to historical levels (Table 15-1). Only 31 steelhead were observed in the fish ladder in 1990/91, compared to 1,952 in 1986/87 and 2,168 in 1987/88 (SEC, 1992). All of the 31 steelhead that reached the ladder trap, (more than halfway up the ladder), subsequently ascended the upper ladder as well. However, because no tagging studies were conducted in 1990/91, the numbers of steelhead that reached Cape Horn Dam but failed to enter the fish ladder are not known.

Figure 15-6 indicates the sex of chinook salmon and steelhead trout that successfully passed through the Cape Horn Dam fish ladder between 1979/80 and 1990/91. For both salmonid species there was considerable year-to-year variation in passage efficiency but only small differences between the sexes. Size of upstream-migrating fish appear to have little influence on passage effectiveness; jacks (sexually immature male salmon shorter than 61 cm fork length) and half-pounders (male steelhead shorter than 56 cm fork length) were as capable of ascending the ladder as full-grown adults.

15.2 Mitigation Benefits

15.2.1 Benefits to Fish Populations. A total of 328 chinook salmon reached the ladder trap during the 1988–89 spawning season (SEC, 1990). The radio-tagging study estimated that 40% of the salmon in the pool reached the fish trap and 30% of the salmon in the pool ascended the entire ladder. If 40% of the chinook salmon that reached the pool below the Cape Horn Dam ascended the ladder to the fish trap, then an estimated 823 salmon were available for passage. Of the 328 salmon that reached the ladder trap, 28 (8.5%) were found dead in the ladder, 132 (40%) failed to ascend the upper ladder and returned back down, and 168 (51%) successfully exited to the river above. This represents a successful passage of 20% of the salmon estimated to reach the base of the dam.

At present, there are no screens at the Cape Horn Dam intake to prevent the entrainment of downstream-migrating smolts into the Potter Valley diversion. A multiple fyke-net array (FISH RESCUE array) is installed about 0.5 miles upstream from Van Arsdale Reservoir to collect smolts before they encounter the diversion intake (SEC, 1992). Fish collected by these fyke nets are released approximately 1 mile below the Cape Horn dam to continue their downstream movement. A fyke net trap in the Potter Valley Powerhouse tailrace is used to monitor the numbers of smolts entrained in the diversion, and in 1991 a single fyke was installed in the Cape Horn Dam fish ladder to detect fish that move downstream through the ladder. During the 1989/90 season, 27,876 chinook salmon smolts were collected in the FISH RESCUE array above the reservoir and 736 smolts were collected in the Potter Valley powerhouse tailrace net (SEC, 1990). A total of 3,607 and 25 juvenile steelhead were collected in the FISH RESCUE and Potter Valley powerhouse fykes, respectively. The numbers of downstream migrants were considerably lower in the 1990 and

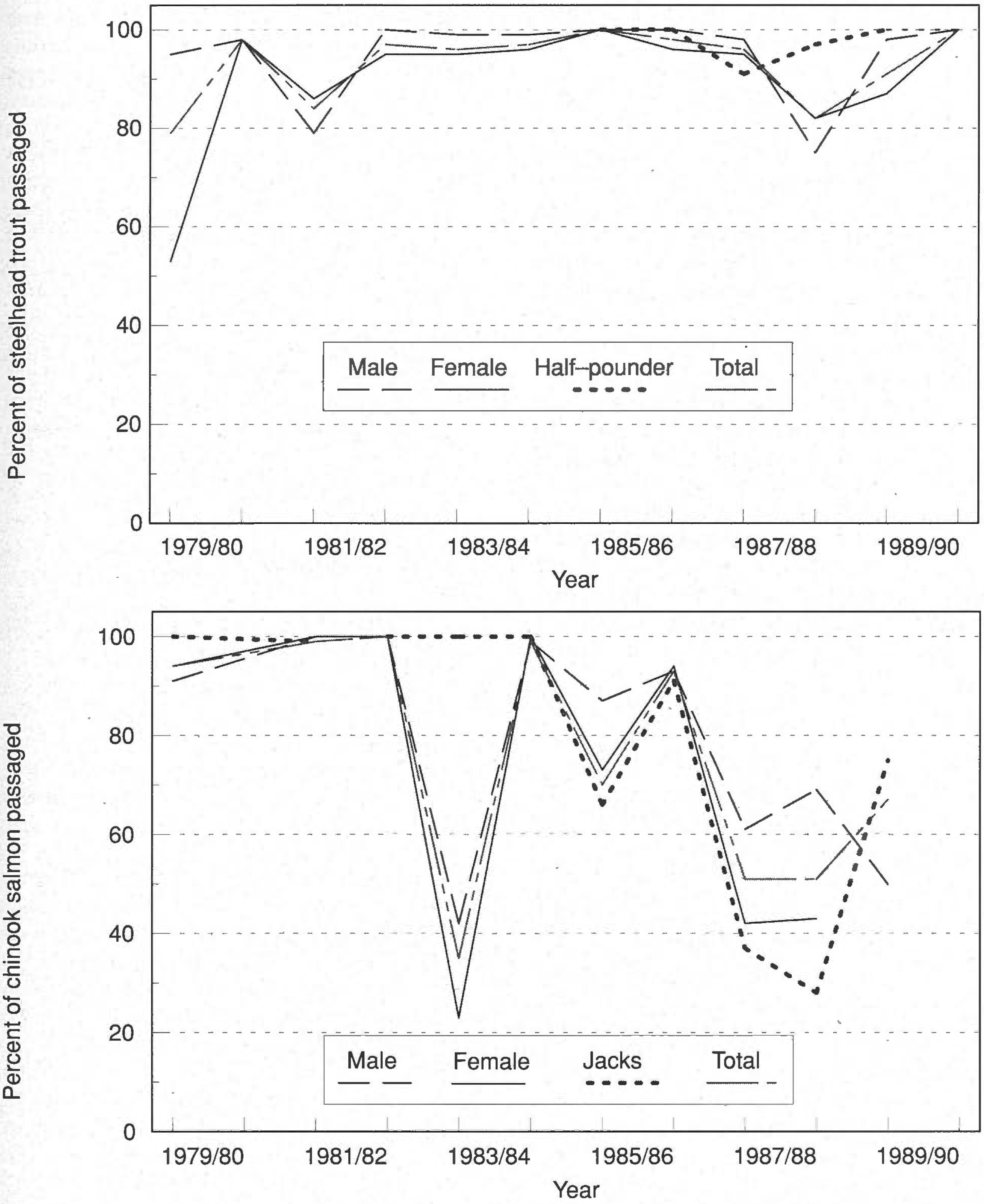

Figure 15-6. Percent of chinook salmon (bottom graph) and steelhead trout (top graph) passed at the Potter Valley fish ladder from 1979 through 1990. Source: SEC (1992).

1991 season. No chinook salmon smolts were collected in the FISH RESCUE, Potter Valley powerhouse, or fish ladder fyke nets. Steelhead smolts were collected in all three traps; 405, 266, and 97 steelhead were collected in the FISH RESCUE, Potter Valley powerhouse, and fish ladder traps, respectively (SEC, 1992). Mortality among entrained fish subsequently captured in the Potter Valley powerhouse traps was not reported. These fish are discharged to the East Fork of the Russian River and are thus removed from the Eel River populations.

No population-level data are available to indicate whether the modifications to the Cape Horn Dam fish ladder have increased the number of adult salmonids returning to the Eel River. The very small spawning runs in recent years have prevented an overall assessment of benefits of this mitigative measure. In fact, the 1990 and 1991 runs of salmon and steelhead have been so small that planned studies of the fish ladder could not be carried out (SEC, 1992). Specific numerical goals for the enhancement of salmon and steelhead are not available, but a reasonable target might be to restore the size of the spawning runs to historical levels, i.e., salmon and steelhead escapement in excess of 1,000 at the Cape Horn Dam (Table 15-1). These numbers have been observed as recently as the 1986/87 season, but low stream flows and other stresses on anadromous fish have resulted in severe declines since then. Factors other than the potential delay at Cape Horn Dam are thought to have limited recent runs of anadromous fish. These factors include the loss of smolts to predation by the recently established Sacramento squawfish, poor ocean conditions, and recent drought conditions in California. Evaluation of the population-level effects of the mitigative measures at the Potter Valley project will have to take into account these other stresses that complicate the restoration of anadromous salmonids in the Eel River.

15.3 Mitigation Costs

The Potter Valley project mitigation costs were not obtainable.

16. T. W. SULLIVAN CASE STUDY

16.1 Description

The T. W. Sullivan Plant (FERC number 02233) is a run-of-river diversion project on the Willamette River (Figure 16-1) Multnomah County, Oregon. The project has 13 turbines and a total installed capacity of 16.6 megawatts and began operation in 1952.

Portland General Electric has been developing a downstream migrant bypass system at T. W. Sullivan since 1971 in an effort to reduce the turbine-passage mortality of salmon and steelhead (Clark and Cramer, 1993). A fish diversion screen was retrofitted inside of the Unit 13 penstock in October 1980 (Stone and Webster, 1991). The fish that enter Unit 13 penstock encounter the smooth-surfaced, wedge-wire material fine-mesh screen, which inclines upward and diverts the fish to a bypass (Figures 16-2 and 16-3). The screen has two components: a pivotable screen across the penstock and, downstream from that, a fixed screen above the turbine and surrounding the generator shaft, which prevents entrained fish from passing through the turbine. The pivoting screen was designed by George Eicher and is commonly referred to as the "Eicher Screen."

The Eicher screen installed inside the Unit 13 11-foot-diameter penstock is 21 feet long, and is inclined at an angled of 19 degrees to the flow (Stone and Webster, 1991). The fine-mesh screen material has 0.08-inch (2-mm) diameter bars and 0.08-inch (2-mm) openings between the bars. Average water velocity through the penstock is approximately 5 fps, which is maintained to the fish bypass. The front portion of the Eicher screen is pivoted down for cleaning and accumulated debris is flushed off the screen face and passes through the turbine. The screen is then rotated back up into the normal position to divert fish.

The T. W. Sullivan bypass system has two major components: guidance and bypass (Clark and Cramer, 1993). Because only the Unit 13 penstock has an Eicher screen, downstream-migrating fish must be guided away from the intakes for the other 12 units and toward the Unit 13 intake. This is done by means of a training wall and trashracks that act as a louver system to guide fish through the forebay to Unit 13. Once entrained in Unit 13 intake flows, fish are diverted by the Eicher screen to the bypass conduit, from which they can be either captured in an evaluator for examination or passed directly to the tailrace.

Since the initial installation and testing in 1981 and 1982, several changes have been made to the T. W. Sullivan bypass system (Clark and Cramer, 1993). Two alterations were made to the guidance component of the system. First, a set of leaf gates

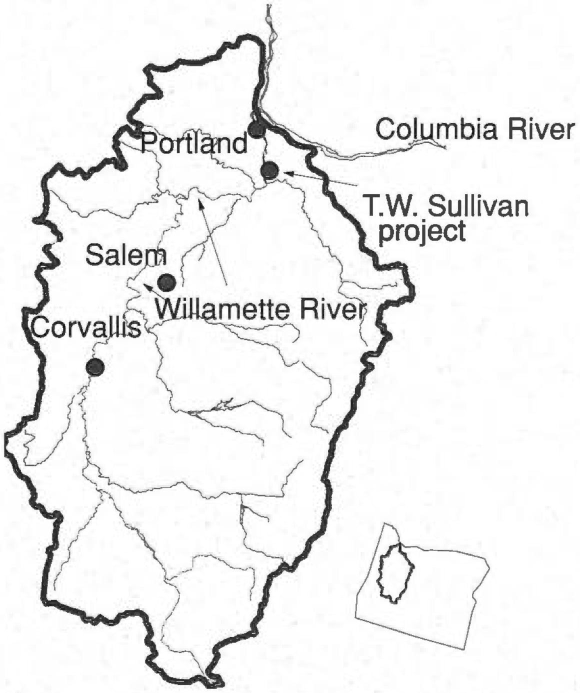

Figure 16-1. Location of the T. W. Sullivan project on the Willamette River.

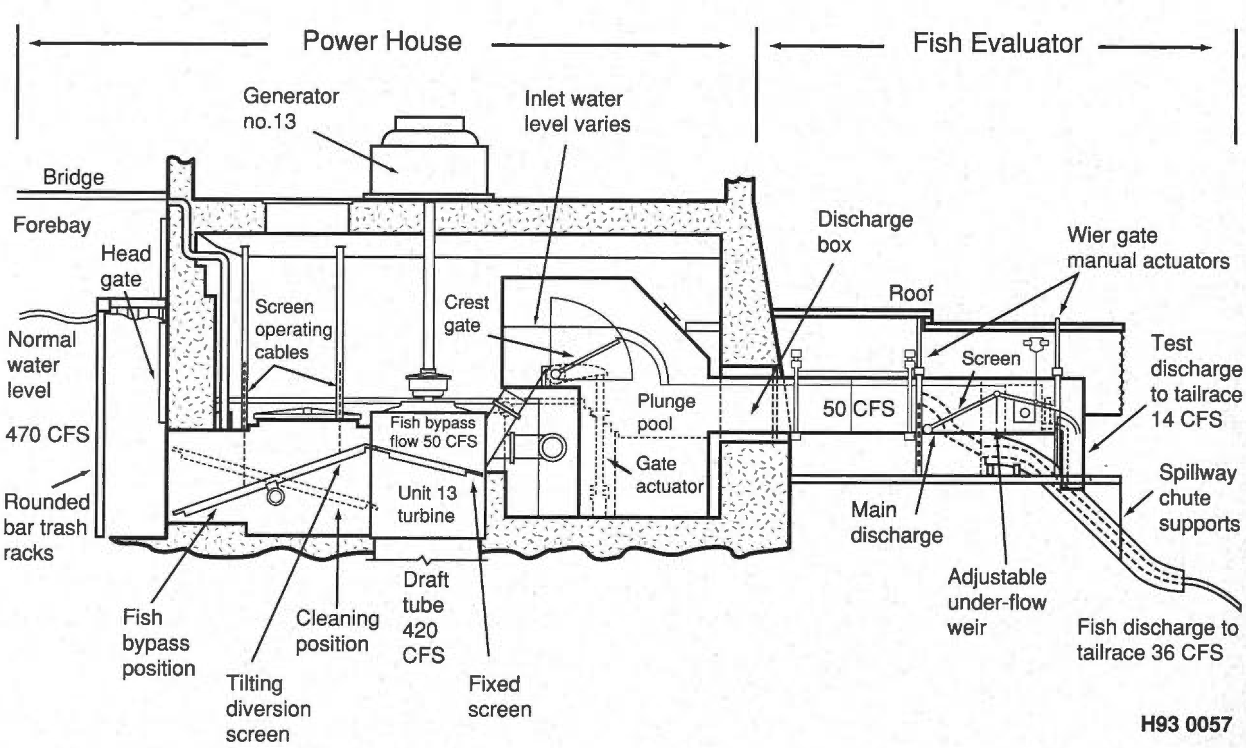

Figure 16-2. Side view of the T. W. Sullivan Unit 13, turbine, generator, tilting Eicher screen, fish bypass, and fish evaluator.

that separated Unit 13 from the other units (and were believed to cause adverse flow conditions for fish diversion) were removed. Second, trashracks in front of Unit 13 were realigned to the vertical position, and the individual bars were changed from flat bars on 2-inch centers to cylindrical bars on 5-inch centers to encourage fish movement into the Unit 13 penstock and to reduce the injury to fish passing through the trashrack. In the bypass portion of the system, modifications were made to create more uniform flows and to reduce roughness in the penstock and bypass system.

16.1.1 Fish Resource Management Objectives of Mitigation. The overall goal of the resource agencies is to decrease the number of downstream migrants adversely affected by turbine entrainment at the T. W. Sullivan project. This could be accomplished by diverting the fish over Willamette Falls instead of through the T. W. Sullivan Plant (e.g., by shutting down the plant during the outmigration period), by reducing mortality of fish that pass through the 13 turbines in the powerhouse, or by using the penstock screen in Unit 13 to safely bypass downstream-migrating fish. Cramer (1993) estimates that 10% to 15% of the fish that pass through the turbines are killed; in order to demonstrate a benefit of the mitigative measure, mortality through the penstock screen bypass system should be lower than this turbine-passage mortality.

Because the turbine-passage mortality rate was considered too high, the T. W. Sullivan Plant has had to shut down for 6 to 8 weeks each year to allow the peak migration of salmon and steelhead to pass over Willamette Falls. If the bypass system reduces turbine-passage mortality sufficiently, the plant could remain in operation during these fish runs. Under a 1980 agreement with the Oregon Department of Fish and Wildlife, Portland General Electric (project owner) will attempt to achieve a 3% or lower mortality among salmon and steelhead smolts at the T. W. Sullivan Plant (Cramer, personal communication).

16.1.2 Monitoring Methods. Initial evaluation studies in 1981 and 1982 indicate that the Eicher screen had a high diversion efficiency; recovery of spring chinook, fall chinook, coho salmon, and steelhead trout smolts after passage through the facility ranged from 94.9% to 99.6%

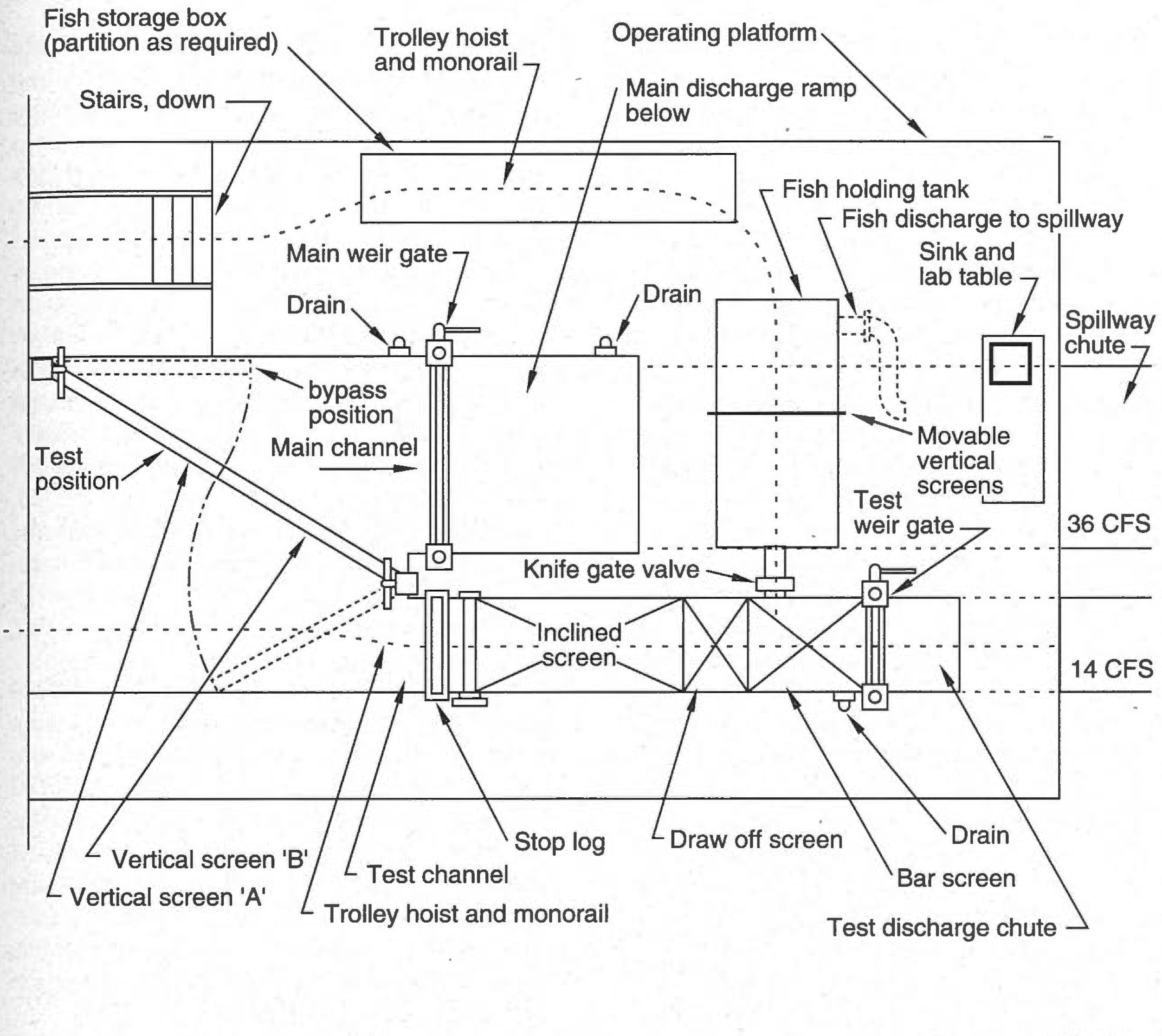

Figure 16-3. Top view of the T. W. Sullivan fish evaluator.

(Stone and Webster, 1991). These early tests indicated that fish entering the Unit 13 penstock could be prevented from passing through the turbine by the Eicher screen. However, the studies were unable to accurately assess either fish injury (e.g., descaling) caused by the Eicher screen and collection facilities or the overall effectiveness of the bypass system in guiding downstream migrants to the Unit 13 intake. No testing was conducted between 1983 and 1991; rather, the T. W. Sullivan Plant was shut down for 6 to 8 weeks each year during the peak of downstream migration to reduce turbine passage mortality (Clark and Cramer, 1993).

Modifications of the bypass system were completed in 1991, in time for initial tests using hatchery releases of spring chinook salmon (Clark and Cramer, 1993). Fin-marked fish began appearing in the evaluator, located downstream of the bypass screen, on November 18, 1991, but high river flows 3 days later flushed most of the fish from the river and put a premature end to the testing. Tests were resumed in March 1992 using hatchery spring chinook salmon and steelhead trout smolts. These tests were hampered by unusually low flows (which resulted in excessive numbers of fish in the evaluator) and by other testing problems.

To increase the efficiency of processing bypassed fish, a Passive Integrated Transponder (PIT) tag system was installed at the end of October 1992. This system has several advantages over the fin-mark technique used earlier: (a) fish do not have to be anesthetized and handled for identification; (b) larger numbers of fish can processed; (c) multiple tests can be run at one time; (d) extended fish passage time does not affect the tests; and (e) errors associated with fish marking, mark identification, and data transcription are reduced. PIT-tagged, hatchery spring chinook salmon were released upstream of the T. W. Sullivan Plant beginning on November 9, 1992 and began appearing in the evaluator on November 16. A single guidance efficiency test was run before high river flows on November 23 again flushed most of the fish from the river.

16.1.3 Performance of Mitigation. Numerous species of fish swim through the T. W. Sullivan bypass system to get downstream, including steelhead trout, chinook and coho salmon, resident trout, bass, carp, bluegill, and sturgeon. As many as 3 million fish may use the bypass annually, including large numbers of downstream-migrating hatchery smolts. Clark and Cramer (1993) have estimated that the bypass system handles as many as 90,000 chinook salmon smolts per day during the peak period of outmigration. Because of resource agency concerns about chinook and coho salmon and steelhead populations, all tests of the T. W. Sullivan Plant bypass system to date have focused on these species.

Two guidance efficiency tests of the T. W. Sullivan fish bypass system have been completed (Table 16-1). In both tests, marked hatchery spring chinook salmon were released into the forebay and recovered in the evaluator following diversion by the Eicher penstock screen in Unit 13. Recoveries of fin-marked and PIT-tagged chinook salmon smolts averaged 81.9% and 93.8%, respectively. Release location had no statistically significant effect on the percent of fish diverted by the penstock screen in Unit 13 (Clark and Cramer, 1993). Lengths of fin-marked salmon ranged from 135 to 210 mm (mean = 178 mm); lengths of PIT-tagged smolts ranged from 154 to 238 mm (mean = 195 mm). There was no difference in the average size of fish released and the average size of fish recaptured. Because of debris loads during the 1992 tests, the screen was cleaned (i.e., pivoted out of the diversion position) 11 times between November 19 and November 23.

Other guidance efficiency tests in 1992 did not yield useful information. A single test beginning April 27, 1992, with steelhead trout smolts was aborted because large numbers of nontest, fall chinook outmigrants made it impossible to examine all fish passing through the system. A test on June 4, 1992, using fall chinook smolts was also unsuccessful; in this case, high water temperatures (70° F) and poor fish condition caused a high prerelease mortality (38%) and diversion efficiencies ranging from 43.7% to 56.9%.

Clark and Cramer (1993) examined descaling and injury rates among fish diverted by the Eicher penstock screen. A total of 278,594 hatchery spring chinook salmon were examined, of which an average of 3.3% were descaled or injured

Table 16-1. Bypass system guidance efficiency tests for hatchery spring chinook salmon released into the forebay of the T. W. Sullivan Plant. Fin-marked fish were released in November 1991, and PIT-tagged fish were released in November 1992. Source: Clark and Cramer (1993).

	Fin mark		PIT tag	
Release location	Number released	Percent recaptured	Number released	Percent recaptured
Left bank	210	76.7	207	91.7
Middle bank	210	87.1	205	95.1
Right bank	210	81.4	204	94.6

(Table 16-2). Depending on the month, average descaling/injury rates ranged from 1.6% to 4.8% of the fish diverted by the bypass system. Other species of salmonids had similar descaling and injury rates; all averaged 3.9% or less. Because no controls were used for these tests, there are no estimates available of either preexisting descaling and injuries (which might have occurred in the hatchery or Willamette River before encountering the T. W. Sullivan bypass) or descaling and injuries caused by handling within the evaluation facility. Therefore, the rates reported in Table 16-2 may overestimate the injuries caused by the T. W. Sullivan bypass system.

A limited series of tests were conducted to estimate delayed mortality among spring chinook salmon and steelhead trout that had been diverted by the penstock screen. Groups of fish were held in tanks for 96 hours; groups were classified as either injured, descaled, or OK (uninjured). There was no delayed mortality among uninjured fish (Table 16-3). Delayed mortality among groups of descaled chinook salmon ranged from 2.0% to 27.5% (mean = 8.5%). Only a small number of injured fish were obtained, but the delayed mortality in this single group was a relatively high 23.1% (Clark and Cramer, 1993). Apparently all fish in these tests had gone through the bypass system and been subjected to handling and holding stresses, including those designated as "OK." Because some mortality in these tests groups may have been the result of postdiversion handling and holding stresses, these delayed

Table 16-2. Summary of descaling and injury rates among salmonid smolts recovered in the T. W. Sullivan Plant fish bypass system during 1991 and 1992. Source: Clark and Cramer (1993).

Species	Number examined	Average percent descaled or injured	Mean monthly percent descaled or injured
Hatchery spring chinook salmon	278,594	3.3	1.6–4.8
Wild spring chinook	9,368	3.9	0.5–9.3
Fall chinook salmon	2,144	3.2	3.2
Hatchery steelhead	4,001	2.1	2.1
Wild steelhead	610	1.2	1.2
Coho salmon	71	1.4	1.4

Table 16-3. Delayed (96-hour) mortality among salmonid smolts recovered in the T. W. Sullivan Plant bypass system in 1992. Test groups contained approximately 50 fish. Source: Clark and Cramer (1993).

Species	Condition	Number of test groups	Total number of fish	Total number dead	Total mortality (%)	Mortality range among groups (%)
Hatchery steelhead	Uninjured	1	52	0	0.0	—
Hatchery steelhead	Descaled	1	49	1	2.0	—
Hatchery spring chinook	Uninjured	2	100	0	0.0	0.0
Hatchery spring chinook	Descaled	7	351	30	8.5	2.0–27.5
Hatchery spring chinook	Injured	1	39	9	23.1	—

mortality estimates may overestimate the effects of the bypass system alone.

16.2 Mitigation Benefits

16.2.1 Benefits to Fish Populations. Average descaling rates at the T. W. Sullivan Plant have been slightly higher than the target of 3%, but delayed mortality, even among descaled fish, was lower than that estimated for turbine-passed fish. The information on descaling and delayed mortality rates can be combined to estimate mortality associated with the bypass system. For example, if 3.3% (or 0.033) of hatchery spring chinook salmon diverted by the penstock screen are descaled (Table 16-2), and 8.5% (or 0.085) of descaled fish suffer mortality within 96 hours (Table 16-3), then 0.3% (0.033 multiplied by 0.085) of this species would suffer delayed mortality from the bypass system. Similarly, if 2.1% of hatchery steelhead trout are descaled or injured in the bypass, and 2.0% of these subsequently die, then an estimated 0.04% of the steelhead diverted by the screen would suffer delayed mortality.

These mortality rates associated with the penstock screen and bypass facility are considerably smaller than the 10% to 15% mortality estimated for turbine-passed fish. Comparisons of the numbers of hatchery spring chinook salmon and steelhead trout that could be killed by turbine passage and the bypass system, based on fish passage at Willamette Falls in 1992, are shown in Table 16-4. For example, assuming that all 2.2 million spring chinook salmon smolts were entrained in the 13 units of the T. W. Sullivan Plant and experienced an average mortality of 10%, an estimated 223,735 spring chinook would have been killed by turbine passage in 1992. This can be compared to an estimated mortality of 6,712 bypassed chinook smolts at a mortality rate of 0.3%. These rough comparisons of mortality associated with turbine passage and the bypass system designed to mitigate that impact do not take into account the fact that not all downstream migrating fish will pass through the turbines (some may pass over Willamette Falls), and even under full operation of the bypass system some fish will still be entrained in the other 12 turbine units (Table 16-4). A strict accounting of mortality associated with each of the three routes for downstream migrants (i.e., turbine passage, penstock screen/bypass system, and Willamette Falls) must take into account the possibility of mortality associated with passage over the waterfall as well.

No specific information is available about the benefits of the T. W. Sullivan project bypass system to resident and anadromous fish populations. That is, although individual effects have been examined, the impacts of injury, descaling, and delayed mortality have not been studied at the population level. The effects of losing 6,712 or 223,735 downstream-migrating smolts on the number of fish available to the ocean fishery or the numbers of spring chinook adults that return to the Willamette River several years in the future have not been examined.

16.2.2 Benefits to Fisheries. No information about the effects of this mitigative measure on the salmon and steelhead fisheries is available.

16.3 Mitigation Costs

16.3.1 Introduction. The mitigation cost analysis for the T. W. Sullivan hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; an upstream fish passage/protection system section, providing some noncost upstream mitigation information; a downstream fish passage/protection system section, discussing the downstream mitigation costs; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal written correspondence and from telephone calls. Two site visits greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

Table 16-4. Estimates of the numbers of hatchery spring chinook salmon and steelhead trout that could be killed by turbine passage and the bypass system at the T. W. Sullivan Plant, based on numbers of downstream-migrating smolts in 1992.

Species	Total number at Willamette Falls[a]	Turbine passage mortality (%)[b]	Number of fish killed by turbine passage	Bypass system mortality (%)[c]	Number of fish killed by bypass system
Hatchery spring chinook salmon	2,237,350	10	223,735	0.30	6,712
Hatchery steelhead trout	383,673	10	38,367	0.04	153

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a. Data are from Clark and Cramer (1993).

b. Based on an estimated survival of 85% to 90% of turbine-passed fish at the T. W. Sullivan project (Cramer, personal communication).

c. Based on estimates for descaling, injury, and delayed mortality rates in Clark and Cramer (1993).

16.3.2 Cost Summary. The 20-year levelized annual cost analysis suggests that the total downstream mitigation costs at the T. W. Sullivan project average about 6 mills per kilowatt-hour of generated electricity (Table 16-5). A significant portion (73%) of the total costs is from the lost generation resulting from the 10 years (1981–1990) of required eight-week plant shutdowns. Because of the passage/protection success exhibited by the screen system, it appears that the annual 8 weeks of plant shutdowns will not be a requirement in the future. For this reason, it may be argued that excluding this lost generation results in an estimated future levelized annual cost in the 2 mills per kilowatt-hour range. The inverse of this argument is that during the 10 years of annual shutdowns, the cost of mitigation per kilowatt-hour is about 8.3 mills, or almost 1 cent per generated kilowatt-hour. In spite of these fluctuations, the use of 5.8 mills as a cost of mitigation at this plant is a fair estimate of not just past mitigation costs but also of future mitigation costs. Other events and costs of an unseen nature may change requirements and influence future costs. For instance, as equipment ages the operations and maintenance costs often increase, or perhaps the screens may prove to require periodic replacement. The first reported costs associated with environmental mitigation were incurred in 1975. These capital costs (~$1,440,000) are a significant percentage (37%) of the total capital costs. The costs of lost generation have driven the magnitude of annual mitigation costs at the T. W. Sullivan plant (Figures 16-4 and 16-5).

16.3.3 Upstream Fish Passage/Protection. The T. W. Sullivan project does not have any upstream mitigation requirements; however, there is a fish ladder located at the nearby Willamette Falls (Figure 16-6). This ladder is run by the Oregon Department of Fish and Wildlife. The T. W. Sullivan plant's construction did not require a dam or diversion; instead, the plant was constructed to the side of the Falls, taking advantage of the existing hydraulic head at the Falls.

The licensee did share in the capital cost of the Willamette Falls fish ladder, constructed in 1971. The total ladder cost is not known. This information is included only as a note as the ladder is not part of the T. W. Sullivan project. The ladder was built to ensure safe passage upstream past the falls, not past the project. It is not known if sharing of the capital cost was associated with the ownership

Table 16-5. Twenty-year costs incurred for downstream mitigation at T. W. Sullivan.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital costs	3,491,500	174,575	1.4
Annual costs	10,762,000	538,100	4.4
Total costs	14,253,500	712,675	5.8

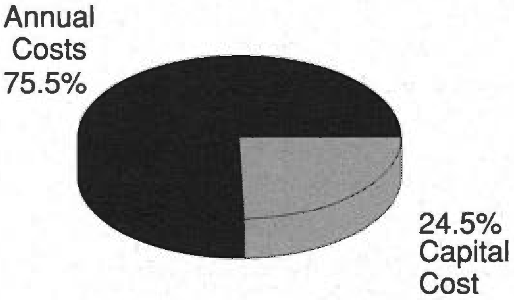


Figure 16-4. Capital and annual downstream mitigation costs at the T. W. Sullivan project. Annual costs include operations and maintenance, monitoring, and lost generation costs.

of the T. W. Sullivan project or in conjunction with other licensee-owned projects along this river. The licensee's share was $1,400,00 (1993 dollars). The original arrangement specifics beyond the sharing of the capital costs is unknown.

The fish ladder is of a unique design. It is contained within a concrete walkway that wraps around the exterior of an antiquated paper mill building (Figure 16-7). The only hint the casual observer would have that there is a fish ladder situated within the concrete walkway would be if the viewer looked through the steel grates on the walkway surface and viewed the water flowing immediately below his or her feet.

16.3.4 Downstream Fish Passage/ Protection.

16.3.4.1 Capital Costs. The 1975 capital costs totaled $1,452,000. This includes the realignment of the original trash rack from an "L" shape to the current configuration, with wider bar spacing in front of Unit 13. The training wall was installed in conjunction with the trash rack realignment to increase velocities for attracting juveniles to Unit 13. The Unit 13 penstock was modified to bypass fish via 50 cfs flows, avoiding the turbine and returning the juveniles into the tailrace. This modification did not include installation of any type of fish screen. The flow through Unit 13 included 420 cfs through the turbine and 50 cfs through the bypass. It was hoped that this 11% (50 cfs) of the total Unit 13 flow would successfully pass a corresponding percent (11%) of juvenile migrants.

The goal of the 1975 effort was to prove the concept of successfully enticing the migrating juveniles to pass through Unit 13. It was thought that if the attraction proved successful, a possible next step would be the removal of the Unit 13 turbine and the smolts would pass thought the empty turbine housing. The biological results of this experiment suggested that attraction to Unit 13 was working as anticipated. At this point it was decided to install the tilting screen in Unit 13 instead of removing the turbine.

The 1980 capital cost of $408,000 was for the installation of the tilting screen and the required penstock modifications to install the screen and bypass into the tailrace. The trash racks in front of Unit 13 were replaced in 1981 with rounded bars to minimize descaling. Because of the uncertainty of passage rates the plant shut down for 8 weeks every year during out-migration. The current fish evaluator and associated bypass system was installed in 1991, at a cost of $1,638,000, to determine the bypass system mortality rates.

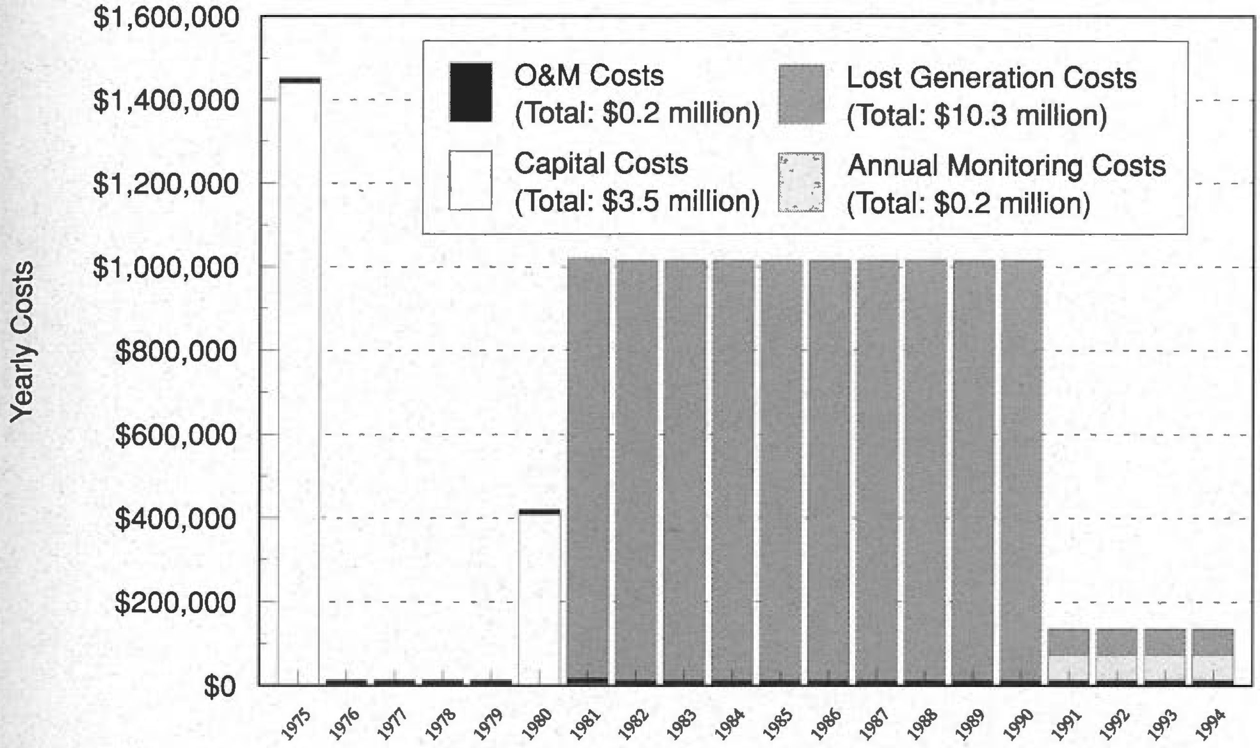


Figure 16-5. Yearly costs of downstream mitigation incurred at the T. W. Sullivan hydroelectric plant.

The total capital costs at T. W. Sullivan from 1975 through 1994 are estimated to be $3,492,000. This equates to a 20-year levelized annual cost of $175,000. The plant has an average annual energy production (1990 and 1991) of 122,832 megawatt-hours, which equates to an average cost per kilowatt-hour for the capital costs of 1.4 mills.

16.3.4.2 Annual Costs. Total operations and maintenance costs have been estimated at $240,000 since mitigation inception through 1994. The current fish evaluator staff cost of $60,000 per year is assumed to have started the same year the evaluator was placed in operation. The largest single total 20-year cost of $10,030,000 is for generation losses from plant shutdowns required before the current evaluator was used to document the passage rates. The evaluator bypass flows, another source of lost generation, have totaled $252,000 over 20 years. The total downstream mitigation annual costs for the period 1975 through 1994 is $3,492,000. Using the 20-year levelized annual cost suggests an annual average cost of $538,100. Using the aforementioned annual generation of 122,832 megawatt-hours of energy results in a cost per kilowatt-hour for annual costs of 4.4 mils.

16.4 Cost Descriptions and Assumptions

This section explains the individual cost items and the assumptions and estimates required to quantify the respective items and derive totals. The item numbers correspond to the 20-year spreadsheet (Table 16-6) used to determine cost dimensions. All costs have been converted to 1993 dollars and are discussed as such.

16.4.1 Capital Costs.

1. **Trash Rack Remodel/Rebuild.** The trash rack was redesigned to direct the smolts toward Unit 13. The Unit 13 trash rack is 25 feet high and extends 6 feet in

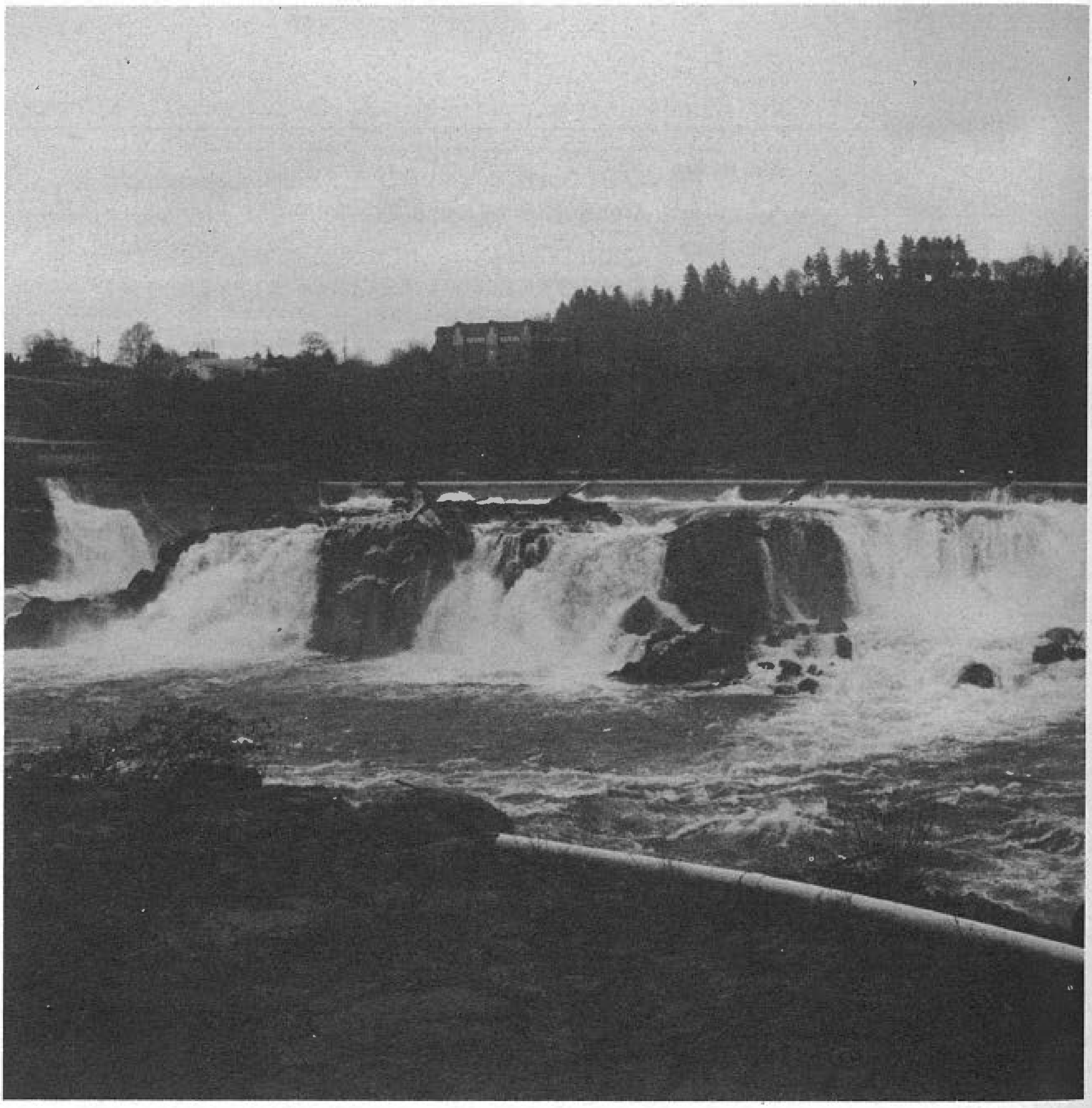


Figure 16-6. Willamette Falls adjacent to the T. W. Sullivan project.

front of the headgate. The trash rack uses 2.5-inch diameter pipe bars because their rounded contour minimizes smolt mortality from the potentially sharp edges of conventional trash racks. Units 1 through 12 have trash racks fabricated in a conventional flat bar design, using flat bars approximately 2.5-inch wide, spaced approximately 1 inch apart. Entrance to Unit 13 can only be gained past the pipe bars in front of the unit or at the end of the trash rack. The side toward Unit 12 is blocked. The total cost for the trash rack remodel/rebuild is $599,429. Most of this cost was incurred in 1975 when the rack was installed across all 13 units with the current spacing and bars. The cost incurred in 1981 was for the removal of the flat bars in front of unit 13 and replacement with the rounded contour pipe bars.

In addition to the turbine inlet trash racks, another set of trash racks are located perpendicular to the flow at the head of the forebay. This second set of racks is intended only to catch debris. The cost of the second set of racks is not included here as a mitigation cost as they are not part of the mitigation system.

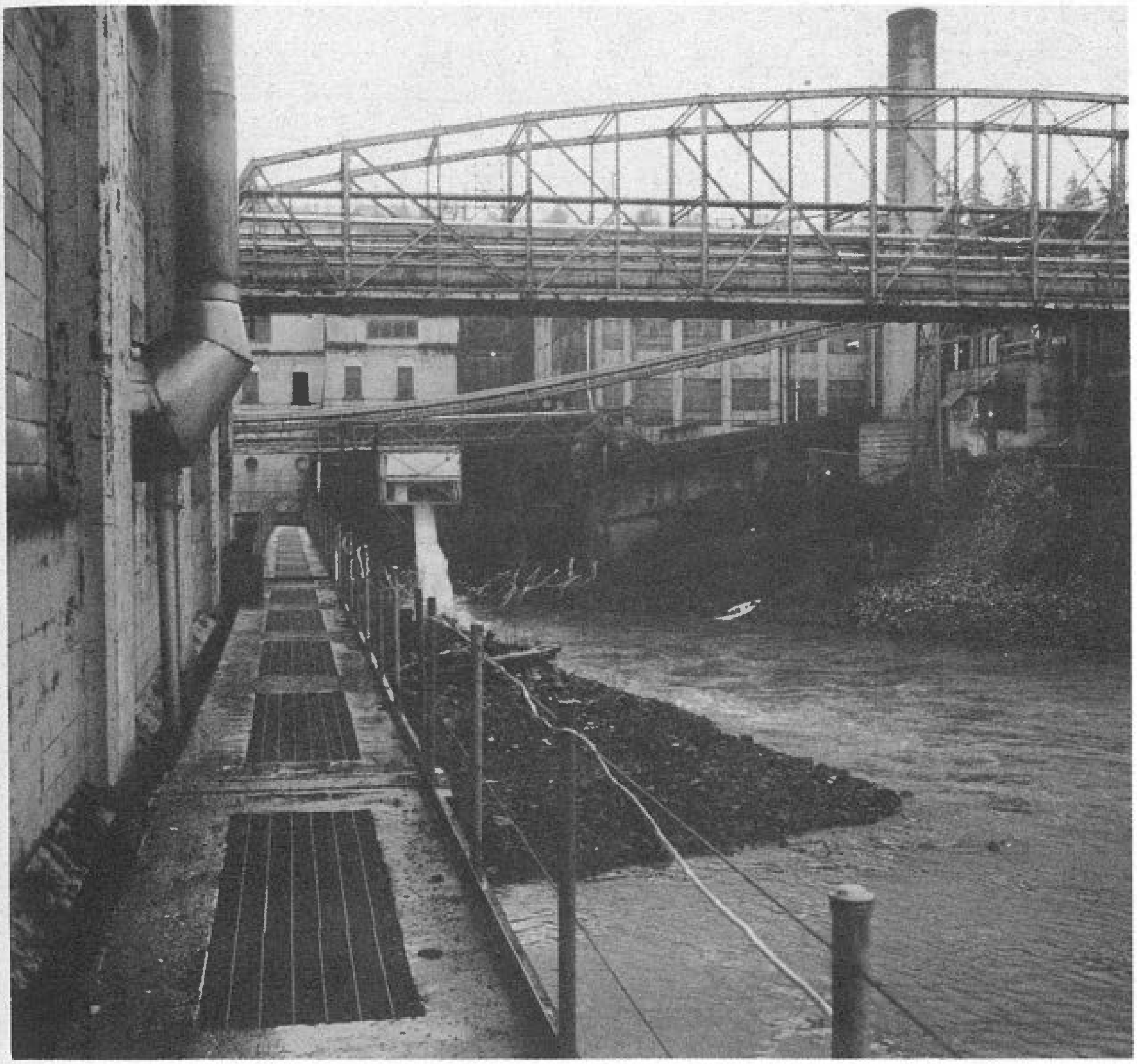


Figure 16-7. Willamette Falls fish ladder under concrete and steel grate walkway. Fish and water are visible through the steel grates.

2. **Tilting Screen.** The tiling screen, also known as an Eicher screen, was installed during 1980 at a cost of $170,007. The tilting screen system consists of a fixed screen about 12 feet in length and a titling diversion screen about 21 feet in length. Both screens are about 11 feet wide. The surface material is a two-millimeter slot stainless steel. When in bypass mode, the tilting screen's downstream end (by the turbine) tilts up into place flush with the fixed screen at an angle 19 degrees above horizontal (Figure 16-2). An average flow of 420 cfs passes through the screens into the Unit 13 turbine. Flows of 50 cfs are used to pass downstream migrants through the fish bypass, into the plunge pool. The downstream migrants are then directed either into the evaluator or the tailrace via the discharge spillway. The screens are backwashed approximately 100 times per year by tilting the screen's downstream end down, so that the upstream end of the tilting screen is tilted 14 degrees above horizontal.

Figure 16-8. Training wall used to guide migrants to T. W. Sullivan Unit 13. The Unit 13 intake is under the bridge. The intakes for Units 1 through 12 are to the right of the bridge, through the bar racks.

3. **Penstock Modification.** The Unit 13 penstock required modification to enable the installation of the tilting screen. The modification occurred in conjunction with the installation of the tilting screen. The modification cost was $238,406.

4. **Training Wall Installation** ($631,612). The training wall was designed and constructed for the specific purpose of guiding the migratory smolts toward Unit 13. The angled design (Figure 16-8) causes a velocity increase that attracts juveniles to the Unit 13 bypass.

5. **Fish Bypass.** Installation of a fish bypass pipe cost $214,021. This bypass was connected to the evaluation pool behind Unit 13, and was used to pass the smolts from the screen area to the Unit 13 tailrace. It was originally used in conjunction with the original evaluator and wooden evaluation pool, which was replaced by the current bypass evaluator system.

6. **Permanent Fish Evaluator.** The fish evaluator was constructed in 1991 at a cost of $1,638,038 (1993 Dollars). It is approximately 725 square feet in size. The evaluator overhangs the Unit 13 draft tube (Figure 16-9). The evaluator consists of several fish holding tanks, pulleys, screens and channels (Figure 16-10), and it can operate in bypass or evaluation modes. Water flows of 50 cfs are continuously passed through the bypass system, except for a two-week period each year when Unit 13 is shut down for maintenance. When the smolts are being evaluated, the 50 cfs flow is split between 15 cfs flows through the test and evaluation canal and 35 cfs through the main discharge ramp and into the tailrace. Downstream migrants pass through the main discharge spillway chute (35 cfs), dropping an average of 13 feet to the tailrace.

   A temporary evaluator was constructed in 1975, the cost of which is not available but believed not to have been of a significant amount. It was replaced by the current evaluator.

16.4.2 Annual Operations and Maintenance Costs.

7. **O&M Passage/Protection.** The operations and maintenance costs for all of the equipment associated with downstream mitigation, excluding the fish evaluator staff costs, are approximately $12,000. This includes costs for equipment, maintenance, and the cleaning and removal of debris. This cost may have varied from a lesser cost during the period before evaluator or tilting screen installation to a higher cost after evaluator installation. However, conversations with plant operators suggest the number is appropriate to use to estimate operations and maintenance costs for the downstream passage/protection system.

16.4.3 Annual Monitoring Costs.

8. **Fish Evaluator Staff.** This $60,000 per year annual cost includes a part-time supervisor and attendants at the evaluator to count and tag smolts during out-mitigation. It also includes all downstream mitigation reporting requirements. The cost started with the installation of the permanent evaluator (1991). The monitoring performed at the evaluator was mandated by FERC, Oregon Department of Fish and Wildlife, United States Fish and Wildlife, and National Marine Fisheries. The monitoring has been performed as a follow up on the modifications performed at T. W. Sullivan over the years and is intended to identify success or failure of the various modifications. The evaluator is currently being used to monitor the affects of the Unit 13 tilting wedgewire bar screen on the downstream migrating smolts.

16.4.4 Lost Generation Costs.

9. **Preevaluator 8 Week Shutdown.** During the 10 years prior to installing the evaluator in 1991, the plant was completely shutdown each year for approximately 8 weeks during the downstream spring and fall chinook salmon and steelhead smolt runs. The 1991 installation of the evaluator provided information showing acceptable safe smolt passage rates through Unit 13, and the plant was no longer required to shut down during this out-migration period. The estimated annual cost for the shutdown is $1,003,000.

10. **Evaluator/Bypass Flows** (50 cfs). The fish bypass system, which includes the Unit 13 tilting diversion screen, fixed screen, plunge pool, evaluator unit, and fish discharge spillway has a constant bypass flow of 50 cfs. The only time the 50 cfs does not flow is during 2 weeks each year when maintenance is performed on the Unit 13 turbine/generator and the evaluator/bypass system is not operational. The estimated annual cost for the evaluator/bypass flows is $63,000.

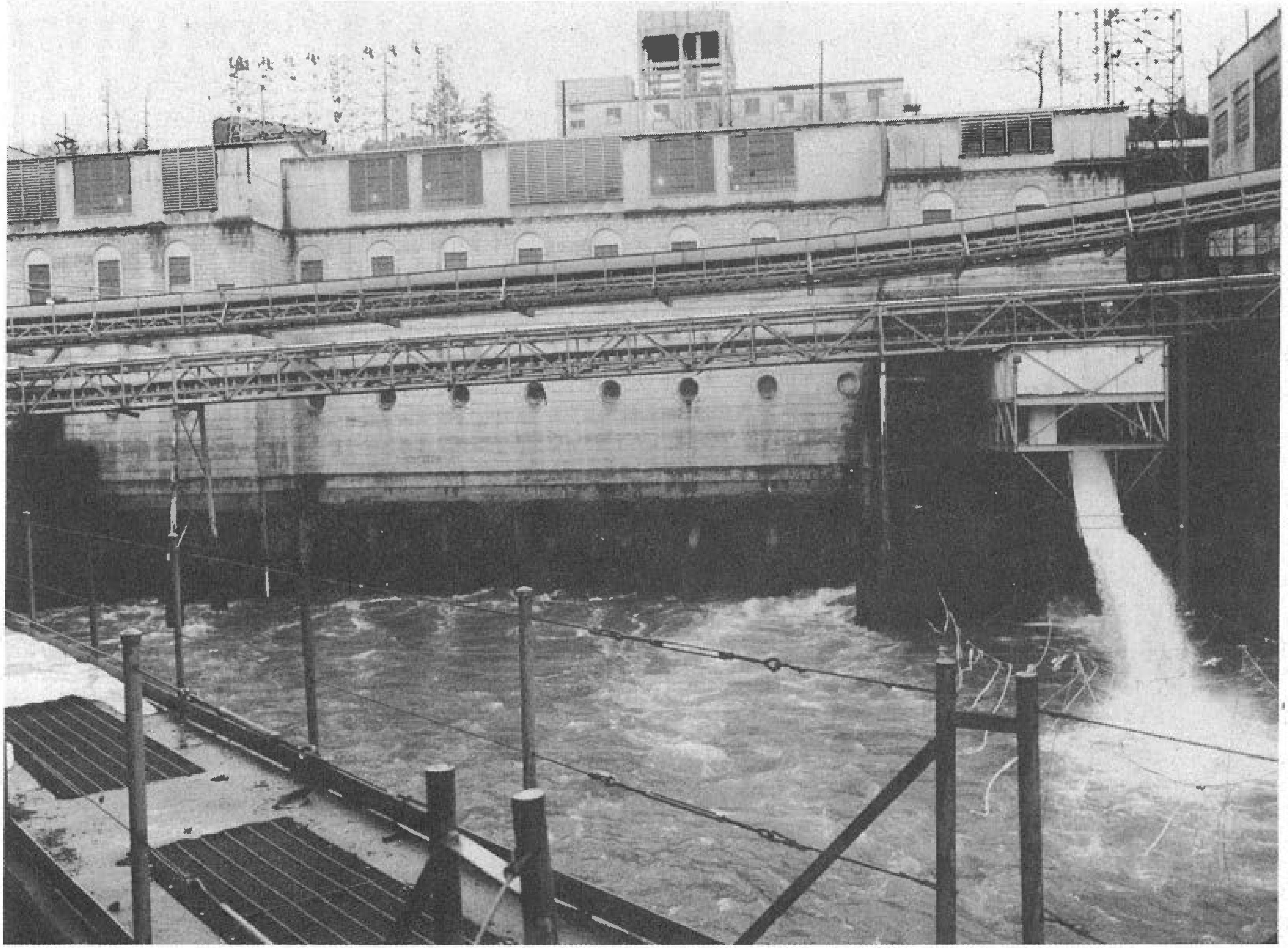


Figure 16-9. Fish evaluator connected to T. W. Sullivan Unit 13. Some of the draft tubes for Units 1 through 12 are visible to the left of the fish evaluator. In the picture foreground is the under-walkway fish ladder.

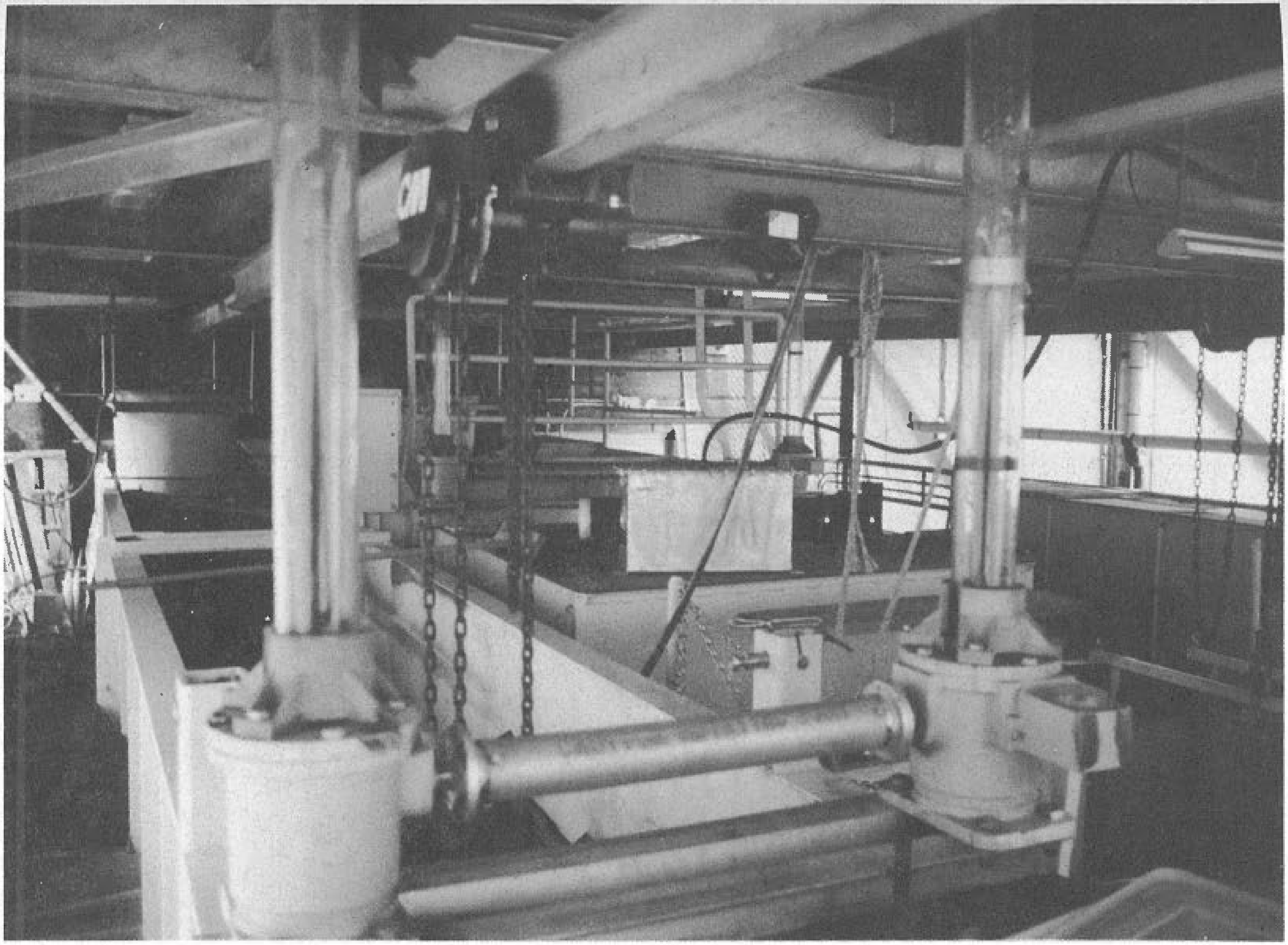


Figure 16-10. Interior of the T. W. Sullivan fish evaluator.

Table 16-6. T. W. Sullivan mitigation costs.

T. W. Sullivan Project—Mitigation Cost Analysis—All Values in 1993 Dollars

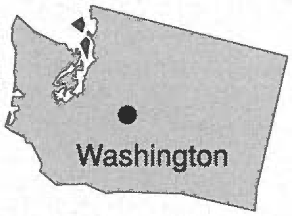
9/09/93	–18	–17	–16	–15	–14	–13	–12	–11	–10	–9	–8	–7	–6	–5	–4	–3	–2	–1	0	1	
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTALS
Capital Costs																					
1) Trash Rack Remodel/Rebuild	$594,333						$5,096														$599,429
2) Tilting Screen						$170,007															$170,007
3) Penstock Modification						$238,406															$238,406
4) Training Wall Installation	$631,612																				$631,612
5) Fish Bypass	$214,021																				$214,021
6) Permanent Fish Evaluator																	$1,638,038				$1,638,038
Annual Operations & Maintenance																					
7) Operations & Maintenance	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$240,000
Annual Monitoring																					
8) Fish Evaluator Staff																	$60,000	$60,000	$60,000	$60,000	$240,000
Annual Generation Losses																					
9) Pre–Evaluator 8 Week Shutdown							$1,003,000	$1,003,000	$1,003,000	$1,003,000	$1,003,000	$1,003,000	$1,003,000	$1,003,000	$1,003,000	$1,003,000					$10,030,000
10) Evaluator/Bypass Flows (50 cfs)																	$63,000	$63,000	$63,000	$63,000	$252,000
Subtotal Capital Costs	$1,439,966	$0	$0	$0	$0	$408,413	$5,096	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,638,038	$0	$0	$0	$3,491,513
Subtotal Annual Costs	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$135,000	$135,000	$135,000	$135,000	$10,762,000
Total Expenses—1993 Dollars	$1,451,966	$12,000	$12,000	$12,000	$12,000	$420,413	$1,020,096	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,015,000	$1,773,038	$135,000	$135,000	$135,000	$14,253,513

Notes: 4.5% Index rate used to present values as 1993 dollars
Some costs are estimated, see mitigation cost text for details
Subtotal Capital Costs includes items: 1,2,3,4,5,6
Subtotal Annual Costs includes items: 7,8,9,10

17. TWIN FALLS CASE STUDY

17.1 Description

The Twin Falls Hydroelectric project (FERC number 04885) is located at river mile 10.2 of the South Fork of the Snoqualmie River (Figure 17-1), within the Snohomish River Basin, in King County, Washington. It is a run-of-river development using the hydraulic potential of approximately 450 feet of stream profile, and has licensed hydraulic capacity of 710 cfs. The project began operation in December 1989, and annually generates approximately 80,000 megawatt-hours of electrical energy. The project capacity is 24 megawatts. The Twin Falls project has unique design features; it is built mostly underground except for the diversion weir (Figure 17-2). This subterranean construction was a licensing requirement to avoid any visual impact. The project is located along Interstate 90 and is virtually impossible to detect from the highway. The two intake caverns are each 150 feet in length and 11 feet wide. A road provides access to the powerhouse through a tunnel with a vertical drop of 514 feet. The tunnel is 16 feet high and 15 feet wide with a grade of 18%.



The project is situated upstream of hydraulic barriers that prevent movement of salmonid and nonsalmonid fish species from downstream areas, but entrainment of fish could occur as a result of

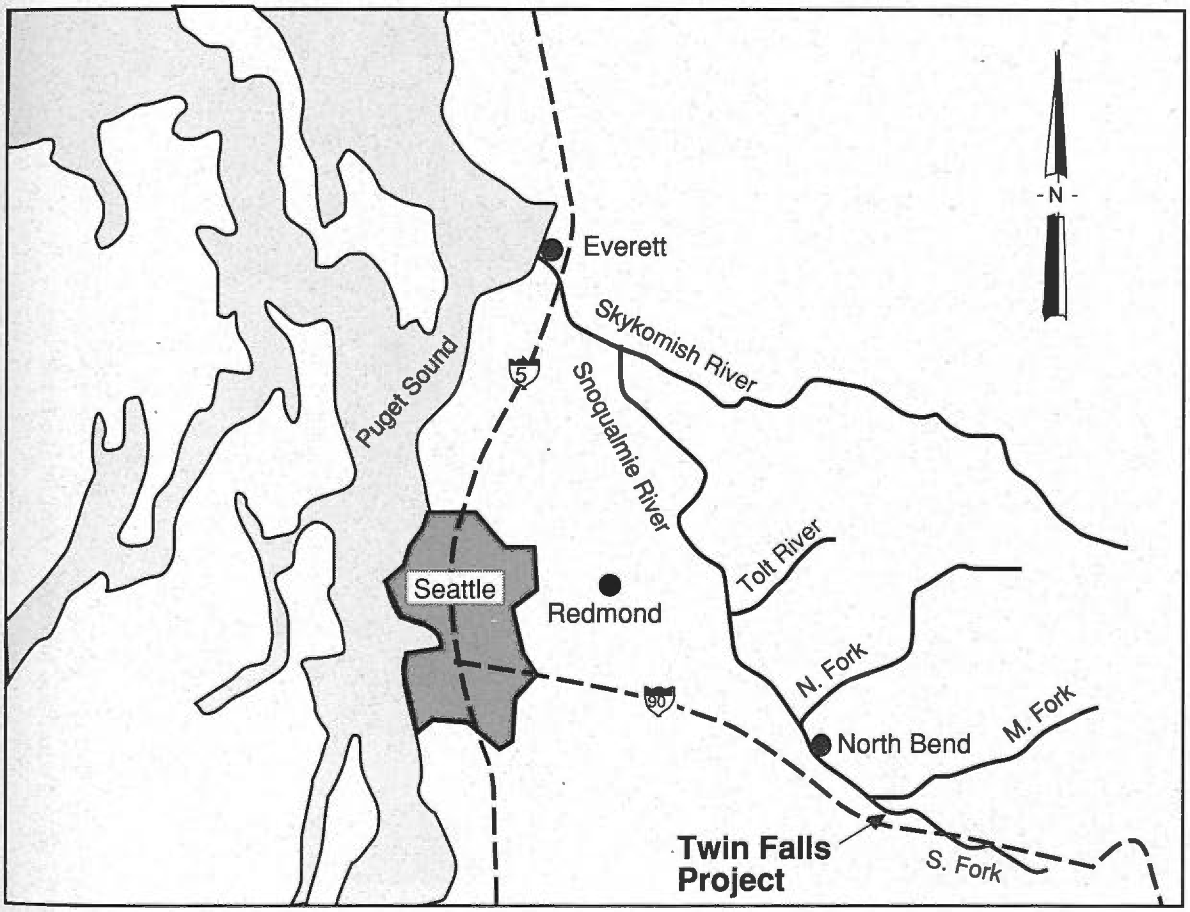


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Figure 17-1. Location of the Twin Falls project on the South Fork of Snoqualmie River.

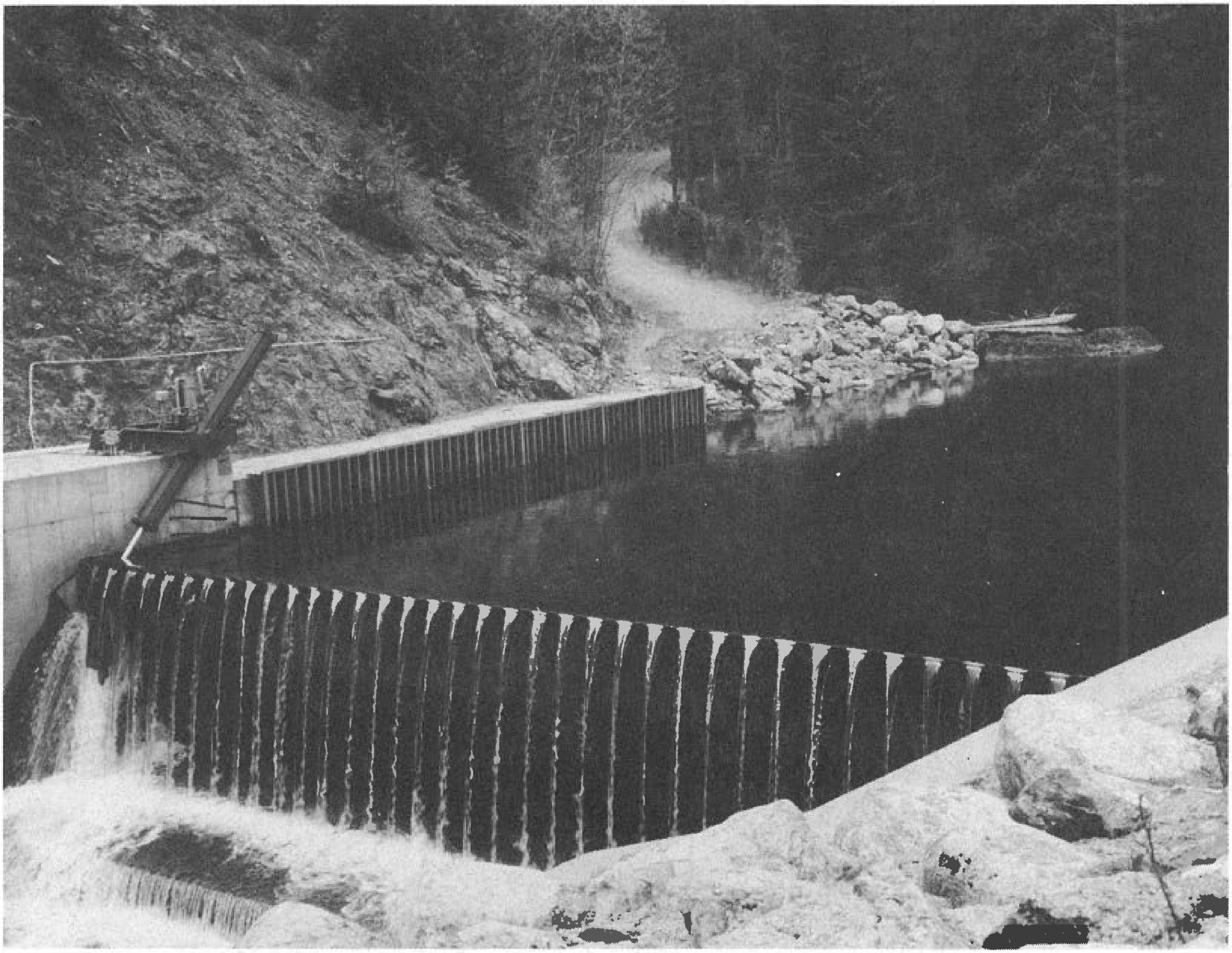

Figure 17-2. Twin Falls Diversion and intake trash racks.

passive and nonpassive movement of resident species from upstream areas. Fish screens are used as a mitigation measure to prevent entrainment of fish. This measure primarily targets resident trout species such as rainbow, cutthroat, and brook trout.

Passive inclined-plane fish screens are fitted within the project's two identical intake caverns. Stream flow, equally divided under normal operating conditions, is diverted from the river into the caverns and passes through the fish bypass screens into the vertical drop shaft leading to the turbines. Approximately 15 to 50 cfs of flow passes over a full-width weir at the downstream end of each screen into a common fish bypass canal (Figure 17-3). The fish bypass canal reenters the river 105 feet downstream of the project's diversion dam–a collapsible steel weir 65 feet long and 9.9 feet high.

The design criteria for the screens as established by the fish and wildlife agencies include

- Maximum clear screen opening of 0.25 inches

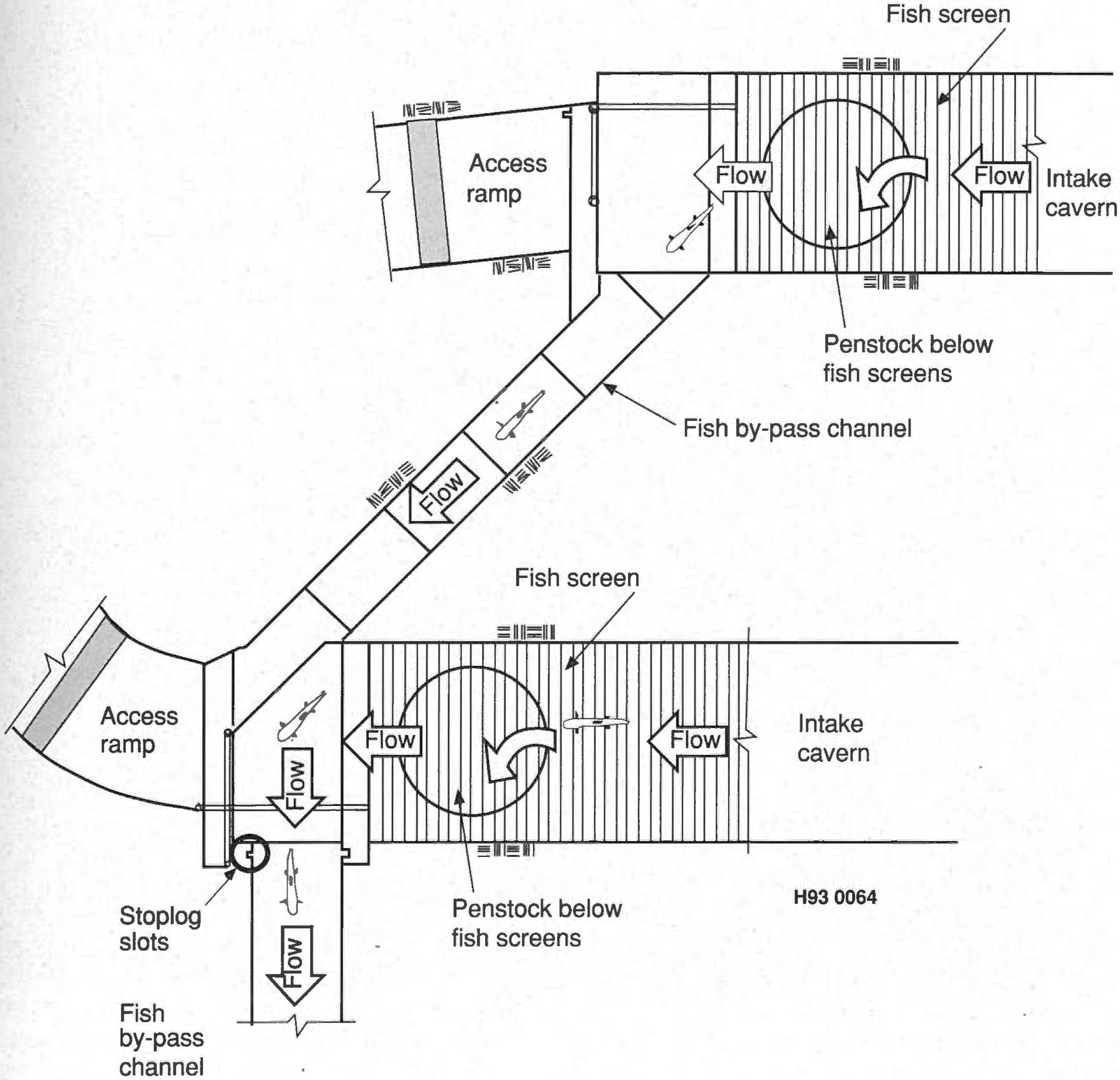

Figure 17-3. Twin Falls fish bypass channel and intake caverns.

- Minimum velocity ratio (sweeping velocity:approach velocity) of 2:1
- Maximum approach velocity of 0.5 fps.

Each fish bypass screen is 11-feet wide and 136-feet long, with the downstream end raised from horizontal at an angle of 4 degrees. The screens are manufactured of stainless-steel wedge-wire panels with 0.25-inch openings between the wedge-wire bars and are supported from below with steel I-beams spaced 2 feet 9 inches on center along the length of the screen. The bottoms of the excavated caverns are nearly rectangular and uniform in section, and they slope downward at approximately 3 degrees toward the openings of the eight-foot-diameter drop shafts. The depth of flow over the screens varies from approximately 10 feet at the upstream end to approximately 6 inches near the bypass weir (Figure 17-4).

An airburst screen cleaning system (Figures 17-5 and 17-6) is installed to prevent debris clogging of the inclined plane screens and to maintain uniform water velocities on the screen surface. The design of this cleaning s [illegible] was derived from the airburst system ope [illegible] he Arbuckle Mountain Hydroelectri [illegible] in Northern California (another case study).

The fish bypass conduit, which also serves as a reliable means to divert minimum flow releases to the river, is approximately 56 feet in length and deposits fish directly into a naturally occurring plunge pool about 105 feet downstream of the diversion dam (Figure 17-7). Fish entering the intake cavern proceed downstream along the fish screen, pass over a shallow rounded crest at the end of the fish screens, and drop directly into the plunge pool below the bypass conduit.

17.1.1 Fish Resource Management Objective of Mitigation. The resource management objective of the downstream passage/protection facility for Twin Falls is predicated on the fisheries agencies' policy that operation of the project will not result in mortalities to resident fish species.

17.1.2 Monitoring Methods. A comprehensive field study was conducted to evaluate the effectiveness of the bypass screening system. The study was performed to determine if the screens meet the Washington State criteria for approach and sweeping velocity limitations. The evaluation involved the measurement of real-time and averaged velocity components along the length of the screen at full and half-load conditions. Based on the results of the screen system evaluation, the fisheries agencies and FERC agreed that the screens complied with the requirement to protect the resident fishery.

Electronic level sensors are used to determine the differential across the screens and to determine the amount of bypass flow off the end of the screens. If the differential exceeds a preset amount the control system starts the airburst screen cleaner system. If differential continues to increase there is an alarm level to notify operations personnel and an automatic shutdown level to protect the screens.

Project personnel make daily visits to the project and an inspection of the fish screens is included. Operations personnel look for debris build-up and fish impingement (none seen to date), and verify screen cleaner operation. The control system logs the spill to the diversion reach at each release point (crestgate and weir at the end of each screen), and this information is made available to the fisheries agencies and FERC.

17.1.3 Performance of Mitigation. The bypass screens must meet screen criteria for approach and sweeping velocities established by the State of Washington. This criteria states that the approach velocity must be 0.5 fps or less, and the sweeping velocity must be at least twice the approach velocity.

To date, the downstream fish bypass screening system has performed in concurrence with the policy that no induced mortalities of resident fish species will result from operation of project components.

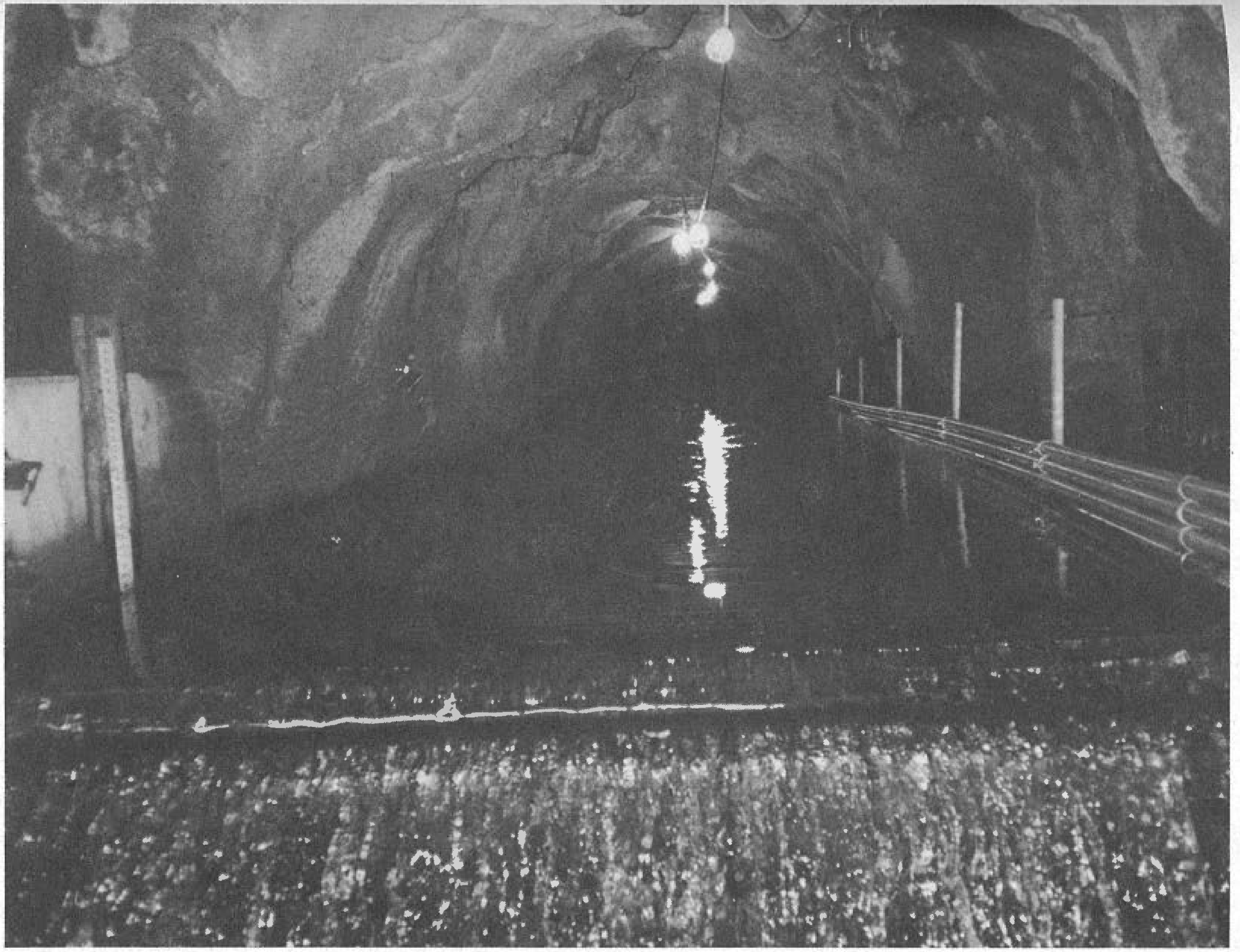

Figure 17-4. Twin Falls juvenile fish screen, downstream end of 136-foot-long left-side screen.

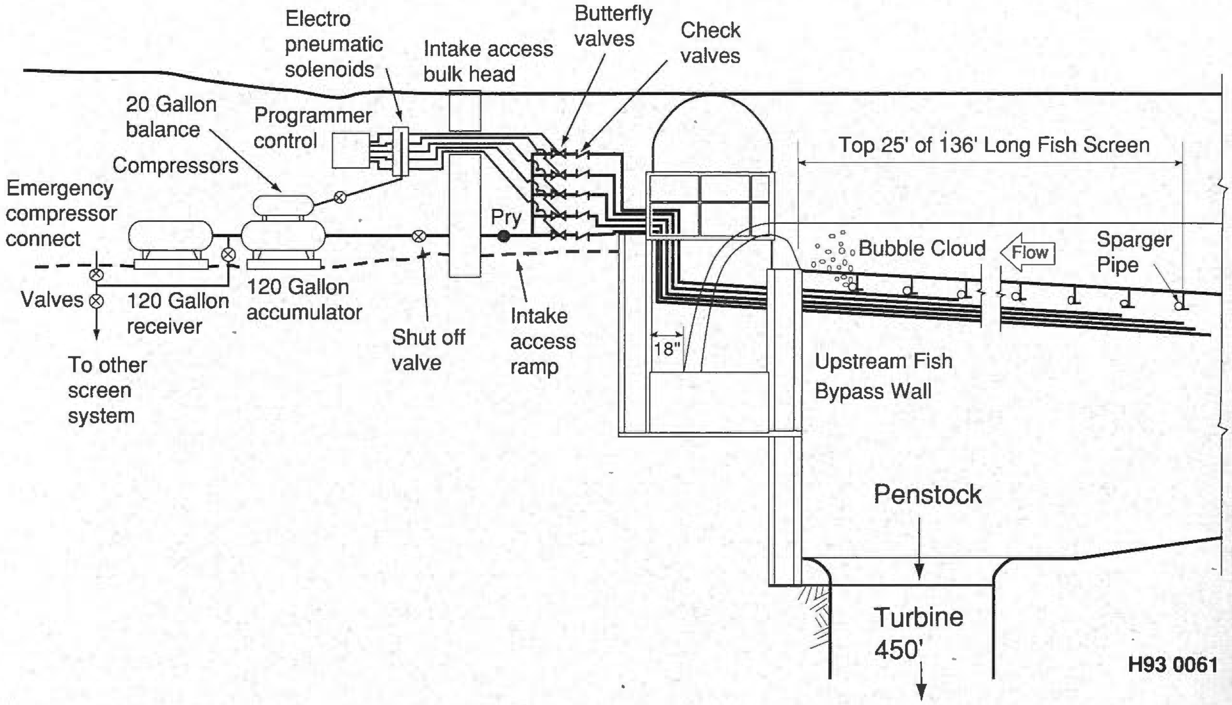

Figure 17-5. Twin Falls airburst screen cleaning system and last downstream 25 feet of one of two identical screens.

17.2 Mitigation Benefits

17.2.1 Benefits to Fish Populations and Associated Fisheries. The downstream fish screen bypass system has effectively protected the resident fish species, which passively and nonpassively move within the project intake structure, from induced mortalities. As a result of the project's screen bypass system, the sport fishery for resident trout species in the Snoqualmie River (South Fork) has not been impacted by the operation of this project.

17.3 Mitigation Costs

17.3.1 Introduction. The mitigation cost analysis for the Twin Falls hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; a downstream fish passage/protection system section, discussing the downstream mitigation costs; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal written correspondence, telephone calls, and a site visit that greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

17.3.2 Cost Summary. The Twin Falls project has no anadromous species and no upstream fish passage/protection requirements. All of the costs are for the downstream passage/protection of resident species (Table 17-1). The total cost of mitigation primarily consists of capital and study costs (Figure 17-8). In fact, 57% of all costs for the 20-year period of analysis are in the form of capital costs at project inception. The annual operation and maintenance costs for mitigation are anticipated to remain low (Figure 17-9) in relation to total up-front mitigation costs. The single largest mitigation cost item is the excavation costs for the tunnels containing the fish bypass and the two fish screens. The wedge-wire screens and screen supports are the next two most costly items (Table 17-2).

The magnitude of influence on the total costs that the up-front capital and study costs have is clearly evident when looking at the costs over time (Figure 17-9). The total estimated mitigation

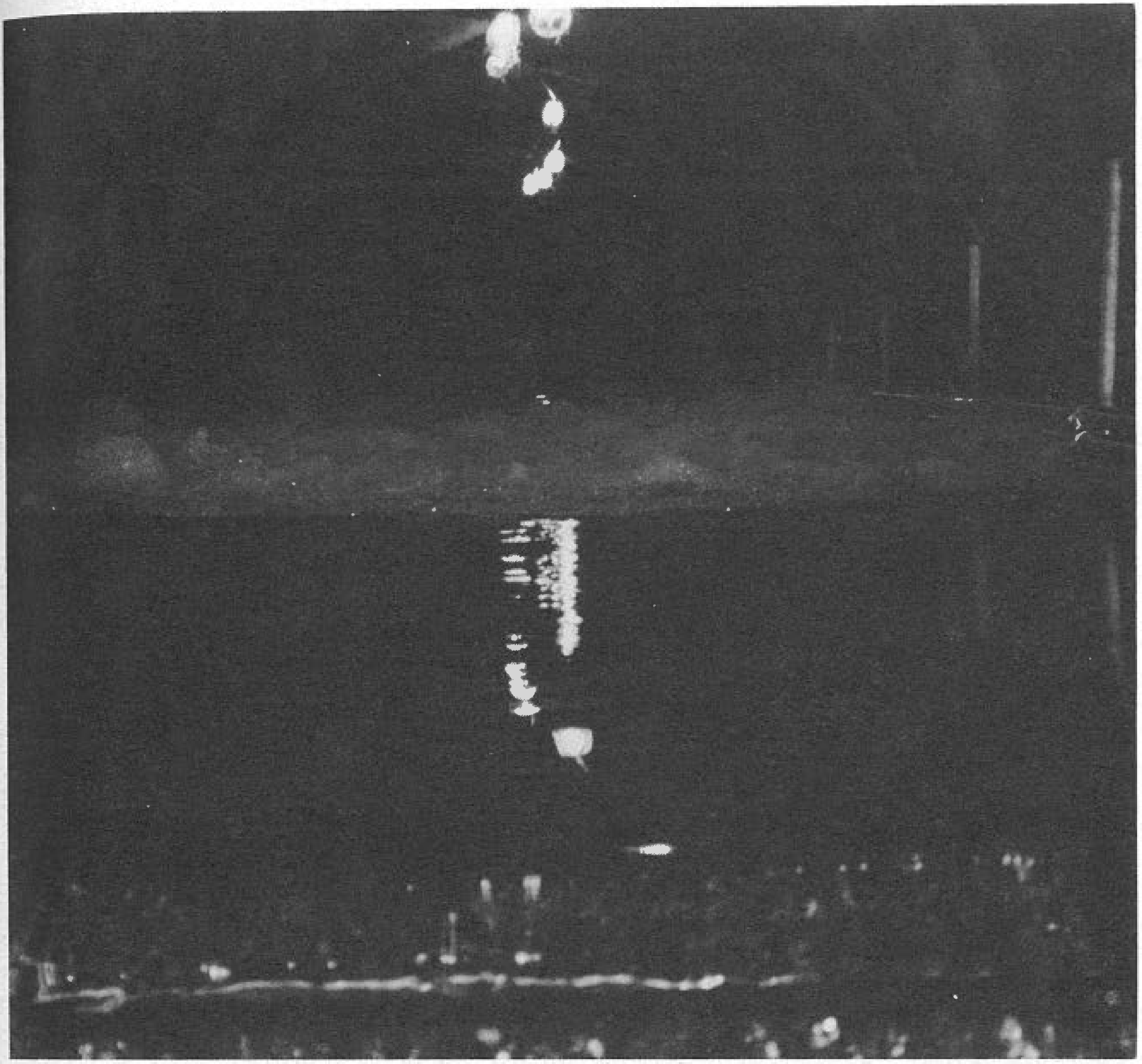

Figure 17-6. Twin Falls airburst fish screen cleaning system in operation, viewed from downstream end of right-side screen. Cleaning bubbles are cycling towards viewer.

cost over the 20-year period 1989 through 2008 is $1,517,030 (Table 17-1). The cost analysis assumes that benefits (and costs) will be spread over a period of time, so a period of 20 years has been used to estimate mitigation costs. Following this assumption, the costs were levelized over 20 years and then computed against the average annual energy production of 80,000 megawatts-hours to derive a per kilowatt-hour cost of mitigation. At the Twin Falls hydroelectric plant the cost per kilowatt-hour is 0.9 mills. This is the equivalent of about one-tenth of a cent per kilowatt-hour.

17.3.3 Capital and Study Costs. Because of the underground construction, the capital costs of the fish passage/protection system include the cost of excavation. One tunnel was excavated for each of the two fish screens, and a bypass tunnel was excavated to return fish to the stream. The cost of the mitigation-related excavation is $357,750. Each of the two wedge-wire screens is 11 feet wide by 136 feet long, and they cost a total of $298,130. The wedgewire screens are supported by I-beam structural steel supports, which originally cost $178,880. The I-beam supports collapsed in 1991, and the rebuilding cost was

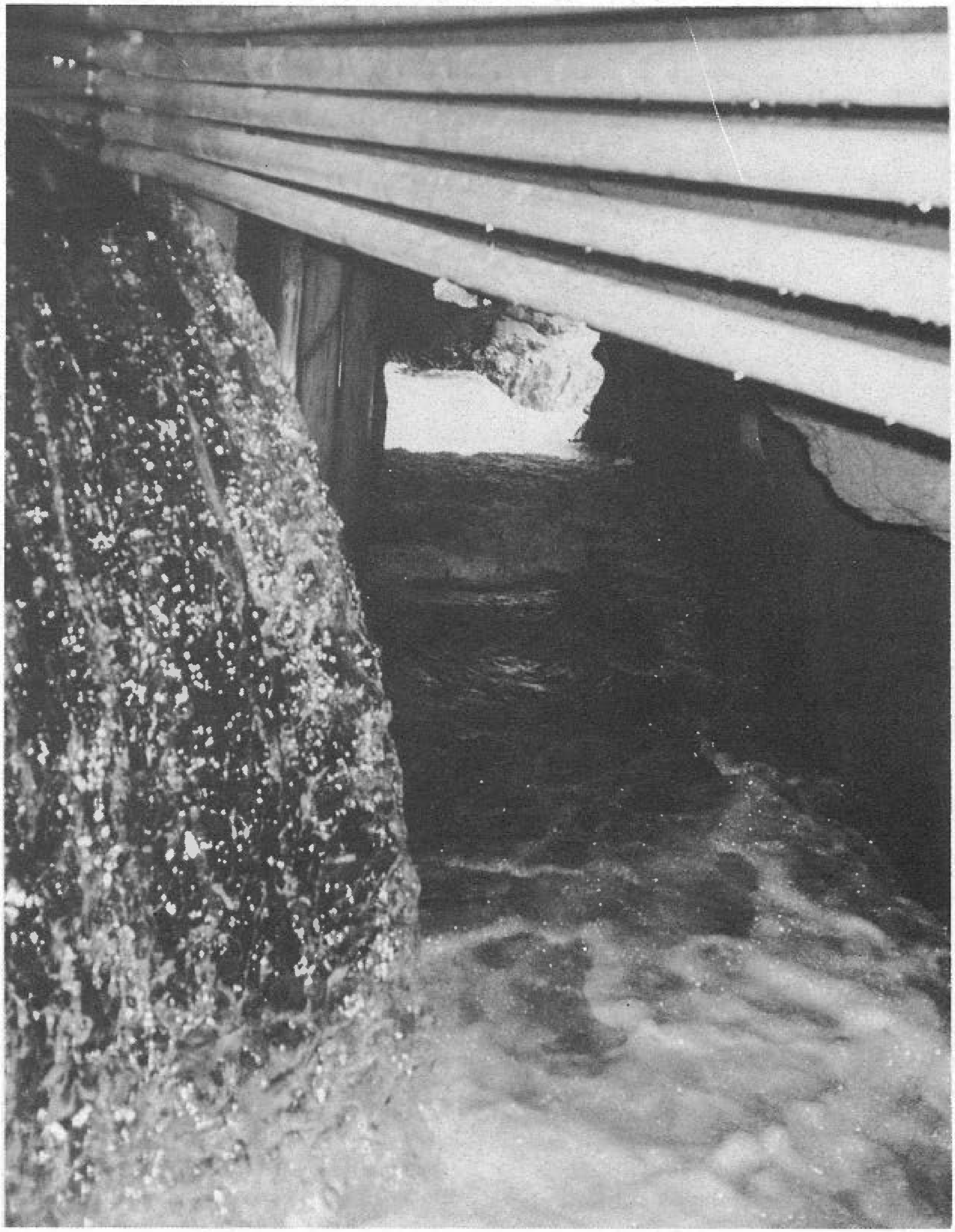

Figure 17-7. Twin Falls fish bypass conduit. Viewing out towards return to stream (sun light).

Table 17-1. Breakdown of 20-year total costs for downstream mitigation at the Twin Falls project. Because of rounding, totals may not sum exactly.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital and study	1,060,350	53,020	0.7
Annual	306,680	15,330	0.2
Lost generation	150,000	7,500	0.1
Total costs	1,517,030	75,850	0.9

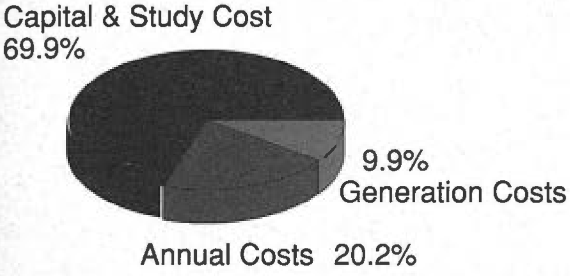

Figure 17-8. Capital, study, annual and lost generation costs for fish mitigation at the Twin Falls project.

substantial. However, the collapse is not considered a mitigation-related cost, so only the additional cost beyond the original cost is added to the cost analysis. The reasoning is that the added cost represents higher quality materials and better engineering judgment, and if this was part of the original effort then the collapse would have been avoided. The additional cost was $54,600.

The airburst screen cleaning system was installed in 1991 at a cost of $87,360. As originally installed, only the last 42 downstream feet of each screen was cleaned by the airburst system.

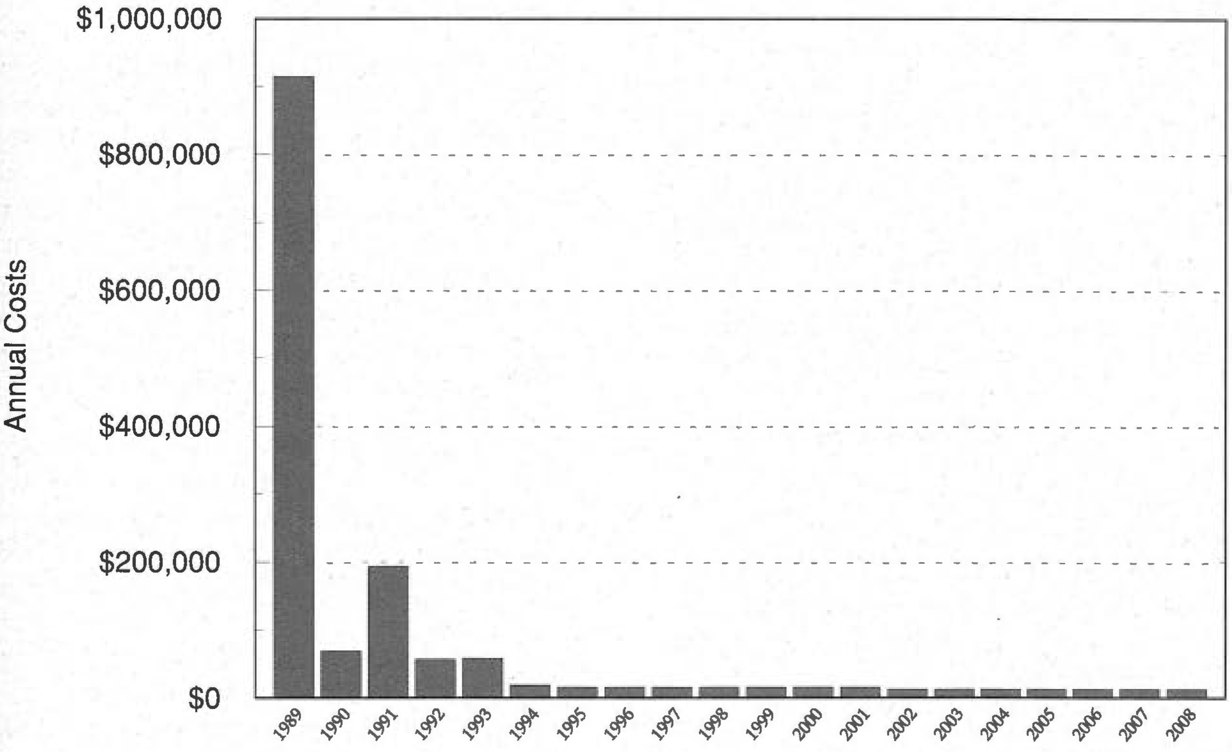

Figure 17-9. Yearly costs of mitigation at the Twin Falls project.

During 1993, another 40 feet of each screen are being fitted with the airburst cleaning system at an estimated cost of $20,000. (A total of 82 feet of the downstream ends of each screen will be cleaned by the airburst cleaning system). The airburst system will cost a total of $107,360 when the retrofit is completed. The cost to design the fish screens was $27,820. Preconstruction and postconstruction modeling and evaluation of the fish screens were also performed. The combined costs of these two studies is $35,810.

The capital and study costs for the mitigation-related requirements total $1,060,350. The benefits of the fish screen system have been accrued several years and will continue to accrue for many more. To reflect these many years of benefits, the capital costs are levelized over 20 years to a value of $53,020 per year. Comparing the average annual energy production quantifies the annual levelized cost as an order of magnitude in relation to plant size. With an annual energy production of 80,000 megawatt-hours, the levelized capital cost per kilowatt-hour is 0.7 mills.

17.3.4 Annual Costs. The annual costs (excluding lost generation) of mitigation are limited to three items. An average annual cost of $5,000 is assigned to the annual monitoring and demonstration of the fish protection facilities. The 20-year total cost is $100,000. Another annual cost is the management of mitigation issues. This function's hours are anticipated to decrease as issues are resolved. For this reason, the mitigation management hours are estimated to decrease from 15% to 10% and again to 5%. The total 20-year cost of mitigation management is $121,000. Another annual cost is the operations and maintenance of the airburst system. The estimated annual cost is $5,000, which is primarily driven by air compressor maintenance requirements. The airburst system was installed in 1991, and the total cost of maintenance for the years 1992 through 2008 is $85,000.

The 20-year total for the annual costs is $306,680. The average annual levelized cost is $15,330. As a function of energy production, the levelized annual cost per kilowatt-hour is 0.2 mills.

17.3.5 Lost Generation Costs. Debris loading on the fish screens has resulted in an estimated annual power loss of ~500 megawatt-hours. This problem is expected to be rectified with the upgrading of the airburst cleaning system during 1993. The total cost of lost revenue resulting from fish screen debris loading is $150,000. The 20-year levelized annual cost is $7,500, and the levelized cost per kilowatt-hour of electricity is 0.1 mills.

17.4 Cost Descriptions and Assumptions

This section explains the individual cost items, assumptions, and estimates required to quantify the respective items and derive totals. The item numbers correspond to the 20-year spreadsheet (Table 17-2) used to determine costs. All costs have been converted to 1993 dollars and are discussed as such.

17.4.1 Capital Costs.

1. **Excavation Underground Chambers.** The total capital cost to excavate the two underground chambers that contain the fish screens is $715,500. This includes all excavation related to the two fish screen chambers and the fish bypass tunnel. Each of the bypass fish screens is 136 feet long and 11 feet wide. Each intake tunnel is 150 feet long and 11 feet wide. The fish bypass tunnel is approximately 56 feet long.

   To assign the total excavation cost of $715,500 as a fish protection mitigation cost would be erroneous because the project is not subterranean for fish mitigation reasons. The underground siting is to minimize visual impacts. However, if the fish screens were not required by the Washington State Department of Wildlife, then the tunnel would not have been nearly as large. Additionally, the fish bypass tunnel is a fish mitigation requirement. Because of these factors, it was recognized that for this cost analysis some but not all of the $715,500 cost should be included as a fish mitigation cost. To account for the expanded tunnel diameter requirement for the screens, the expanded tunnel length to accommodate the screens, and the additional fish bypass tunnel for fish mitigation, one-half of the total cost has been assumed to be the cost ($357,750) of downstream fish mitigation.

2. **Wedge-wire Screens.** Two wedgewire screens are located within two intake tunnels. Each screen is 11 feet wide and 136 feet long, and is inclined up from horizontal at an angle of 4 degrees from the upstream end. The stainless steel wedgewire screen has 0.25-inch openings between each wedge-wire and is supported from below with steel I-beams. The total screen surface is 2,992 square feet. The total screen cost is $298,130. A small percentage of the screen was replaced in 1991 when the supports failed. This small cost is included in the 1991 cost of rebuilding the structural steel supports.

3. **Structural Steel Supports.** The 1989 cost ($178,880) was for the structural steel support material, fabrication, and installation. The steel supports failed in 1991 for nonmitigation reasons. The total costs incurred with this failure are discussed in the section "Other Costs Not Included in Totals." The 1991 costs of rebuilding the steel supports were greater than the original 1989 costs, and it is assumed for this analysis that the greater cost ($54,600) was for stronger materials and perhaps more advanced engineering. It is the intent to avoid double counting of the costs of support structures, so only the additional cost to rebuild was included in the analysis.

4. **Air-Burst Screen Cleaning System.** When the screens were originally constructed an automated cleaning system was not installed. The automated airburst cleaning system was installed in 1991, using two-inch and three-inch diameter steel pipe, air compressors, valves, electronic pneumatic solenoids, and a programmable control. Several criteria were required of the system: uniformly released air across the screen section to be cleaned, variable airburst pressures, variable airburst duration, starting the airbursts downstream and working upstream, air would not be entrained into the penstocks, and variable airburst cycles dependant on water debris conditions. The airburst system as installed in 1991 was designed to clean the downstream 42 feet of each of the two screens. The $20,000 (1993) airburst screen cleaning system cost is the estimated cost to add airburst cleaning capability to 40 more feet of each screen (82 feet total per screen). The capital cost of the airburst system when the 1993 addition is completed is $107,360.

5. **Fish Screen Design Costs.** The fish screen system design was part of the entire project design cost. The estimated fish screen system design cost of $27,820 was derived by dividing the original (1989) fish screen system cost by the entire project cost. This factor was multiplied by the entire project design cost ($1,000,000) and indexed to 1993 dollars ($27,820).

17.4.2 Study Costs.

6. **Screen Model Study** (1988). $18,690 is the estimated cost of the 1988, preconstruction modeling study to evaluate the fish screen intake arrangement.

7. **Screen Evaluation Study.** This 1990 study evaluated the fish screens after construction by measuring the velocity components over a range of flows at a number of locations on the fish screens. The total cost of this study was $17,120.

17.4.3 Annual Monitoring and Reporting Costs.

8. **Fish Protection Facilities Monitoring.** An annual operational demonstration of the fish facilities is required by the FERC

license and consists of inviting the involved fish and wildlife agencies to view the facility and demonstrate operation in compliance with the license. The $5,000 cost includes overhead, labor, and miscellaneous expenses for the annual demonstration and mitigation-related reporting.

9. **Mitigation Management.** The licensee has estimated that 15% of the operations manager's time is spent on mitigation issues. It is anticipated that this commitment will decrease over time as various issues are resolved. To estimate a dollar value for this resource commitment, the following assumptions were employed: an hourly rate of $30, a 40-hour work week, and 52 weeks per year. It is assumed that the time commitment would decrease from 15% for the years 1989 to 1994, to 10% for the years 1995 to 2001, and finally to 5% for the years 2002 to 2008.

17.4.4 Annual Operations and Maintenance Costs.

10. **Airburst Cleaning System.** The two air compressors used in the airburst system have undergone mechanical failures. The estimated annual cost to repair and maintain the compressors is $5,000. This cost includes labor and parts.

17.4.5 Lost Generation Costs.

11. **Screen Debris.** Debris buildup on the fish screens accounts for approximately 500 megawatt-hours per year of lost generation. It is anticipated that the 1993 upgrade to the airburst cleaning system will alleviate this loss. Discussion with the project operators suggested that partial losses occurred in 1989 and 1993, and full 500 megawatt-hours losses occurred 1990, 1991, and 1992. With an energy value of $75 per megawatt-hour, the full year loss is $37,500. The total five-year loss is estimated to be $150,000.

17.4.6 Other Cost Considerations. Total combined flows of between 15 and 50 cfs pass over each weir at the downstream end of the two fish screens. These flows pass through the fish bypass and return to the stream. These flows have not been included as lost generation for the fish passage/protection mitigation because they are used as part of the minimum instream flow requirements.

The original fish screens and supports installed in 1989 failed November 1991. The plant was not able to operate at full seasonal capacity from November 5, 1991 through December 9, 1991. The failure of the screens was related to the inadequate structural steel support system for the wedge-wire screen panels. Additionally, no venting method was included to limit negative pressures on the penstock side of the screens should the submerged screens clog and the turbines not immediately come off-line.

The 1991 total cost to rectify the screen support failure was $855,000 (1991 dollars). Of this cost, $200,000 was spent on materials ($35,000 wedge-wire), labor, and professional fees to correct the design and upgrade the supports after the failure. The remaining $655,000 was the cost of lost revenue resulting from the failure. This is based on a contractual kilowatt-hour value of 7.5 cents, and a generation loss of 8,733 megawatt-hours during the 34 days. The megawatt-hours value is based on hydrological stream flow data during this high-flow season.

The fish screens and supporting structure failure would not have occurred had the mitigation not been required. This may be a justifiable argument to include this cost ($855,000) as a mitigation cost. However, this failure was a result of inadequate design criteria, not a failure of the mitigation method. While some may argue that the $855,000 is the cost of learned knowledge, the analysis did not include this cost in the mitigation costs. If the $855,000 had been levelized and computed on a 20 year basis, the levelized cost per kilowatt-hour would have added approximately 0.5 mills to the mitigation costs.

Table 17-2. Twin Falls mitigation costs.

Twin Falls Project—Mitigation Cost Analysis—All Values in 1993 Dollars

[illegible] 9/09/93	–4	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	TOTALS
[illegible] Costs—Downstream Mitigation																					
[illegible]cavation Underground Chambers	$357,750																				$357,750
2) Wedgewire Screens	$298,130																				$298,130
3) Structural Steel Supports	$178,880		$54,600																		$233,480
4) [illegible]ir–burst Screen Cleaning System			$87,360		$20,000																$107,360
5) Fish Screen Design Costs	$27,820																				$27,820
[illegible] Costs																					
[illegible]en Model Study (1988)	$18,690																				$18,690
7) Screen Evaluation Study		$17,120																			$17,120
[illegible]al Monitoring and Reporting																					
[illegible] Protection Facilities Monitoring	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$100,000
9) Mitigation Management	$9,360	$9,360	$9,360	$9,360	$9,360	$9,360	$6,240	$6,240	$6,240	$6,240	$6,240	$6,240	$6,240	$3,120	$3,120	$3,120	$3,120	$3,120	$3,120	$3,120	$121,680
[illegible]al Operations & Maintenance																					
[illegible] Air–burst Cleaning System				$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$85,000
Annual Lost Generation																					
[illegible] Screen Debris	$18,750	$37,500	$37,500	$37,500	$18,750																$150,000
Subtotal Capital & Study Costs	$881,270	$17,120	$141,960	$0	$20,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,060,350
Subtotal Annual Costs	$14,360	$14,360	$14,360	$19,360	$19,360	$19,360	$16,240	$16,240	$16,240	$16,240	$16,240	$16,240	$16,240	$13,120	$13,120	$13,120	$13,120	$13,120	$13,120	$13,120	$306,680
Subtotal Annual Lost Generation	$18,750	$37,500	$37,500	$37,500	$18,750	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$150,000
[illegible]al Expenses—1993 Dollars	$914,380	$68,980	$193,820	$56,860	$58,110	$19,360	$16,240	$16,240	$16,240	$16,240	$16,240	$16,240	$16,240	$13,120	$13,120	$13,120	$13,120	$13,120	$13,120	$13,120	$1,517,030

[illegible]: 4.5% Index rate used to present values as 1993 dollars
Subtotal Capital & Study Costs includes items: 1, 2, 3, 6 & 7
Subtotal Annual Costs includes items: 8, 9, 10 & 11

18. WADHAMS CASE STUDY

18.1 Description

The Wadhams project (FERC number 09691) is a 0.56 megawatt run-of-the-river hydroelectric facility on the Boquet River in northeastern New York (Figure 18-1). The project (Figure 18-2) began operating in 1904. In 1983 an angled bar rack was installed to protect downstream-migrating Atlantic salmon smolts. The bar rack is 18-feet long, extends 6 to 8 feet into the water, and consists of 0.25-inch steel bars with 1-inch spacing. The rack is set at an angled of 36 degrees to incoming flow, and is also inclined about 10 degrees from vertical (Figure 18-3). A fish diversion chute at the downstream end of the trash rack transports fish below the dam (Figures 18-4 and 18-5).

Angled trash racks have been commonly prescribed in the eastern U.S. to prevent turbine passage of downstream-migrating fish. It is believed that setting the trash rack at an acute angle, rather than perpendicular, to the turbine intake flow changes flow patterns in a way that will cause fish to be diverted to a bypass rather than between the bars of the trash rack. Despite the frequent use of this mitigative measure, the angled trash rack at the Wadhams project appears to be the only facility at which the performance of this mitigative measure has been tested.

18.1.1 Fish Resource Management Objectives of Mitigation. Installation of the experimental angled trash rack at Wadhams was recommended by the U.S. Fish and Wildlife Service and the New York State Department of Environmental Conservation in support of efforts to restore Atlantic salmon to the Lake Champlain watershed (Nettles and Gloss, 1987). The New York State Department of Environmental Conservation has stocked Atlantic salmon fry in the accessible headwater regions of the Boquet River and yearlings and smolts upstream from the Wadhams project.

18.1.2 Monitoring Methods. Nettles and Gloss (1987) equipped salmon smolts with external or internal radio transmitters, released them upstream from the Wadhams project reservoir (Figure 18-6), and monitored their passage through the reservoir and dam with both mobile and fixed receivers. Smolt passage through the bypass chute and the penstock (turbine) were directly monitored; smolt passage over the dam via spill flows was estimated by subtracting the numbers passed by the other routes from the total number of tagged fish that appeared downstream of the dam. Water temperatures, stream flows, and the amounts of water passing through the penstock, bypass chute, and spillway were also measured. Smolt passage via each of the routes was monitored first with the angled bar rack, then with a conventional trash rack constructed of the same materials but installed perpendicular to the intake flow.

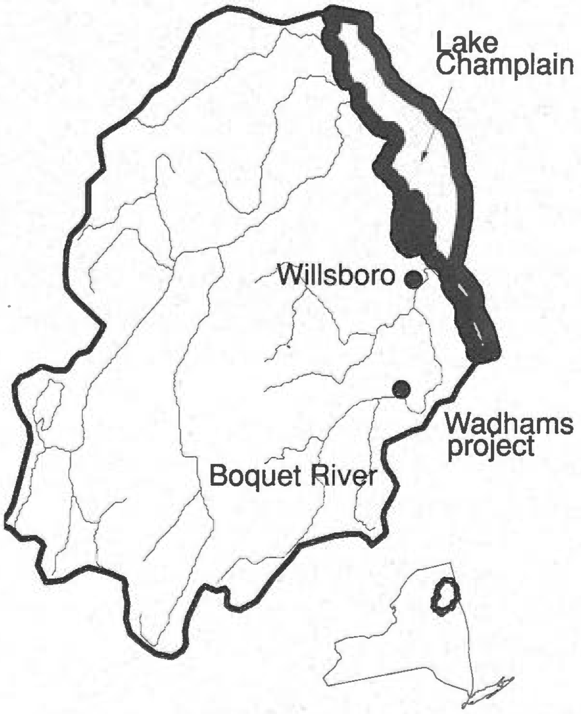

Figure 18-1. Location of the Wadhams project on the Boquet River.

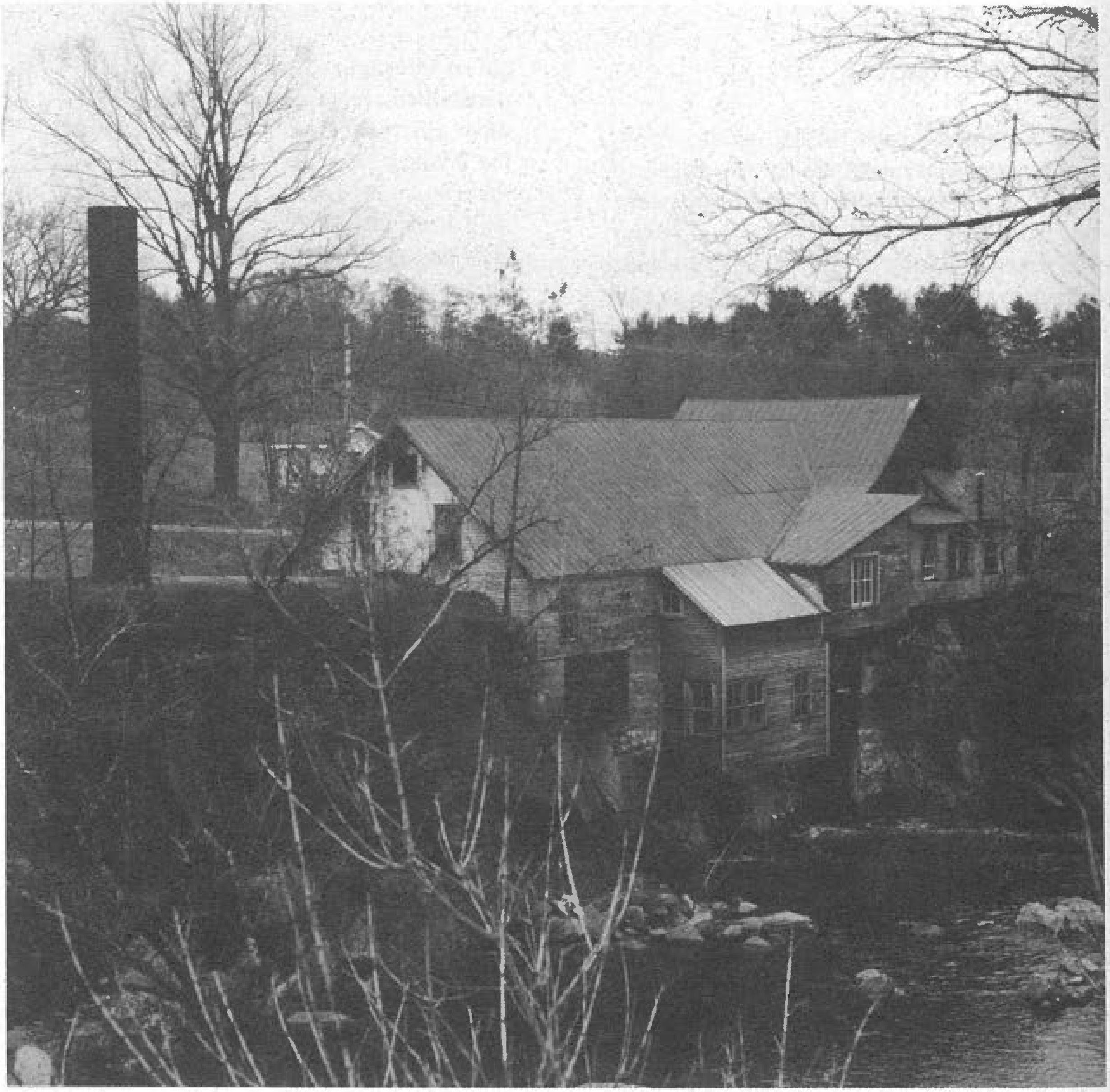

Figure 18-2. Wadhams powerhouse and vented penstock.

18.1.3 Performance of Mitigation. Many of the tagged smolts released by Nettles and Gloss (1987) interrupted their downstream migrations upon reaching the reservoir or the dam, and most (79% of 170 tagged fish) failed to migrate past the dam during the 3- to 4-week life of the radio transmitters. Thirty-six tagged fish passed the dam during the study period when either the angled trash rack or a conventional perpendicular trash rack was in place. Thirty tagged smolts passed the dam when the angled trash rack was in place, 18 passed downstream via the bypass chute from the trash rack, 12 passed over the spillway, and none passed through the penstock (Table 18-1). On the other hand, out of six fish that passed the dam when the conventional perpendicular trash rack was in place, three went through the bypass chute and three passed through the penstock.

Nettles and Gloss (1987) reinforced the common observation that reservoirs can slow down or stop downstream migrations of anadromous fish. Modified trash racks can do little to mitigate this

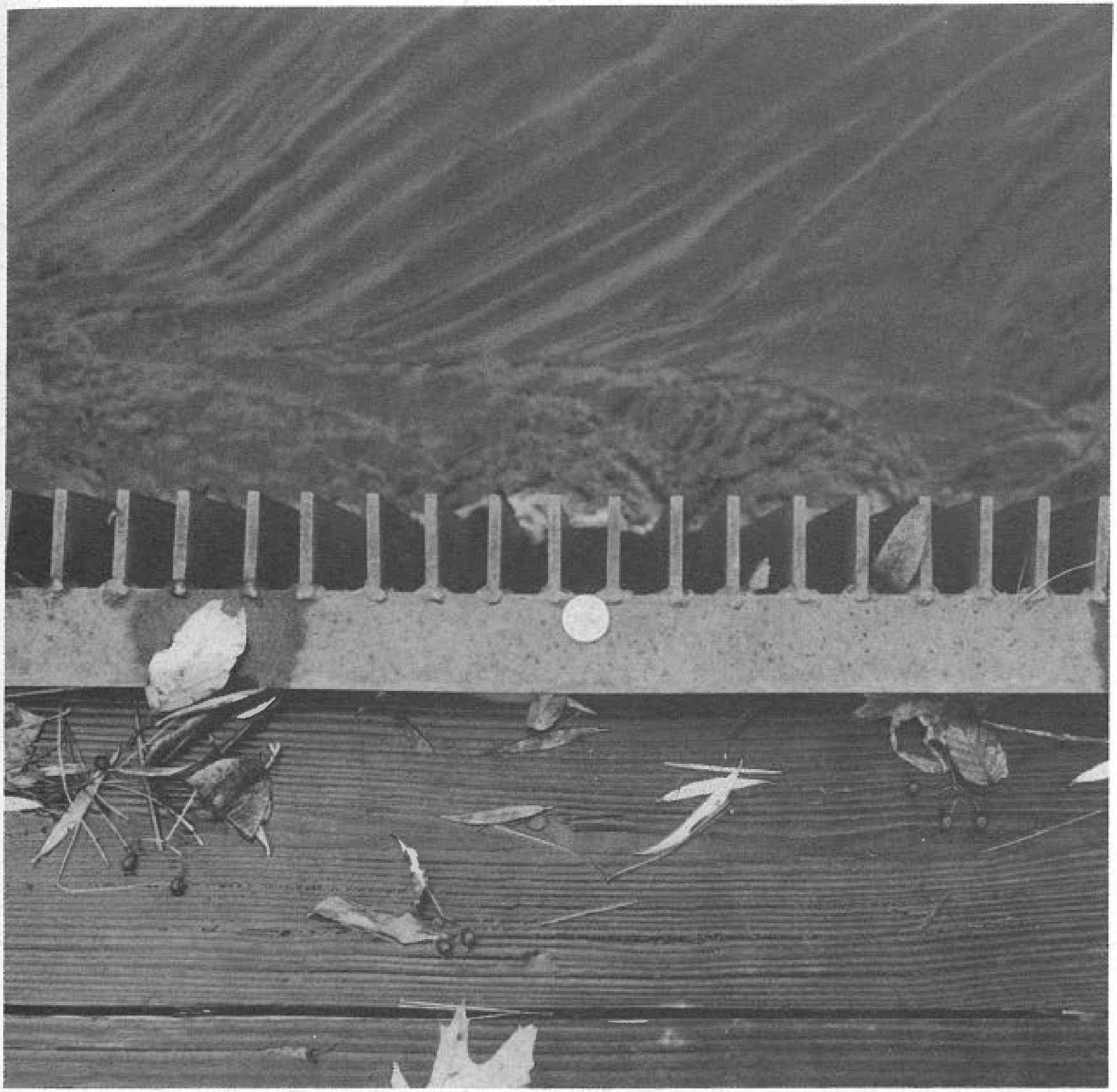

Figure 18-3. Wadhams angled bar rack with quarter on rack. Flow is angled to rack.

problem. Moreover, spill flows were very important for moving tagged smolts downstream in this study; 40% of the tagged fish that were transported below the dam when the angled trash rack was in place passed over the spillway rather than the angled screen's diversion chute. It is difficult to assess the general value of angled screens as a mitigative measure because of the small numbers of a single species of fish that have been tested. However, the Wadhams study indicates that angled trash racks can divert a significantly greater proportion of downstream-migrating fish from a turbine intake than can a conventional perpendicular trash rack.

18.2 Mitigation Benefits

18.2.1 Benefits to Fish Populations. No information about the effects of the angled bar rack on the Atlantic salmon population is available.

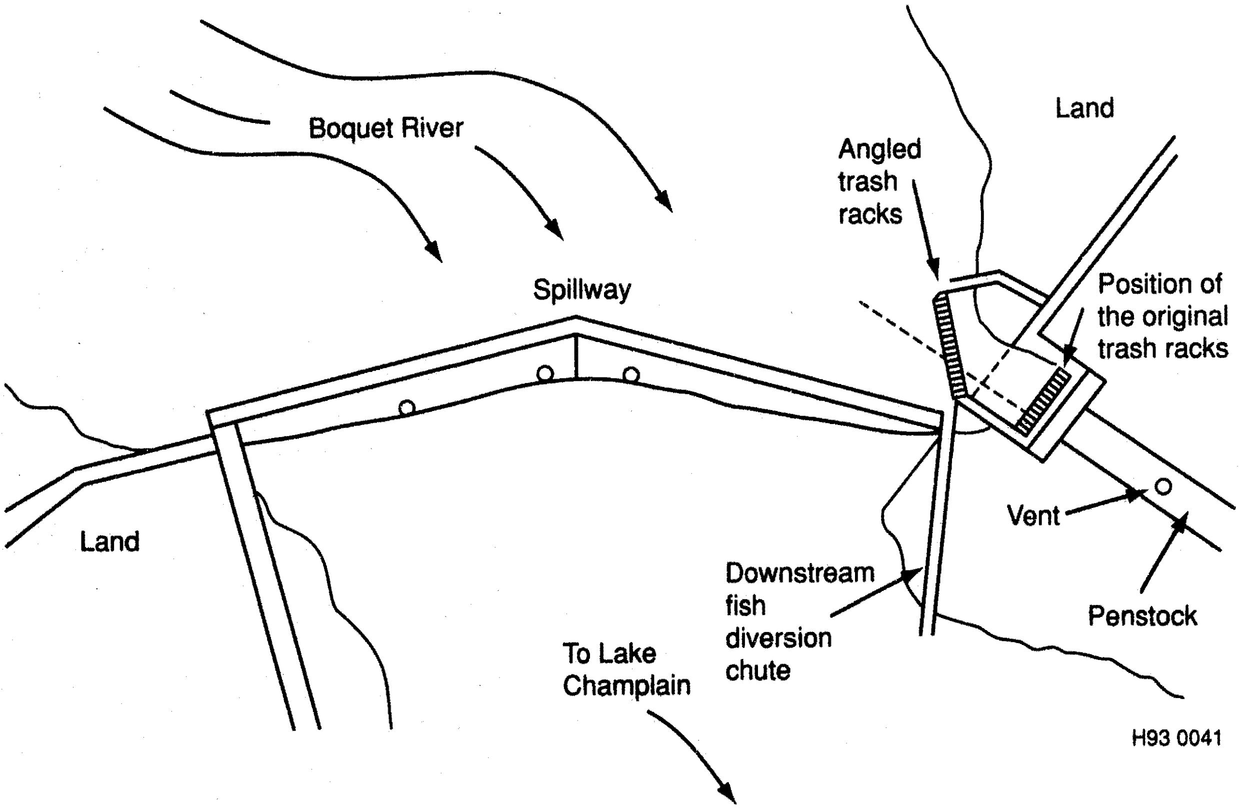

Figure 18-4. Layout of Wadhams project, including the fish diversion chute and angled trash rack. The powerhouse is to the right, downstream of the penstock.

18.2.2 Benefits to Fisheries. No information about the effects of the angled bar rack on the Atlantic salmon fishery is available.

18.3 Mitigation Costs

18.3.1 Introduction. The mitigation cost analysis for the Wadhams hydroelectric plant consists of a cost summary section discussing the downstream mitigation costs in general terms, and a downstream mitigation section discussing the components and costs of the downstream fish passage/protection system. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal correspondence, telephone calls, and a site visit that greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

18.3.2 Cost Summary. The Wadhams downstream fish passage/protection mitigation system includes an angled trash rack to avoid turbine entrainment and a fish bypass for the stocked Atlantic Salmon smolts that migrate to Lake Champlain. There are no upstream passage/protection costs as there is no upstream mitigation.

The capital costs total $4,700 and the average annual cost is $2,184 (Table 18-2). Combining the capital costs and the 20-years of annual costs equates to a total mitigation cost of $48,380 and a levelized annual cost of $2,419. The project generates approximately 2,000 megawatt-hours of electricity annually. Based on the levelized annual cost of $2,419, the average cost of downstream mitigation is 1.2 mills per kilowatt-hour of electricity.

18.3.3 Trash Racks. The angled trash rack was fabricated in 1983 by the operator, following the recommendations of the U.S. Fish and Wildlife Service and the New York State Department of Environmental Conservation. The cost to fabricate and install the angled trash rack was $3,900 (1993 dollars). There are no annual costs associated with the angled trash rack.

Figure 18-5. Wadhams project diversion dam, angled bar racks, and bypass used seasonally with wood deck sluiceway.

18.3.4 Bypass Sluiceway. The sluiceway was fabricated by the licensee and has a wood deck and dual five-inch steel channel I-beam supports (Figure 18-7). The sluiceway is 24-inches wide and 32-feet long. It was constructed and placed in operation in 1983 at a cost of $800 (1993 Dollars). The only annual sluiceway cost is for the installation and removal of the sluiceway each year. The sluiceway is removed during the non-migratory majority of the year to avoid being damaged. It is estimated that the installation/removal process requires a total of 8 hours of labor per year. Assuming an average personnel value of $30 per hour, this cost is $240 per year. A licensee-owned crane is used to ease the installation/removal tasks with minimal additional cost.

18.3.5 Lost Generation Costs. This project has specific spill requirements for the sluiceway that can be recognized and measured. Wadhams spills 10 cfs of water via the sluiceway for 45 days a year to aid the downstream bypass of the

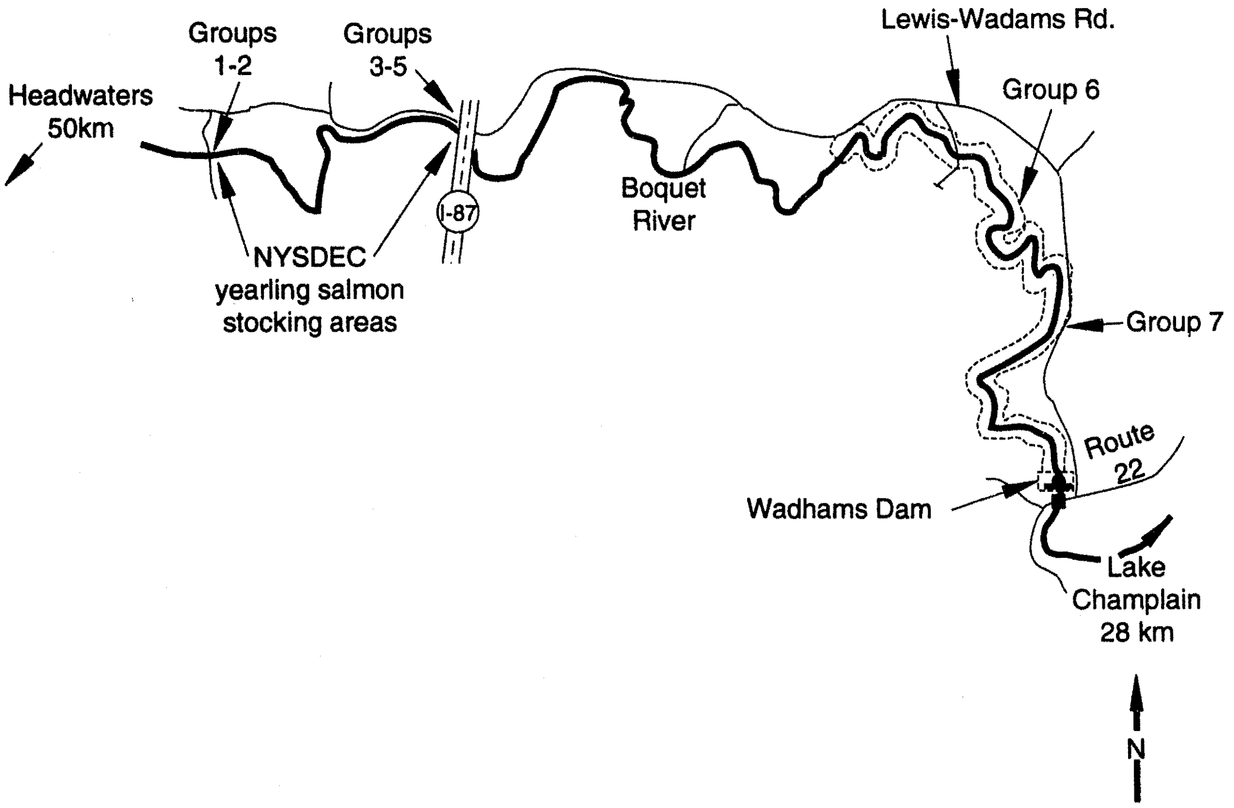

Figure 18-6. Seven release locations of radio-tagged salmon smolts, above the Wadhams Dam (Nettles and Gloss, 1987).

Table 18-1. Numbers of radio-tagged Atlantic salmon smolts that migrated downstream using the three dam passage routes at the Wadhams project. N is the number of fish released in each group. Source: Nettles and Gloss (1987).

Release group (N)	Dam passage routes				Percent of fish not accounted for after 2 weeks
	Penstock	Bypass chute	Spillway	Total	
1(24)	0	1	5	6	13
2(24)	0	2	2	4	24
3(23)	0	9	4	13	22
4(23)	2[a]	6	1	9	9
5(22)	0	0	0	0	68
6(27)	0	3[a]	0	3	74
7(27)	1[a]	0	0	1	74
Total	3	21	12	36	42

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a. Passages occurred after trash rack had been changed from the experimental angled bar rack to a conventional bar rack perpendicular to flow.

Table 18-2. Twenty-year capital and annual cost items and totals at Wadhams.

	Cost ($)	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital costs				
Angled trash rack	3,900	3,900		
Sluiceway	800	800		
Subtotal	4,700	4,700	235	0.1
Annual costs				
Sluiceway (in/de-stall)	240	4,800		
Lost generation	1,944	38,880		
Subtotal	2,184	43,680	2,184	1.1
Total costs		48,380	2,419	1.2

Atlantic salmon smolts. Each cubic foot of water has a energy value of 3 kilowatts. Assuming an energy value of $0.06 per kilowatt-hour of electricity, the lost generation equation is

3 kWh × 24 hours × 45 days × 10 cfs × $0.06 = $1,944.

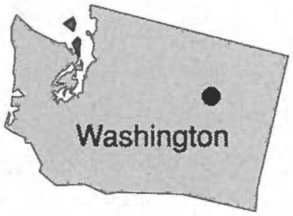
The total annual lost generation cost for the downstream fish passage/protection system is $1,944. Additional spill flows occur from approximately April 1 through June 30, during spring runoff. These runoff flows exceed plant capacity and are not included as a cost of lost generation.

Figure 18-7. Wadhams wood deck sluiceway.

19. WELLS CASE STUDY

19.1 Description

The Wells Hydroelectric project (FERC number 02149) is located on the main stem Columbia River (Figure 19-1), in Douglas and Chelan Counties, Washington, and is a run-of-river development (Figure 19-2). Its unique hydrocombine design integrates the powerhouse, spillway, switchyard, and fish facilities (upstream and downstream passage/protection) components, in contrast to a conventionally designed hydroelectric project that separates these structural components. A hydrocombine is a dam with the spillway directly above the turbine intakes (Figure 19-3). The project began operating in August 1967, and generates approximately 4,000,000 megawatt hours of electrical energy annually. The hydrocombine is 1,130 feet long and 185 feet high. It has 10 turbines and a generation capacity of 840 megawatts.



The project is at a river location that affects the upstream and downstream passage/protection of anadromous and resident fish species. Upstream and downstream fish passage/protection systems are designed and operated to facilitate primarily the passage of anadromous salmonid species around the project. Anadromous salmonid species that migrate past the project include spring, summer and fall runs of chinook salmon, sockeye salmon, and steelhead trout. Resident fish species (mainly cyprinids and catostomids) are abundant in the main stem Columbia above and below the project. These resident species include: mountain whitefish, large-mouth bass, smallmouth bass, walleye, redside shiner, northern squawfish, peamouth chub, carp, largescale sucker, and sculpins.

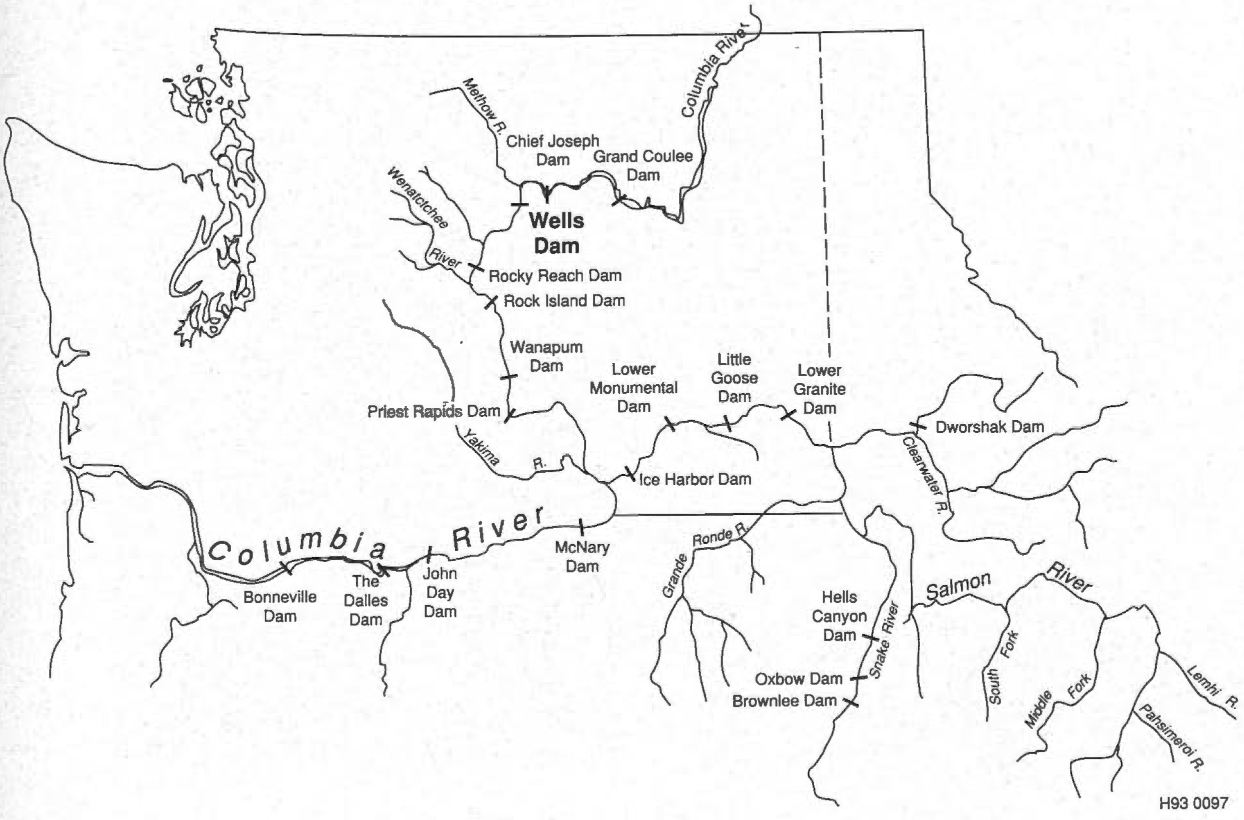


Figure 19-1. Location of the Wells project on the Columbia River.

Figure 19-2. Site Photograph of Wells hydrocombine hydroelectric project.

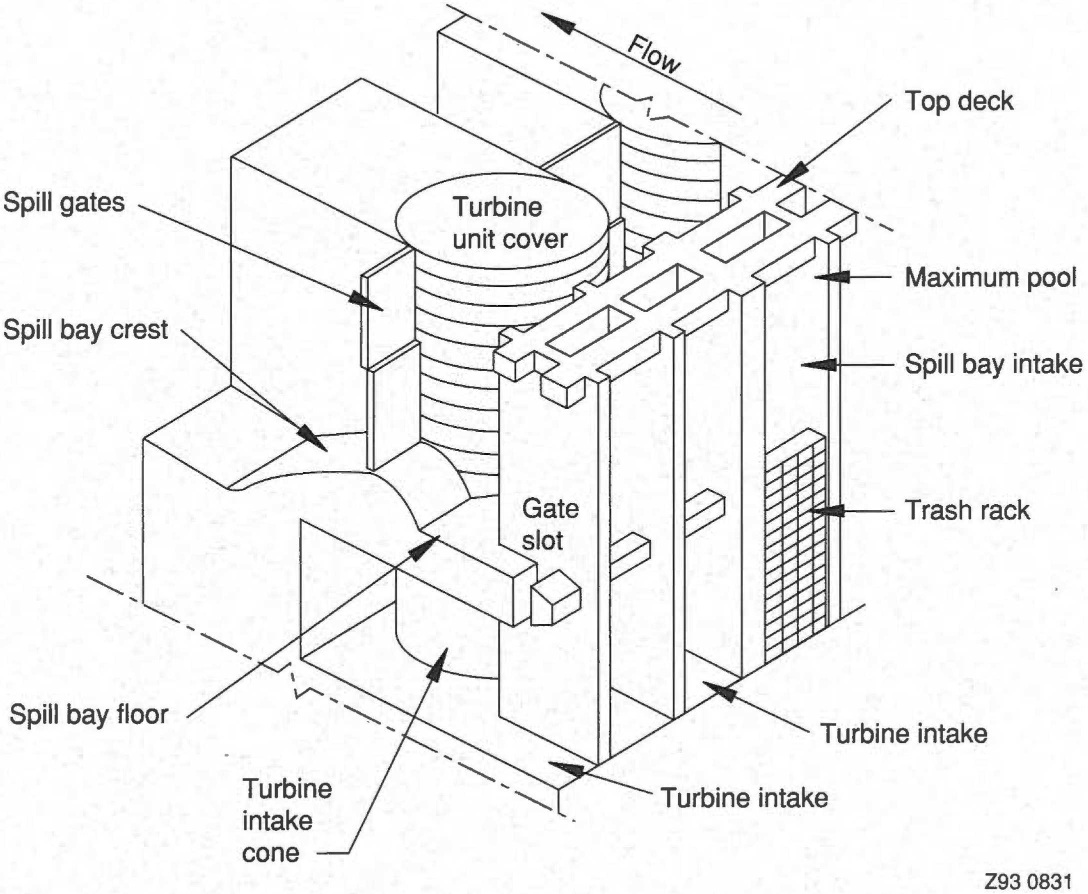


Figure 19-3. Wells hydrocombine structure with spill intakes directly above turbine intakes.

The upstream passage/protection system comprises identically designed fish ladder facilities located on the right and left banks of the project. Each fishway is 12 feet wide and is of pool-weir design (with a submerged orifice), having 73 pools in a staircase configuration (Figures 19-4 and 19-5). About 1 foot of hydraulic head is dissipated at each weir, with variations. The drop in each of the upper 17 pools varies from 1-foot maximum to 6-inch minimum when the reservoir is drawn down; this drop accommodates an 8-foot head of reservoir-level fluctuation to permit power generation. The fishways descend low enough to reach the lowest tailwater elevation anticipated. The upstream passage/protection system also has ancillary facilities for the monitoring (fish counts) and capturing (broodstock collection) of adults (Figure 19-6).

The downstream juvenile passage/protection system is incorporated in the hydrocombine structure. This system has a fish bypass with a vertical slot barrier placed in the spill intakes that creates attraction flows for downstream migrant juvenile fish (Figures 19-7 and 19-8). Once entrained in the attractant flow, fish enter the bypass and are diverted past the dam instead of passing through the turbines.

19.1.1 Fish Resource Management Objective of Mitigation. The resource management objective of the upstream and downstream passage/protection systems for this case study is predicated on the fisheries agencies policy that no induced mortality of fish species will result from the hydroelectric generation components of the project. This objective is facilitated by the design

Figure 19-4. Wells adult fish ladder, looking down the ladder.

and operation of the upstream and downstream passage/protection systems to attract and route adult and juvenile fish species (primarily anadromous) past the project's powerhouse generating units.

19.1.2 Monitoring Methods. A settlement agreement between the fisheries agencies and the project operator sets forth measures and methods for monitoring impacts to fisheries resources relative to the mitigation measures of the project. Schedules, criteria, and conditions of monitoring are described in the agreement. The project operator develops and implements an annual operations plan for the upstream and downstream fish passage/protection systems consistent with the criteria and conditions stated in the agreement. Evaluation studies of the fish passage/protection systems were funded by the operator and have been conducted to substantiate schedules, criteria, and conditions for operating and monitoring components of the project, as described in the agreement.

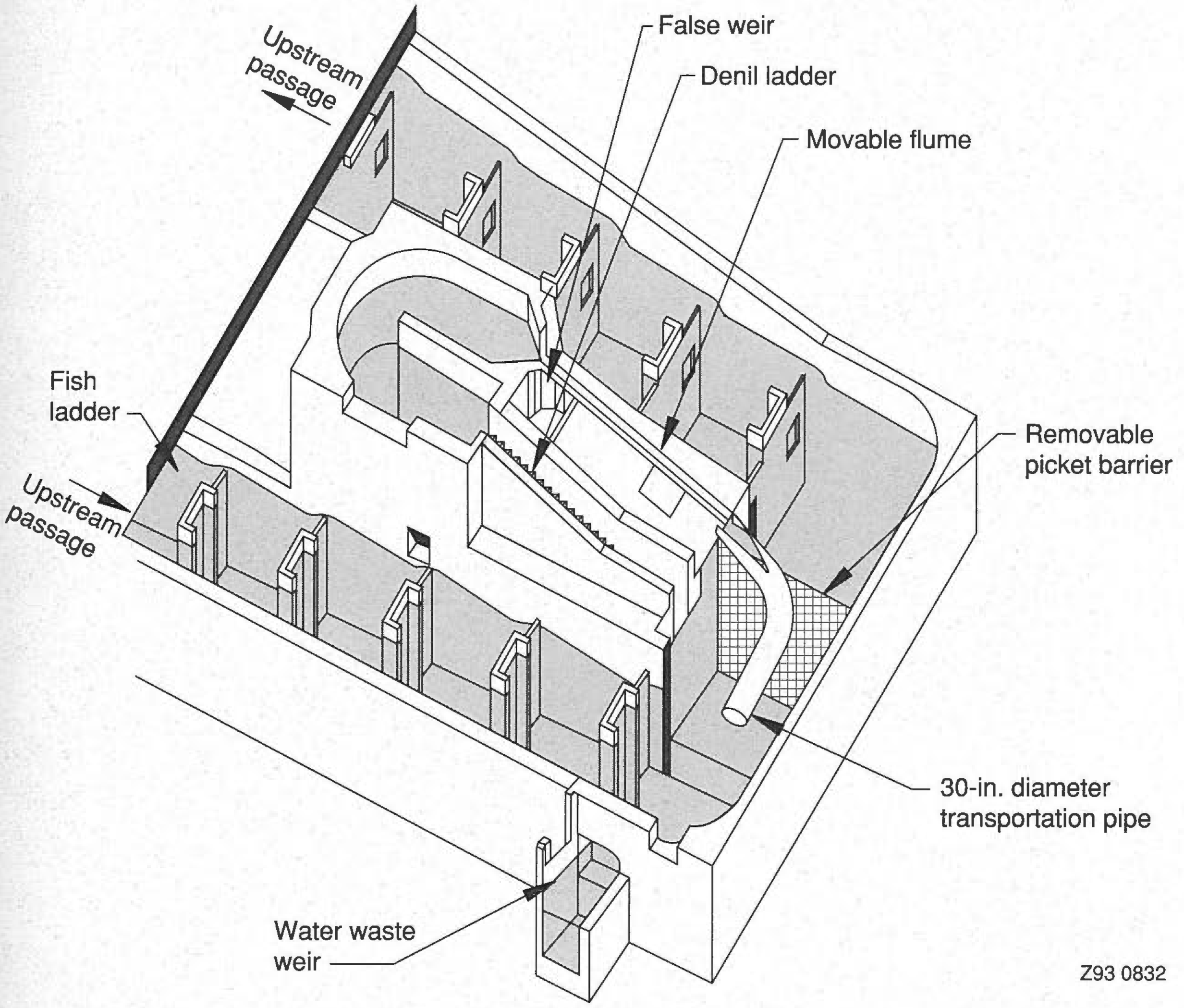


Figure 19-5. Adult fish passage ladder system at Wells. Wells has two ladders, at opposite ends of the powerhouse.

Upstream anadromous fish passage is continuously monitored at the project. The downstream bypass operation of the juvenile fish passage/protection system is monitored in accordance with the fisheries agencies agreement. Indices are currently being developed for monitoring the status of juvenile out-migration past the project (Klinge, personal communication)

19.1.3 Performance of Mitigation. Performance of the downstream passage/protection system has exceeded the criterion for the bypass operations, which is a fish passage efficiency of 80.0% during spring and 70.0% during summer. Downstream passage/protection systems designed for other hydroelectric facilities of the Columbia River basin are generally less efficient than that of this project. For example, Giorgi and Sims (1987) reported that an estimated 54% steelhead and 33% yearling chinook were collected in the bypass system when 76% of the river flow was discharged through the McNary Dam powerhouse. At 40% powerhouse discharge, rates for collecting fish emigrating by the dam was reduced to 16%. Juvenile fish guidance efficiency for chinook and steelhead at Lower Granite Dam on the Snake River was estimated to be 58% and 76%, respectively (Swan et al., 1983).

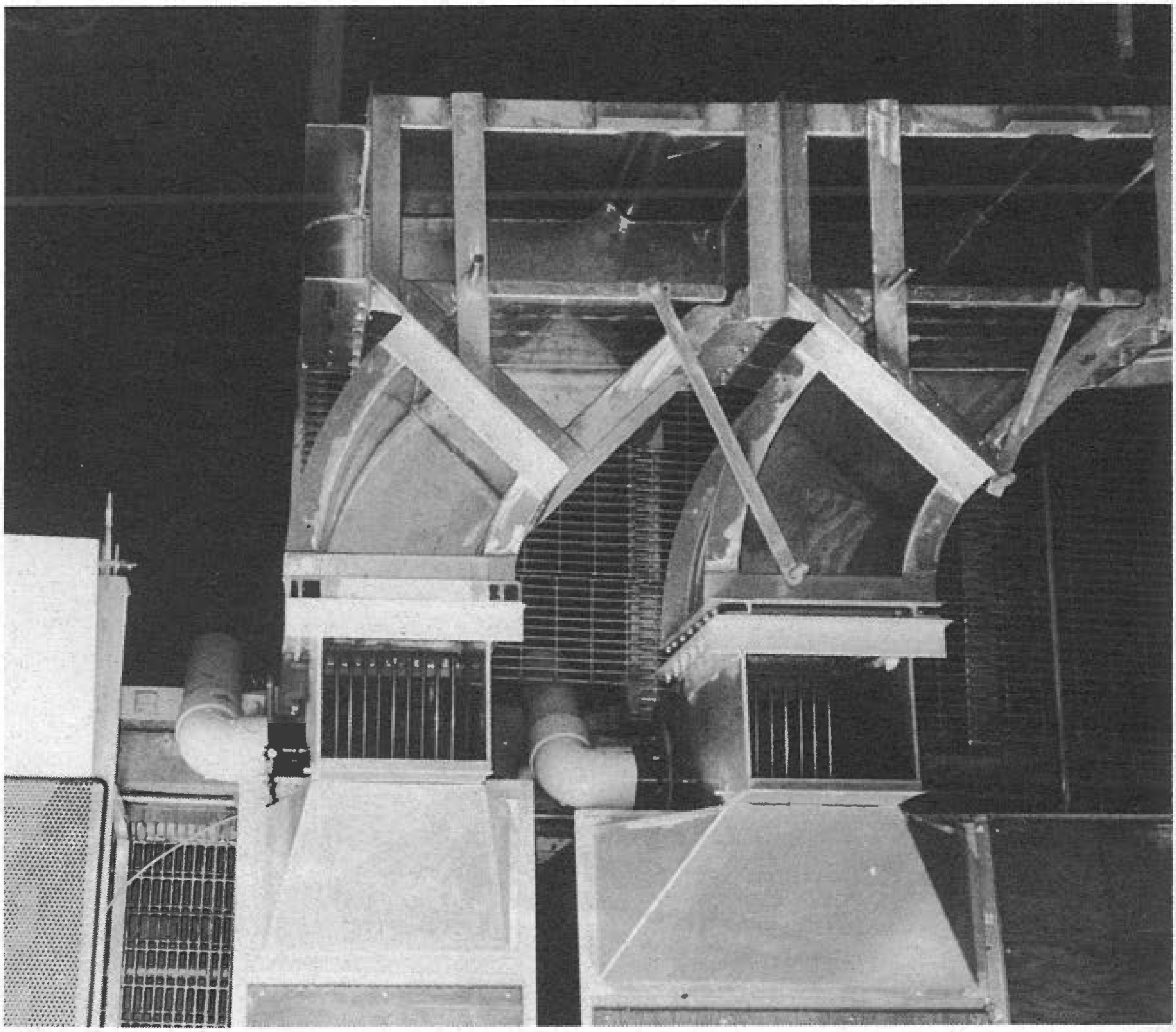


Figure 19-6. Wells broodstock collection facility.

Performance of the upstream passage/protection system (adult passage and collection) is currently under study. To date, the operation of the upstream passage/protection system has effectively passed adult migrants without delays or induced mortalities (Table 19-1).

19.2 Mitigation Benefits

19.2.1 Benefits to Fish Populations and Associated Fisheries. The upstream and downstream fish passage/protection systems of this case study have mitigated for impacts of the project's operations and have assisted in maintaining anadromous fish populations that contribute to significant sports and commercial fisheries above and below the project.

19.3 Mitigation Costs

19.3.1 Introduction. The mitigation cost analysis for the Wells hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; an upstream fish passage/protection system section, discussing the upstream mitigation costs; a downstream fish passage/protection system section, discussing the downstream mitigation costs; a lost generation section, discussing the upstream and downstream

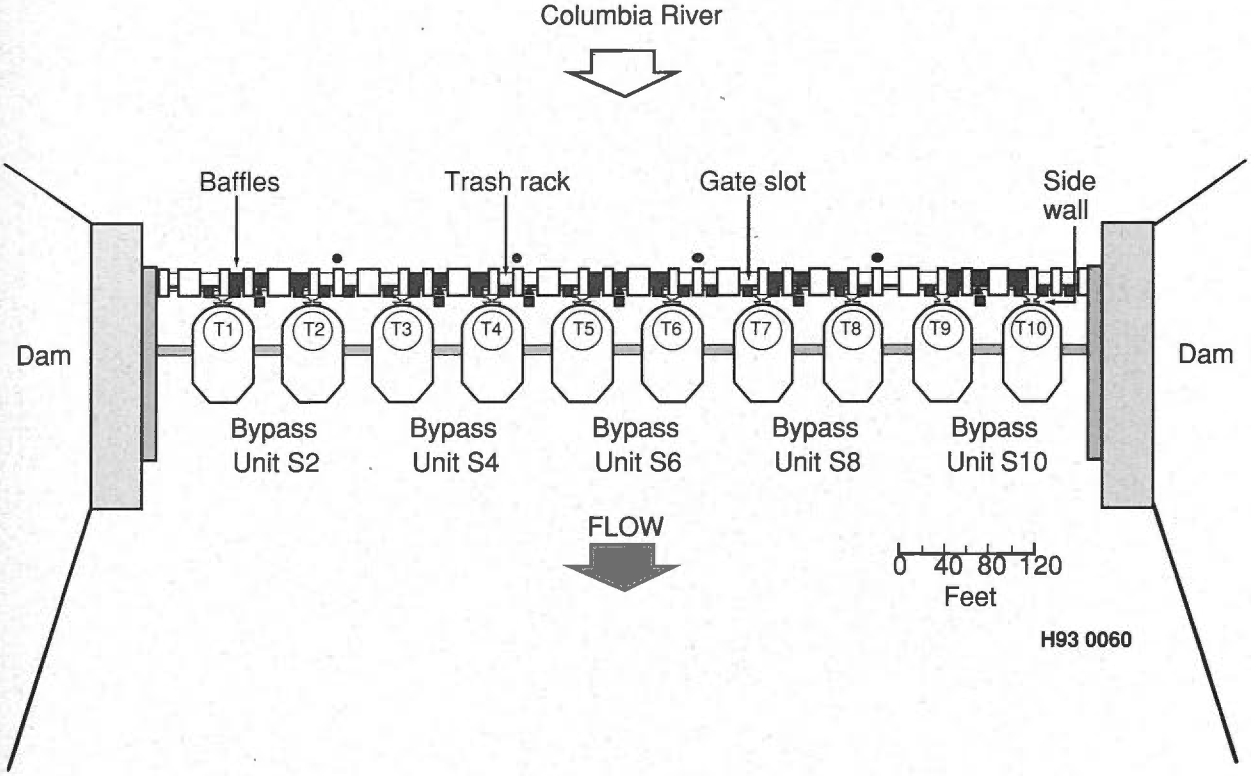


Figure 19-7. Bypass units and baffles of the Wells downstream fish passage/protection system. T1 through T10 are the 10 turbine/generator units.

mitigation costs of lost generation; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal correspondence, telephone calls, and a site visit that greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

19.3.2 Cost Summary. The mitigation methods at Wells are unique in that they are part of a hydrocombine design. Wells' two fish ladders are primarily enclosed within the dam structure. The costs of the ladders ($40.1 million) are the single largest mitigation cost element at Wells. The capital, study, and annual costs of upstream mitigation are 55% of all mitigation costs (Figure 19-9). Generation losses resulting from upstream or downstream mitigation requirements represent another 21% of the total costs. Capital, study and annual costs for downstream mitigation are the remaining 24% of the total cost of $84.3 million.

The 20-year, $84.3 million, total cost of mitigation (Table 19-2) is a large sum of money; however, when it is examined in relation to the entire Wells' facility size and costs, the magnitude of mitigation costs may appear different. For the years 1983 through 1992, Wells generated over 40 million megawatt-hours of electricity. Assuming this is a sufficient sample of yearly generation, the cost analysis then used the average annual net generation of 4,097,851 megawatt-hours to compute the mitigation costs per kilowatt-hour of generation. With the total mitigation cost of $84.3 million levelized over 20 years, the average annual cost is $4.2 million (Table 19-2). Placing the $4.2 million cost into the perspective of the size of the Wells facility, a cost per kilowatt-hour of generation can be derived. Based on the average electrical generation of 4,097,851 megawatt-hours, the cost of mitigation at Wells is 1.0 mills per kilowatt-hour, or about one-tenth of

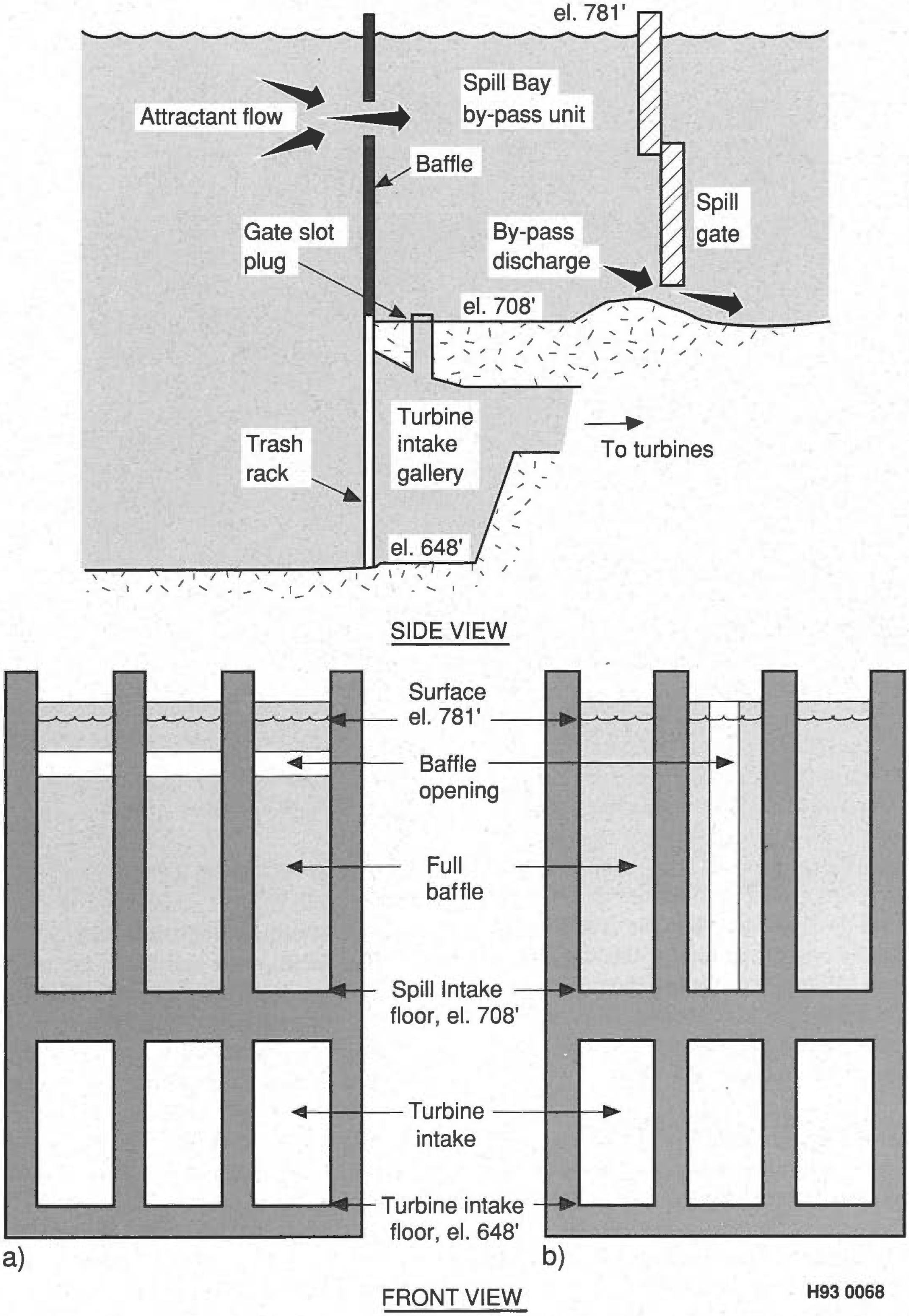


Figure 19-8. Wells hydrocombine front and side views of downstream fish passage/protection bypass unit, showing horizontal and vertical baffle openings and attractant flows.

Table 19-1. Annual upstream adult fish passage counts at the Wells project, 1967–1992.

Year	Spring chinook	Summer chinook	Fall chinook	Chinook trapped	Total chinook	Coho	Sockeye	Steelhead	Steelhead trapped	Total steelhead	Total salmonids	Period of count
1967	1,157	12,504	2,732	2,004	18,397	255	113,232	1,474	171	1,645	133,529	5/21–11/19
1968	4,931	8,922	2,623	2,277	18,753	221	81,530	2,112	413	2,525	103,029	5/21–11/19
1969	3,599	6,846	2,929	2,873	16,247	29	17,352	1,391	530	1,921	35,549	5/01–11/15
1970	2,670	8,003	4,388	1,745	16,806	62	50,667	1,597	399	1,996	69,531	5/01–11/15
1971	3,168	5,988	2,030	1,793	12,979	161	48,172	3,782	358	4,140	65,452	5/01–11/15
1972	3,616	4,141	2,419	1,694	11,870	665	33,398	1,894	354	2,248	48,181	4/30–11/15
1973	2,937	[illegible]052	2,650	2,088	12,727	331	37,178	1,820	627	2,447	52,583	4/30–11/15
1974	3,420	4,567	1,114	2,893	11,994	112	16,716	580	260	840	29,662	4/31–10/31
1975	2,225	8,522	3,806	3,253	17,806	25	22,286	517	227	744	40,861	5/01–10/31
1976	2,759	7,901	3,843	2,518	17,021	99	27,619	4,664	337	5,001	49,740	5/01–10/31
1977	4,211	7,527	3,260	2,628	17,626	68	21,973	5,282	355	5,637	45,304	5/01–11/15
1978	3,615	6,419	1,336	2,259	13,629	77	7,458	1,621	356	1,977	23,141	5/01–11/15
1979	1,103	10,080	1,108	2,352	14,643	63	22,655	3,695	367	4,062	41,423	5/01–10/31
1980	1,182	4,892	709	1,827	8,610	82	26,573	3,443	372	3,815	39,080	5/01–11/16
1981	1,935	4,276	686	1,533	8,430	26	28,234	4,096	650	4,746	41,436	5/01–11/22
1982	2,401	3,349	2,064	700	8,514	357	19,005	7,984	590	8,574	36,450	5/01–11/22
1983	2,869	2,821	1,150	942	7,782	82	27,925	19,535	679	20,195	55,984	5/01–11/22
1984	3,280	5,941	1,812	1,094	12,127	104	81,054	16,632	690	17,322	110,607	5/01–11/30
1985	5,257	4,456	2,097	1,689	13,499	72	53,170	19,867	750	20,617	87,358	5/01–11/25
1986	3,150	4,178	1,143	1,118	9,589	87	34,876	13,303	650	13,953	58,505	5/01–11/22
1987	2,344	3,142	3,253	1,275	10,014	42	39,948	5,493	603	6,096	56,100	5/01–11/14
1988	3,036	2,775	1,935	1,364	9,110	75	33,980	4,401	651	5,052	48,217	5/01–11/13
1989	1,740	3,333	1,435	2,147	8,655	14	15,895	4,600	716	5,316	29,880	5/01–10/31
1990	981	3,354	749	1,109	6,193	32	7,597	3,815	735	4,550	18,372	5/01–10/31
1991	779	2,028	827	1,525	5,159	21	27,492	7,751	726	8,477	41,149	5/01–11/07
1992	1623	1,967	1,503	132	5,225	28	41,844	7,027	633	7,027	54,124	5/01–11/15

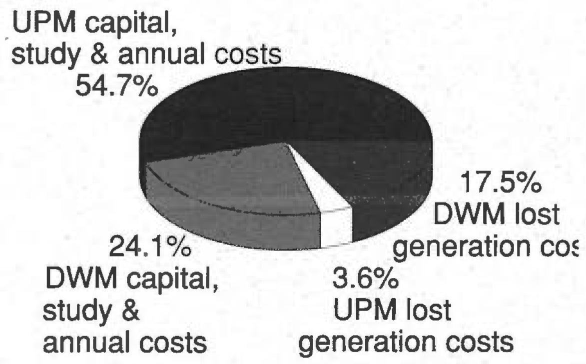


Figure 19-9. Total upstream (UPM) and downstream (DWM) mitigation costs at the Wells project. Upstream and downstream mitigation slices include capital, study and annual costs. Rounding may result in a total other than 100%.

a cent per generated kilowatt-hour. This is about 17% of the cost to produce a kilowatt-hour at Wells. The actual annual costs (excluding the original cost of construction) varies for about $1 million to almost $4 million (Figure 19-10).

19.3.3 Upstream Fish Passage/Protection. The size of the upstream fish passage/protection system costs at Wells are driven by the magnitude of the construction costs of the two fish ladders. The ladders cost $40.1 million, which is 87% of all upstream mitigation costs, excluding lost generation. Including study costs of $2.1 million and 20-year annual operating costs of $3.5 million, the total cost of upstream mitigation over 20 years is $46.1 million (Table 19-3). The operating costs include upstream mitigation related duties such as fish counts, staff personnel, and the operations and maintenance of the ladders and attraction flows system. The 20-year levelized annual cost for upstream mitigation is $2.3 million and the cost per kilowatt-hour is 0.56 mills. With the cost of lost generation due to upstream mitigation practices included, the cost per kilowatt-hour grows to 0.60 mills.

19.3.3.1 Capital and Study Costs. The upstream mitigation capital and study costs total $42.7 million. The single largest mitigation cost for the entire project are the two fish ladders, with a combined cost of $40.1 million, or $20.1 million for each ladder. The ladder cost compares with the cost of other ladders constructed at other hydroelectric projects on the Columbia River (Sale et al., 1991 and general cost information section of this report, Section 3). The other cost items in this category are the adult broodstock collection facilities ($0.48 million), which are adjacent to the fish ladders, and the $2.1 million cost of studies. The $2.1 million is 15% of the total study cost reported by the licensee for mitigation-related studies. The $42.7 million total for capital and study costs equates to a 20-year levelized annual cost of $2.1 million. This $2.1 million average is a poor reflection of the actual yearly costs (Figure 19-11).

19.3.3.2 Annual Costs. The upstream mitigation annual costs total $3.5 million for the entire 20-year analysis period. The 20-year levelized cost for the upstream mitigation related annual costs is $173,000, and the cost per kilowatt-hour of generated electricity is 0.04 mills. The annual upstream mitigation costs include operations and maintenance for the ladders and attraction flows, annual counting of ladder trips, and annual staff costs for upstream mitigation issues.

The annual operations and maintenance costs for the ladders and attraction flows total $1.5 million for 20 years. The 20-year levelized annual cost is $76,000. Annual counting cost a total of

Table 19-2. Twenty-year costs incurred at the Wells project for upstream and downstream mitigation.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Upstream	46,144,349	2,307,217	0.56
Downstream	20,356,321	1,017,820	0.25
Lost generation	17,847,200	892,360	0.2
Total costs	84,347,870	4,217,394	1.0

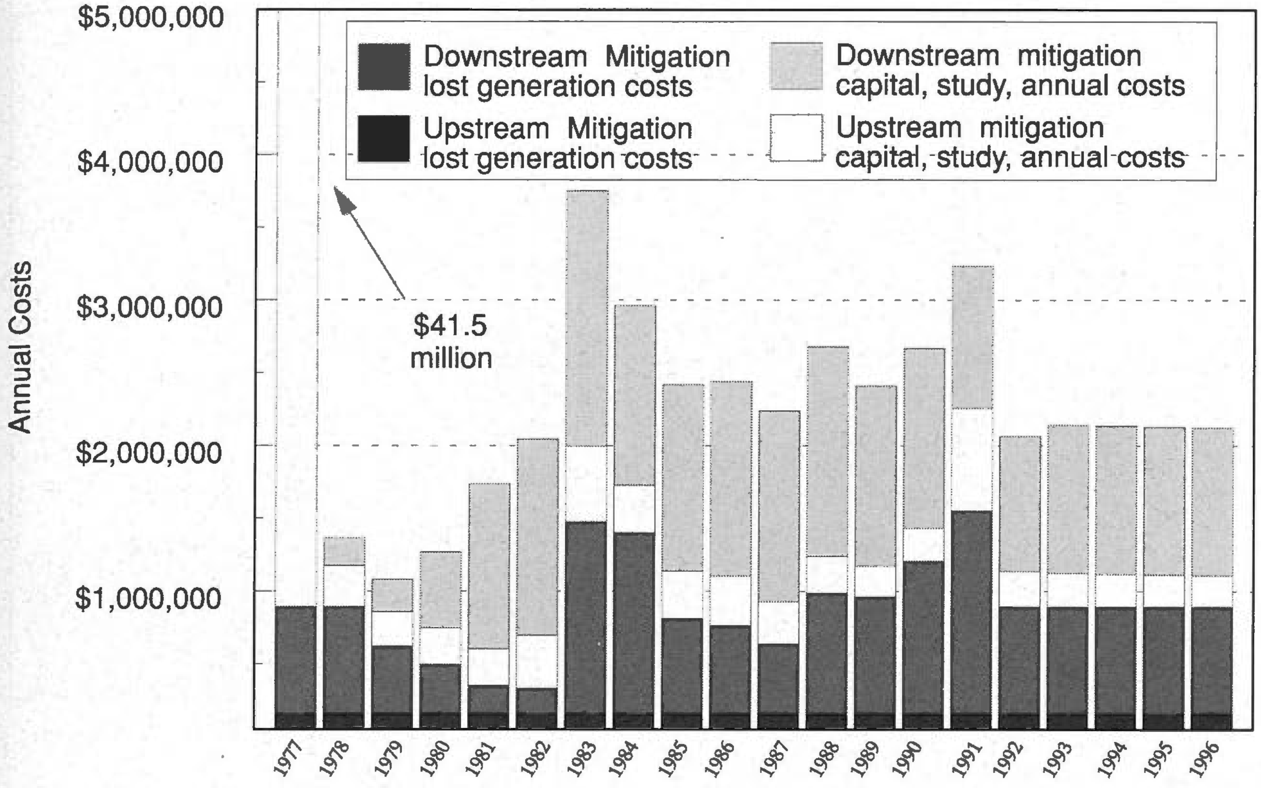


Figure 19-10. Yearly upstream and downstream mitigation costs, which include capital, study and annual costs, and lost generation costs. The fish ladders were constructed in 1967 and are carried in 1977 for analysis purposes, inflating the 1977 costs.

Table 19-3. Twenty-year costs incurred for upstream mitigation at the Wells project.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital and study costs	42,688,164	2,134,408	0.52
Annual costs	3,456,185	172,810	0.04
Total upstream costs	46,144,349	2,307,217	0.56

$1.2 million for the 20 years. The levelized annual cost for counting is $58,000, or $29,000 per ladder. The other annual cost for upstream mitigation is the staff personnel cost. A full-time biologist is assigned to fish passage/protection duties and is assisted by other Wells' staff as required. The staff personnel costs were provided as totals for both upstream and downstream mitigation, and the costs were evenly split for analysis purposes. The 20-year total staff cost for upstream mitigation is $762,000, or $38,000 annually.

19.3.4 Downstream Fish Passage/ Protection. The total 20-year cost of downstream mitigation, excluding lost generation, is $20.4 million (Table 19-4). The downstream mitigation costs are distributed as 64% for capital and study costs and 36% for annual costs. The 20-year levelized annual cost of downstream mitigation is $1 million. With an average yearly energy generation of 4,097,851 megawatt-hours, the levelized cost of downstream mitigation is 0.25 mill per kilowatt-hour. If the cost of downstream-

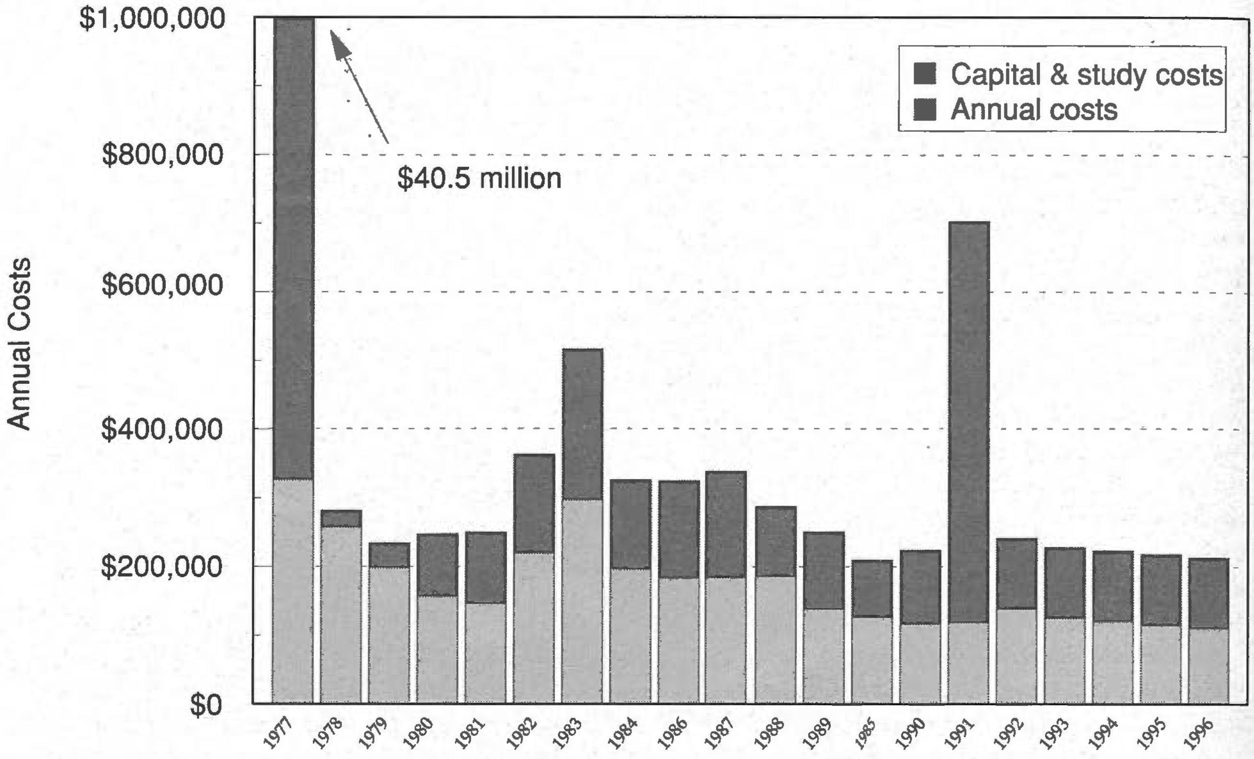


Figure 19-11. Yearly costs of upstream mitigation, including capital and study and annual costs, excluding the cost of lost generation. The fish ladders were constructed in 1967 and are carried in 1977 for analysis purposes, inflating the 1977 totals.

Table 19-4. Twenty-year costs incurred for downstream mitigation at the Wells project.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital and study	13,095,576	654,780	0.16
Annual costs	7,260,745	363,040	0.09
Total downstream costs	20,356,321	1,017,820	0.25

mitigation-related lost generation is included, the cost per kilowatt-hour for downstream mitigation is 0.4 mills, or about four-hundredths of a cent per kilowatt-hour of generated electricity. Variations in actual yearly costs have been driven by lost generation and study costs as well as capital expenditures for the intake barriers (Figure 19-12).

19.3.4.1 Capital and Study Costs. The five spillway intake barriers, at a total of $1.1 million, and the gate hoists, at $200,000, are the only capital cost items. The downstream mitigation study costs are estimated at $11.8 million. The yearly variations in capital and study costs were driven by the fabrication costs of the spillway intake barriers (1987–1990) and the associated spillway intake barrier design studies.

19.3.4.2 Annual Costs. The annual costs for 20 years of downstream mitigation totaled $7.2 million. The annual costs and their 20-year totals included hydroacoustic annual monitoring ($6.5 million) and staff costs ($762,000). The licensee provided combined staff costs for both upstream and downstream mitigation, including a full-time fisheries biologist assigned to fish

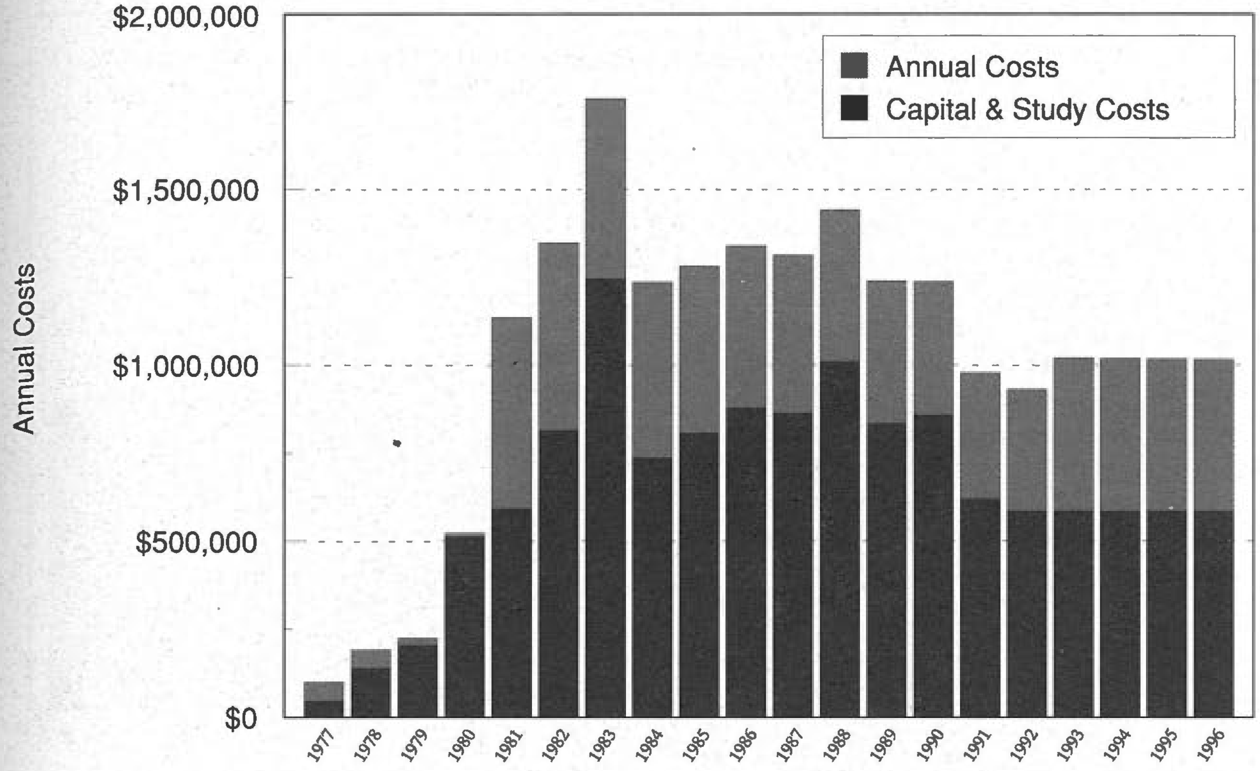


Figure 19-12. Yearly costs of downstream mitigation at the Wells project. Includes capital and study costs and annual costs, and excludes the costs of lost generation.

passage/protection issues, and other staff on a part-time basis. Half of the staff costs were assumed for upstream mitigation and half for downstream mitigation.

19.3.5 Lost Generation Costs. Attempting to determine whether or not water release practices associated with mitigation requirements constitutes a specific cost in the form of lost generation can be very arduous. For instance, it is assumed that the 300 cfs of water used for the two fish ladder flows and fish ladder attraction flows would flow through the turbines if not used for upstream fish passage. These 300 cfs flows would not be used for instream flows or dissolved oxygen requirements; they are used only for upstream mitigation. The flows sent through the downstream juvenile bypass occur only from the middle of April through the middle of August, when salmonid are migrating downstream.

The water flows used for upstream and downstream mitigation at Wells has been computed on a yearly basis and are added to the total and levelized costs. However, the generation losses are reported separately from the upstream and downstream mitigation costs in an effort to allow the reader to differentiate between the hard costs such as ladders, studies and personal, and the soft costs of foregone generation.

It is anticipated that over 300 million cubic feet of water will be spilled for mitigation purposes from 1977 through 1996. This equates to over 1 billion kilowatt-hours of electricity. Of this total, 83% is for the downstream migrants. Operation of the two fish ladders is such that the annual cost of flows for upstream mitigation is constant (Figure 19-13). The costs of lost generation for downstream mitigation has exhibited significant fluctuations, a consequence of the amounts of water released each year for migrating smolts.

The 20-year total cost of lost generation at Wells is $17.8 million; the average annual cost is $892,000 (Table 19-5). The annual net generation at Wells averaged 4,097,851 megawatt-hours possible to directly compare the construction cost with other projects' similarly constructed fish ladders. The cost is, however, comparable to similarly sized projects on the Colombia River.

2. **UPM—East Ladder Fish Sorting.** The $475,000 cost is for an adult monitoring and broodstock collection facility.

3. **DWM—5 Spillway Intake Barriers.** The five spillway intake barriers were constructed during the period 1987 through 1990. A single cost was provided by the licensee and was averaged over the 4 years and indexed to 1993 dollars. The total cost for all of the barriers was $1,062,420. The barriers are placed in the trash rack slots in each of the three spill intake bays. The center barrier has a vertical slot 16 feet across that extends from the surface of the pool to the floor of the spill bay. Five of the 11 spillways were altered by constricting the intake openings from 72 feet to 16 feet. The constriction creates velocities at the face of the dam that attract salmon and steelhead to the spillways instead of to the turbines.

4. **2 Gate Hoists.** Two gate hoists were required for the operation of the spillway gates as part of the downstream migrant bypass system. The cost was estimated at $100,000 per hoist.

19.4.2 Study Costs.

5. **Study, Equipment, Labor, etc.** The total cost of $13.9 million includes the personnel and all equipment required for the numerous fishery studies. A complete breakdown of the total cost by study titles and individual costs is unavailable. The individual studies performed may include efforts not related to fish passage and that may inflate the reported costs of fish passage/protection-associated studies. However, these potential deficiencies are believed to be of a small magnitude. The costs of studies performed and to be preformed during the last 5 years of the cost analysis period (1992–1996) are estimated based on the average for the past years. The total study cost of $13.9 million does include the following study areas: evaluation of the bypass system at Wells; the development and testing of the prototype bypass system between 1982 and 1989; system mortality study of spring chinook for above Wells Dam to below Priest Rapids Dam 1982 to 1984; turbine mortality study at Wells Dam in 1979 and 1980; and monitoring downstream migration of salmon and steelhead with scanning sonar in 1980. These are only a small percentage of the funded studies at the Wells project. It is unknown what exact percentage of study costs were incurred by upstream and downstream mitigation. However, the licensee has estimated that downstream mitigation studies represent 80% to 90% of total study costs. So, 85% of the study costs are assumed as a downstream cost and the remaining 15% are assumed as an upstream mitigation-related study cost.

19.4.3 Annual Operations and Maintenance Costs.

6. **UPM—Ladders/Pumps** (Est. after 1991). This includes the operations and maintenance costs of the two fish ladders and the associated attraction flow pump system used to entice the adults to enter one of the ladder systems. Historical operations and maintenance costs were provided for the years 1977 through 1991. The costs from 1992 through 1996 were estimated by averaging the historical costs. The 20-year total cost for the fish ladder and attraction pumping system is $1.5 million, or a yearly average of $76,000.

19.4.4 Annual Monitoring Costs.

7. **UPM—Counting** (Est. Pre 1983\after 1992). Historical costs of performing fish counts at the Wells ladders were provided for the years 1983 through 1992. Fish counting has occurred continuously since the ladder construction, so the counting costs

before 1983 and after 1992 have been estimated by using the average of the historical costs. The 20-year total cost is $1.2 million. The average annual cost is $58,000.

8. **DWM Migration Monitoring—Hydroacoustic.** The total cost of $6.5 million is for the hydroacoustic monitoring of downstream migration of salmon and steelhead. This activity has occurred since 1981. Based on the anticipation that this activity will continue in the future, the historical average annual cost ($406,180) is used to estimate the 1993 through 1996 costs. The total cost is $6.5 million.

19.4.5 Annual Personnel Costs.

9. **Staff Time** (Est. after 1991). The historical costs of staff time related to fish passage/protection issues at Wells was provided for the years 1977 through 1991. The average yearly historical cost was used to estimate the cost beyond 1991. This cost includes a full-time fisheries biologist dedicated to passage/protection issues, and other intermittent staff support. The 20-year total cost is $1.5 million. The yearly average cost is $76,000.

19.4.6 Lost Generation Costs.

The costs of lost generation associated with both upstream and downstream mitigation have been estimated based on volumes of water not used for generation owning to mitigation. The published energy rate of 13 mills for the Public Utility District Number 1 of Douglas County is used to estimate the costs of items 10 and 11.

10. **UPM—Ladder/Attraction Flows.** Each of the 2 fish ladders have flows of 100 cfs of reservoir water. Additional flows are used for attraction flows in and below the two fish ladders. The attraction flows are estimated at 50 cfs per ladder. The estimated total upstream mitigation flows are 300 cfs. The ladders operate continuously, all year round. Each cubic foot per second of water was converted to kilowatt-hours using the rate of 4.5 kilowatts per cfs. The 20-year total cost of lost generation for upstream mitigation is $3.1 million:

    300 (cfs) × 24 (hours) × 365 days) × 4.5 (kw/cfs) × $0.013 = $153,740

    $153,740 × 20 (years) = $3,074,800.

11. **DWM—Spills** (Est after 1991) (Downstream Mitigation spill flows for juvenile migration). Water is made available for the operation of the juvenile bypass system from the middle of April through the middle of August. There is a break in the downstream migration of salmonids at the Wells facility during the month of June. Operation of the bypass is suspended when salmonids are not actively migrating downstream.

    Records of the volumes of water released for downstream migration were obtained for the years 1979 through 1991. Releases actually have occurred since 1967, and it is assumed that releases will continue during the entire cost analysis period. The average from 1979 through 1991 was used to estimate the 1977, 1978, and 1992 through 1996 volumes. The water volumes were converted to kilowatt-hours of energy at the rate of 4.5 kilowatts/cfs of water. The 20-year total lost generation for downstream juvenile migration is $14.8 million.

Table 19-6. Wells mitigation costs.

Wells Project—Mitigation Cost Analysis—All Values in 1993 Dollars

9/1/93	–16	–15	–14	–13	–12	–11	–10	–9	–8	–7	–6	–5	–4	–3	–2	–1	0	1	2	3	
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	TOTALS
Capital Costs—Upstream Mitigation																					
1) UPM—Fish Ladders (2) (1967)	$40,124,960																				$40,124,960
2) UPM—East Ladder Fish Sorting															$475,000						$475,000
3) DWM—5 Spillway Intake Barriers											$283,390	$271,190	$259,500	$248,340							$1,062,420
4) DWM—2 Gate Hoists												$100,000	$100,000								$200,000
Study Costs																					
5) Study, Equipment, Labor, Etc.	$54,600	$164,500	$240,750	$604,320	$697,010	$959,130	$1,464,480	$866,400	$949,960	$1,034,280	$682,410	$752,700	$558,090	$716,670	$729,460	$689,320	$689,320	$689,320	$689,320	$689,320	$13,921,360
Annual O & M Upstream Mitigation																					
6) UPM—Ladders/Pumps (Est. after 1991)	$188,080	$123,860	$100,000	$72,660	$42,400	$107,100	$186,360	$84,710	$73,950	$73,490	$75,530	$34,890	$34,580	$33,090	$39,310	$56,150	$53,730	$51,420	$49,200	$47,090	$1,527,600
Annual Monitoring																					
7) UPM—Counting (Est. pre 1983\after 1992)	$85,960	$82,260	$78,720	$75,330	$72,080	$68,980	$65,260	$60,370	$62,650	$60,740	$52,260	$48,190	$45,420	$48,170	$49,030	$51,960	$42,510	$40,670	$38,920	$37,250	$1,166,730
8) DWM Migration Monit.—Hydroacoustic					$511,510	$489,490	$468,410	$448,230	$428,930	$410,470	$392,800	$375,880	$359,680	$344,210	$329,370	$315,190	$406,180	$406,180	$406,180	$406,180	$6,498,890
Annual Personnel Costs																					
9) Staff Time (Est. after 1991)	$105,160	$102,570	$38,890	$17,720	$62,750	$87,640	$91,630	$102,540	$92,440	$99,350	$114,600	$109,670	$91,820	$70,750	$60,060	$60,190	$57,600	$55,120	$52,740	$50,470	$1,523,710
Annual Lost Generation Costs																					
10) UPM—Ladder/Attraction Flows	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$153,740	$3,074,800
11) DWM—Spills (Est. pre 1979\after 1991)	$738,620	$738,620	$467,530	$343,980	$197,960	$178,310	$1,322,570	$1,246,750	$658,580	$609,340	$484,380	$833,980	$807,300	$1,053,000	$1,398,380	$738,620	$738,620	$738,620	$738,620	$738,620	$14,772,400
Subtotal UPM Capital & Study Costs	$40,133,150	$24,675	$36,113	$90,648	$104,552	$143,870	$219,672	$129,960	$142,494	$155,142	$102,362	$112,905	$83,714	$107,501	$584,419	$103,398	$103,398	$103,398	$103,398	$103,398	$42,688,164
Subtotal UPM Annual Costs	$326,620	$257,405	$198,165	$156,850	$145,855	$219,900	$297,435	$196,350	$182,820	$183,905	$185,090	$137,915	$125,910	$116,635	$118,370	$138,205	$125,040	$119,650	$114,490	$109,575	$3,456,185
Subtotal UPM—All Costs	$40,459,770	$282,080	$234,278	$247,498	$250,407	$363,770	$517,107	$326,310	$325,314	$339,047	$287,452	$250,820	$209,624	$224,136	$702,789	$241,603	$228,438	$223,048	$217,888	$212,973	$46,144,349
Subtotal DWM Capital & Study Costs	$46,410	$139,825	$204,638	$513,672	$592,459	$815,261	$1,244,808	$736,440	$807,466	$879,138	$863,439	$1,010,985	$833,877	$857,510	$620,041	$585,922	$585,922	$585,922	$585,922	$585,922	$13,095,576
Subtotal DWM Annual Costs	$52,580	$51,285	$19,445	$8,860	$542,885	$533,310	$514,225	$499,500	$475,150	$460,145	$450,100	$430,715	$405,590	$379,585	$359,400	$345,285	$434,980	$433,740	$432,550	$431,415	$7,260,745
Subtotal DWM—All Costs	$98,990	$191,110	$224,083	$522,532	$1,135,344	$1,348,571	$1,759,033	$1,235,940	$1,282,616	$1,339,283	$1,313,539	$1,441,700	$1,239,467	$1,237,095	$979,441	$931,207	$1,020,902	$1,019,662	$1,018,472	$1,017,337	$20,356,321
Subtotal Lost Generation	$892,360	$892,360	$621,270	$497,720	$351,700	$332,050	$1,476,310	$1,400,490	$812,320	$763,080	$638,120	$987,720	$961,040	$1,206,740	$1,552,120	$892,360	$892,360	$892,360	$892,360	$892,360	$17,847,200
Total Expenses—1993 Dollars	$41,451,120	$1,365,550	$1,079,630	$1,267,750	$1,737,450	$2,044,390	$3,752,450	$2,962,740	$2,420,250	$2,441,410	$2,239,110	$2,680,240	$2,410,130	$2,667,970	$3,234,350	$2,065,170	$2,141,700	$2,135,070	$2,128,720	$2,122,670	$84,347,870

Notes: 4.5% Index rate used to present values as 1993 dollars
UPM = UPstream Mitigation
DWM = Downstream Mitigation
Subtotal UPM Capital & Study Costs includes items: 1, 2, 3 * 0.15
Subtotal UPM Annual Costs includes items: 6, 7, 9 * 0.5
Subtotal DWM Capital & Study Costs includes items: 3, 4, 5 * 0.85
Subtotal DWM Annual Costs includes items: 8, 9 * 0.5
Subtotal Lost Generation includes items: 10, 11

20. WEST ENFIELD CASE STUDY

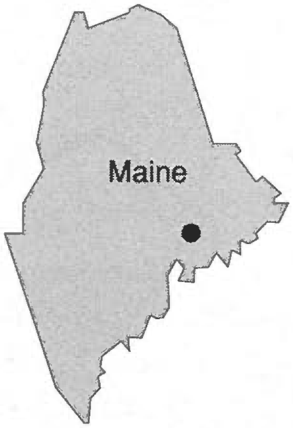
20.1 Description

West Enfield (FERC number 02600), a run-of-river project with a 21-foot head, is the fourth operating dam on the main stem of the Penobscot River in Maine (Figure 20-1). West Enfield is about 33 miles upstream from the Veazie Project (the most downstream operating dam on the river). West Enfield was initially developed in 1894 for a sawmill operation. A Denil fishway was added in 1970.

The new dam and powerhouse (Figures 20-2 and 20-3) was approved at relicensing in 1984 (amended in 1986) and completed in 1988, having a two-unit combined capacity of 13.0 megawatts. The project has a total average discharge capacity of 9,000 cfs and annually generates an average of 96,000 megawatt-hours.

20.1.1 Fish Resource Management Objectives of Mitigation . Upstream and downstream fish protection measures were incorporated into redevelopment when the project was relicensed in 1984. Upstream fish passage/protection is accomplished by a 600-foot-long, 33-step, vertical slot fish ladder, with a fish counting window, on the east abutment. The ladder has an attraction flow 3% of the powerhouse flow. It began operation in 1989 and operates during the upstream migration period, May 15 through November 10. Species assisted are the Atlantic salmon at present, and alewife and American shad in the future. The fishway has a design capacity of 10,000 salmon, 14,000,000 alewife, and 1,400,000 shad per year.

Downstream fish passage/protection is facilitated by the use of up to five overflow weirs leading to a steel pipe through the dam between the powerhouse and the gated spillway section. Initially operated in 1989, the 36-inch-diameter pipe and weirs have flows up to 150 cfs during the migration season, which are the ice-free periods between November 1 and June 1. Species assisted are the Atlantic salmon at present, and alewife and American shad in the future.



The present restoration program for the Penobscot River emphasizes the reestablishment of Atlantic salmon, American shad, and alewife anadromous fish runs upstream to their historic habitat (Table 20-1 for program summary). Before setting the goals for the program, the Atlantic Sea Run Salmon Commission drew on studies to estimate the magnitude of the potential that the river might support. It was estimated that the river could support 6,000 to 10,000 adult salmon per year; 5,000,000 to 10,000,000 lbs of alewives per year; 50,000 adult shad per year; a substantial fishery for eels; and excellent sport fishing opportunities for brook trout, lake trout, and bass. Based on this input, the Atlantic Sea Run Salmon Commission established formal objectives for the anadromous fishery reestablishment program in 1983, which included the following: (a) achieve an annual production of 185,000 wild salmon smolts within the river drainage; and (b) ensure that a minimum of 6,000 adult salmon be available annually for spawning in the river drainage. (This would be accomplished by stocking 600,000 smolts annually until the year 2006. [Under this scenario, a "wild" run of 6,000 salmon per year would be established by the year 2001—the number determined to be marginally effective in producing the escapement required for maximum use of the existing habitat]).

20.1.2 Monitoring Methods. The monitoring program currently focuses on documenting the achievements of the Atlantic salmon restoration program. The objectives are to document the behavior of the fish in the vicinity of the West Enfield project and the adequacy of the fishway.

Upstream. Adult salmon are captured at the trap at the Veazie project about 33 miles downstream from West Enfield, transported to the

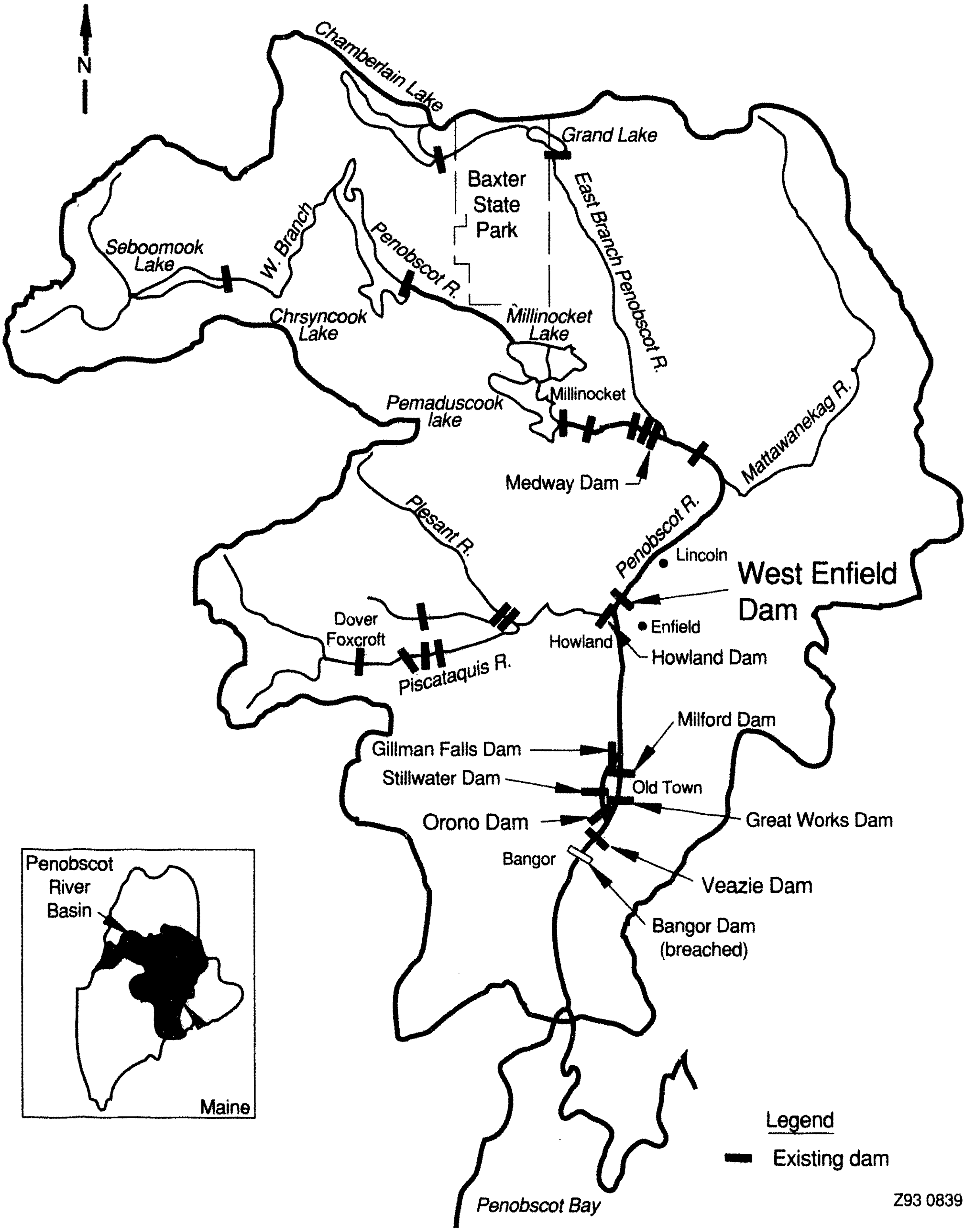


Figure 20-1. Location of the West Enfield project within the Penobscot River basin.

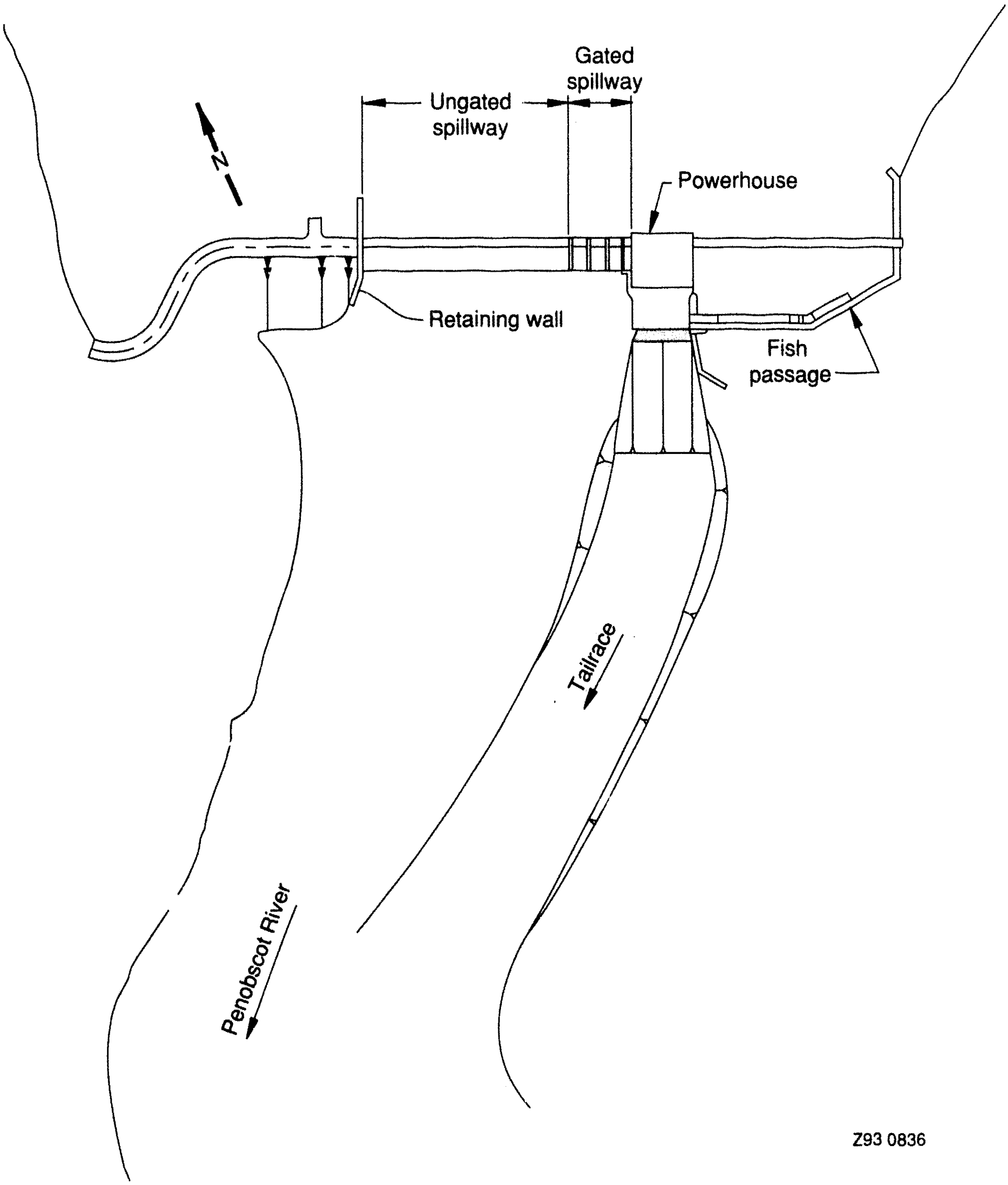


Figure 20-2. Layout of the West Enfield project and fish ladder.

shore, and placed in a tank containing a fish anesthetic. A radio tag (micro-transmitters) is inserted into the stomach of each fish selected from this group. Radio tag data (e.g., frequency, pulse rate), fish size/sex/injury data, and water temperature are recorded and the tagged fish are placed in a tank and trucked to one of four release sites (above Milford Dam about 18 miles downstream from West Enfield, above Great Works Dam about 24 miles downstream from West Enfield,

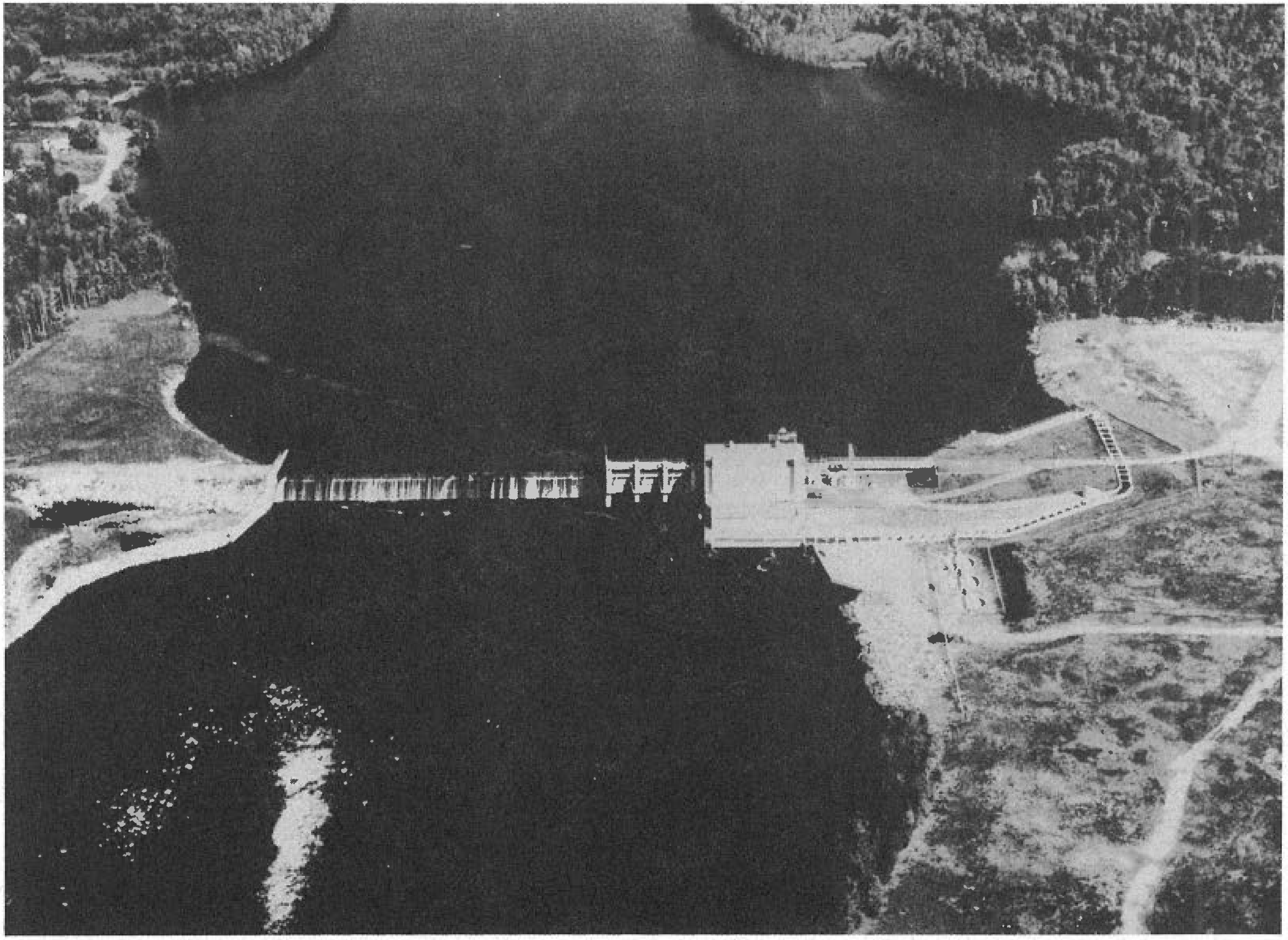


Figure 20-3. West Enfield project and fish ladder.

Table 20-1. Penobscot River anadromous fish restoration program. The overall objective of the program is to restore Atlantic salmon, American shad, and alewife runs to historical spawning areas of the Penobscot River. Source: Bangor Hydro-Electric Company (1990, 1991, 1992).

Species	Present estimated river potential	Long-term agency goals (fish/yr)	Fishway design population (fish/yr)
Alewife	5–10 million lbs/yr	—	14,000,000
American shad	50,000 adults/yr	—	1,400,000
Atlantic salmon			
Wild: smolt production	—	185,000	10,000
Adult returns	—	6,000	—
Adult harvest	—	2,000	—

immediately above the Veazie Dam, or below the Veazie Dam and about 34 miles downstream from West Enfield). Fish movements upstream through the West Enfield fishway are monitored using several stationary receivers and data loggers at the dam to track the signals from the radio tags. Individual fish are identified by the unique frequency and pulse rate assigned to each radio tag. Salmon migrating upstream are also counted at the West Enfield fishway viewing window, using a time-lapse video recorder.

Downstream. A radio tag is inserted into the stomach of selected salmon smolts and relevant data are recorded, as is done for fish passing upstream (paragraph above). The smolts are released about 8 miles upstream from West Enfield. Fish movement downstream past the project are monitored using several stationary receivers, and individual fish are identified by the unique tag signals.

20.1.3 Performance of Mitigation.

Upstream. The monitoring data collected in 1989, 1990, and 1991 were analyzed to assess the performance of the upstream fishway. In 1989, 40% of the total number of fish released into the river above Veazie (33 miles downstream) moved through the fishway. The median time between initial movement of the fish within 0.25 miles of the project and entrance into the fishway was 5.3 hours (range 0.3 hours to 40.5 hours). The median time required for the fish to pass through the fishway once they entered the passage was 1.9 hours (range 1.0 to 20.2 hours).

In 1990, 49% of the total number of fish released into the river above Veazie (33 miles downstream from West Enfield) moved through the fishway. Eighty-three percent of the fish passing Milford (25 miles downstream) moved through the fishway. (The remaining 17% homed to different tributaries and did not move up the main stem of the river; therefore, the ladder was 100% efficient in passing the fish that moved to the project.) The median time between initial movement of the fish within 0.25 miles of the project and entrance into the fishway was 3.8 hours (range 0.1 to 19.5 hours). The median time required for the fish to pass through the fishway once they entered the passage was 2.5 hours (range 0.8 to 9.5 hours).

In 1991, 31% of the total number of fish released into the river above Veazie moved through the fishway. (It appears that a larger percentage homed to tributaries than in 1989 or 1991.) The median time between initial movement of the fish within 0.25 miles of the project and entrance into the fishway was 1.2 hours (range 0.2 hours to 13.9 hours). The median time required for the fish to pass through the fishway once thy entered the passage was 2.6 hours (a range of 0.9 to 10.9 hours).

Downstream. The monitoring data collected in 1990 and 1991 were analyzed to assess the performance of the downstream fishway. In 1990, 82% passed through the turbines, 8% passed by way of spillage, 8% passed by unknown methods (probably by spillage), and 2% passed by the downstream fishway. Total passage survivability was 97.5% (2.5% mortality).

In 1991, 38% passed through turbines, 28% passed by way of spillage, 13% passed by unknown methods (assumed to pass through the downstream fishway), and 22% passed by the downstream fishway. (This dramatic increase from 1990 is attributed to the use of attraction lighting and the fact that the salmon smolts pass the Penobscot River hydroelectric projects at night. Low-intensity underwater lights were placed on the underside of the trash diverters at the downstream fishway intake.) There was a high rate of radio tag failures, though no associated mortality was observed. Of the operating radio tags monitored passing West Enfield, 90% survived at Veazie 33 miles downstream. (90% survived that had passed through West Enfield's turbines, 100% survived that had passed West Enfield by way of spillage, and 75% survived that had passed through West Enfield's downstream fish passage/protection facility).

The basic conclusions drawn from the results of these studies are (a) that the upstream fishway is effective in passing migrating fish upstream past the West Enfield hydroelectric project; virtually identical results were observed for 1989, 1990, and 1991 studies, indicating that salmon approaching the project found the fishway entrance in short order and salmon entering the fishway moved through the facility quickly; (b) low-intensity underwater lighting appears to attract downstream migrating fish to the entrance of the downstream fishway; (c) fish passing through the turbines incur little mortality or stress; (d) fish passing through the downstream fishway appear to be subjected to higher stress than those passing through turbines; and (e) fish passing through the downstream fishway are concentrated in a narrow zone of discharge that may make them easier prey for predators.

A recent FERC staff analysis for two New York hydroelectric projects (*Staff Analysis of Recommendations for Protection and Enhancement of Fishery Resources at the Crescent [#4678] and Vischer Ferry [#4679] Hydroelectric Projects*, Federal Energy Regulatory Commission Division of Project Compliance and Administration, for the New York Power Authority, dated July 7, 1993) concluded that the "...installation of a fish screen/bypass system, as proposed by the [U. S. Fish and Wildlife Service] FWS, would not likely provide greater protection for migrating juvenile [blueback herring] BBH than passage through the licensee's Kaplan turbines." FERC staff also concluded, "therefore, it is unlikely that installation of a fish bypass system for juvenile BBH at the Crescent and Vischer Ferry Projects would limit predation by resident fish."

20.2 Mitigation Benefits

A number of factors were reviewed, assessed, and compared in order to evaluate the benefits of the program to date in meeting the stated program objectives. Each year from 1983 through 1992, the numbers of salmon smolts introduced into the Penobscot River were documented (Table 20-2), and the numbers of fish returning to the Penobscot River each year were compared with the numbers returning from each previous year to determine if the actual return numbers are increasing, both annually and over the long term (Table 20-3). To date, the number of smolts (both 1-year and 2-year) introduced into the Penobscot River has varied over the past few years but has never been below 400,000; more than 5.8 million have been stocked in the river in the past 10 years (Table 20-2). During the past 10 years, the total salmon spawning run has varied from a high of more than 4,500 in 1986 to a low of about 960 in 1983; approximately 26,450 salmon (of 5.8 million stocked, or 0.5% of the number stocked) have returned to the Penobscot River in the past 10 years (Table 20-3). Since 1983, the percent harvest has varied from a high of 19.9% in 1984 to 6.2% in 1988 (Table 20–3).

The benefits derived from the fish passage/protection facilities comprise two separate categories: the benefits expected from the original program based on the objectives of that program and the actual benefits realized to date.

Table 20-2. Number of hatchery-reared 1-year and 2-year old Atlantic salmon smolts released in the Penobscot River drainage, 1983–1992. Source: Bangor Hydro-Electric Company (1993a).

Year	Number released
1983	466,000
1984	618,000
1985	580,500
1986	589,200
1987	539,250
1988	687,200
1989	416,600
1990	429,100
1991	672,800
1992	825,100

Table 20-3. Penobscot River total Atlantic salmon spawning run and angler harvest, 1983–1992. Source: Bangor Hydro-Electric Company (1993b).

Year	Total spawning run	Angler harvest (%)
1983	961	17
1984	1,811	19.9
1985	3,356	10
1986	4,529	9
1987	2,503	7.5
1988	2,853	6.2
1989	3,089	12
1990	3,343	13
1991	1,757	10.5
1992	2,250	6.5

20.2.1 Expected Benefits—Original Program. The Atlantic Sea Run Salmon Commission outlined specific restoration program objectives for sustained annual returns of Atlantic salmon (Table 20-1).

20.2.2 Benefits to Date. Over the past 10 years, the total salmon returns for the spawning run averaged about 2,650 fish (Table 20-3). The annual numbers have been quite variable since 1984. They have not shown steady improvement despite the fact that between 415,000 and 825,000 smolts have been stocked each year. This 2,650 average run is about 44% of the 6,000 targeted, self-sustaining run of adult salmon the Atlantic Sea Run Salmon Commission expects 15 years from now (Table 20-1).

20.2.3 Conclusions. Spawning runs of Atlantic salmon have been variable over the past 10 years and have not shown steady increases (Table 20-3). The percent harvest of the salmon spawning run has averaged 11% per year for the past 10 years, peaking at 19.9% in 1984 (Table 20-3). The targeted, self-sustaining, adult salmon return of 6,000 per year exceeds the average return for the past 10 years by a factor of 2.25. More than 5,800,000 smolts have been stocked in the past 10 years to maintain the existing run.

20.3 Mitigation Costs

20.3.1 Introduction. The mitigation cost analysis for the West Enfield hydroelectric plant consists of a cost summary section, discussing the mitigation costs in general terms; a cost descriptions and assumptions section, describing each of the individual mitigation costs; and a spreadsheet that compiles all of the mitigation costs. All of the mitigation costs have been indexed to 1993 dollars and are discussed as such. The cost information obtained and presented for this case study came from informal correspondence, telephone calls, and a site visit that greatly facilitated the communication and understanding of cost items, requirements, and mitigation systems.

20.3.2 Cost summary. The mitigation costs at West Enfield were not obtainable broken into upstream and downstream mitigation methods. Total mitigation costs for both upstream and downstream passage/protection are discussed together. The West Enfield fish passage/protection mitigation costs totaled $7,520,000 for the 20-year analysis period. The costs per kilowatt-hour, based on a reported annual generation of 96,000,000 kilowatt hours, is 3.9 mills (Table 20-4) or about four-tenths of a cent. The major cost item (46.5%) is the capital cost of

Table 20-4. Twenty-year costs incurred at the West Enfield project for upstream and downstream mitigation. Because of rounding, columns may not total.

	20-year total ($)	Levelized annual cost ($)	Cost per kWh (mills)
Capital and study costs	4,400,000	220,000	2.3
Annual costs	1,080,000	54,000	0.6
Lost generation costs	2,040,000	102,000	1.1
Total costs	7,520,000	376,000	3.9

constructing the facilities (Figure 20-4). The costs to implement the fish passage/protection mitigation are largely up-front costs (Figure 20-5), with 52% of all costs occurring during 1988 (capital costs) and 1989.

The capital cost to construct the 600-foot-long, 33-step fish ladder, and the bypass weirs and pipe was reported as $3,500,000. A 4-year study (1989–1992) to test the ladder effectiveness cost a total of $900,000. No future studies are currently planned. The operations and maintenance of the ladder and bypass pipe are reported to cost $27,000 annually. The annual reporting cost is also estimated annually at $27,000. The annual lost generation value of the flows released through the fish ladder and bypass pipe is estimated at $102,000.

20.4 Cost Descriptions and Assumptions

This section explains the individual cost items and the assumptions and estimates required to quantify the respective items and derive totals.

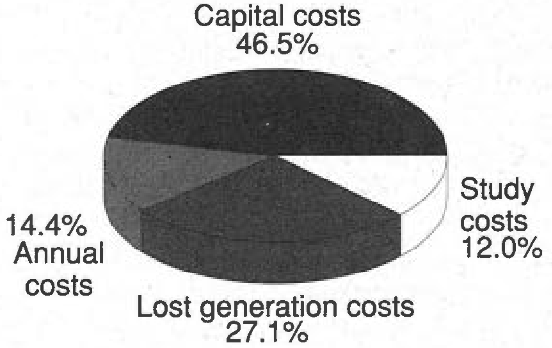


Figure 20-4. Total mitigation costs at the West Enfield project.

The item numbers correspond to the 20-year spreadsheet (Table 20-5) used to summarize costs. All costs have been converted to 1993 dollars and are discussed as such. The annual costs are added to the analysis in 1989 as this is the first year the passage/protection systems operated.

West Enfield has both a fish ladder, used for upstream passage, and five weirs and a 36-inch diameter pipe through the dam, used for downstream passage. The costs associated with each of the respective mitigation measures were not segregated and are grouped together.

1. **Capital costs**—upstream and downstream passage. The licensee reports a total capital cost of $3,500,000 for the fish ladder and the downstream passage/protection system.

2. **Study costs**—ladder effectiveness. Studies to examine upstream passage rates were conducted from 1989 through 1992. The 4-year total cost is $900,000.

3. **Annual costs**—operations and maintenance. The annual cost for operations and maintenance is $27,000. This equates to 0.3 mills per generated kilowatt-hour.

4. **Annual costs**—annual reporting. The annual cost of reporting associated with fish passage/protection mitigation is $27,000. This equates to 0.3 mills per generated kilowatt-hour.

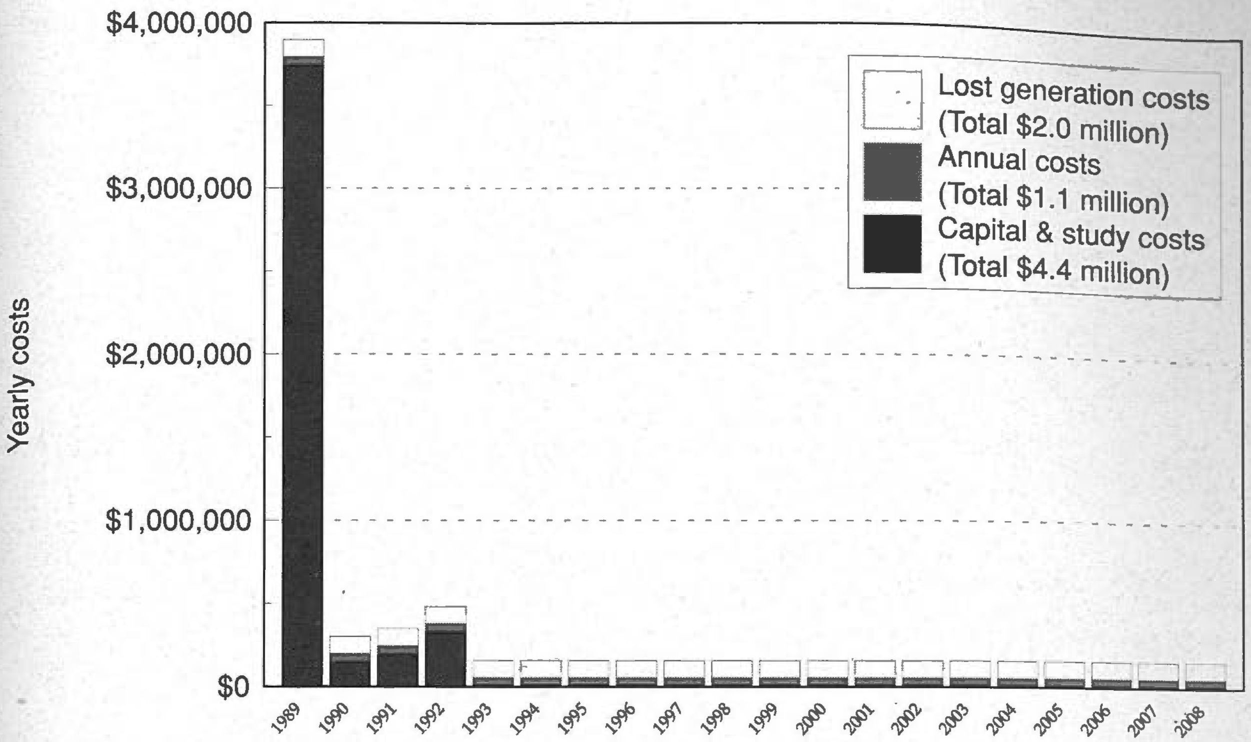


Figure 20-5. Yearly mitigation costs at the West Enfield project.

5. **Lost generation costs**—upstream and downstream mitigation. The fish ladder has water flows of 3% (270 cfs) of the powerhouse flows (9,000). The flows occur May 15 through November 10. Total flows are 270 cfs × 24 hours × 179 days = 1,159,920 cfs. The downstream bypass pipe has average flows of 100 cfs from November 1 through May 31. The downstream bypass flows total 100 cfs × 24 hours × 212 days = 508,800 cfs. The flows for the upstream and downstream passage/protection systems total 1,668,720 cfs. Based on the average annual generation of 96,000,000 kilowatt-hours and the average powerhouse discharge of 9,000 cfs, the kilowatt to cfs value is 96,000,000 kilowatt-hours/(9,000 cfs × 24 hours × 365 days) = 1.22 kilowatt/cfs. Assuming a $0.05 per kilowatt-hour value, the annual cost of the 1,668,720 cfs spilled is 1,668,720 cfs × 1.22 kilowatt/cfs × $0.05 = $102,000. This equates to a per generated kilowatt-hour value of 1.1 mills.

Table 20-5. West Enfield mitigation costs.

West Enfield Project—Mitigation Cost Analysis—All Values in 1993 Dollars

9/07/93	–4	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	TOTALS
Capital Costs																					
1) Upstream & downstream ('88)	$3,500,000																				$3,500,000
Study costs																					
2) Ladder effectiveness	$240,000	$145,000	$190,000	$325,000																	$900,000
Annual costs																					
3) Operations and maintenance	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$540,000
4) Annual reporting	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$27,000	$540,000
Lost generation costs																					
5) Upstream & downstream passage	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$2,040,000
Subtotal capital & study costs	$3,740,000	$145,000	$190,000	$325,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$4,400,000
Subtotal annual costs	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$54,000	$1,080,000
Subtotal lost generation	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$102,000	$2,040,000
Total Expenses—1993 Dollars	$3,896,000	$301,000	$346,000	$481,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$156,000	$7,520,000

Notes: 4.5% Index rate used to present values as 1993 dollars

21. CASE STUDIES SUMMARY

21.1 Case Studies Benefits Summary

The examination of the case studies that have implemented fish passage/protection measures has uncovered a wide range of results. Several projects have been successful in increasing the passage rates or survival of anadromous fish (i.e., the Conowingo, Leaburg, Lower Monumental, Wells, Buchanan, and T. W. Sullivan projects). Six projects (Brunswick, Jim Boyd, Little Falls, Lowell, Twin Falls, and Wadhams) have conducted only limited performance monitoring, and although initial results have been encouraging, these projects have not been adequately studied to determine whether the mitigative measures have long-term, population-level benefits. Adverse environmental conditions that have occurred since implementation of the fish passage/protection measures have prevented an assessment of benefits at the Arbuckle Mountain and Potter Valley projects. The fish ladder installed to allow upstream passage at the Kern River No. 3 project has not been rigorously monitored, but changing management goals may require it to be shut down on the chance that it is effective in permitting undesirable (hatchery trout) fish to move into stream sections reserved for wild trout populations. Finally, monitoring data indicated that the fish ladder at the West Enfield project has allowed upstream passage of large numbers of spawners, but the downstream fish bypass system appears to cause more mortality than turbine passage. Thus, only one of the case studies (West Enfield) appears to have failed in the attempt to enhance fish populations, but for some the benefits are unclear. For most case studies, the benefits of the mitigative measure could be expressed only in terms of the numbers of individual fish that were transported around the dam or protected from entrainment. In some instances, monitoring was limited to visual observations of the passage/protection measure, with no quantitative information being collected. Population-level effects were rarely known.

21.2 Case Studies Costs Summary

Presenting a summary of the 15 case studies that have cost information implies that the 15 case studies are a fairly homogeneous group, about which a single or a few statements hold true for all. However, each of the 15 case studies is unique to itself. Finding similarity in the details between the Wadhams project, with its 0.56 megawatt capacity and 214 cfs average water flows, and the Lower Monumental project, with 810 megawatts capacity and average flows of 48,950 cfs, is difficult. Yes, they are both hydroelectric plants and both have downstream fish passage/protection systems. Wadhams has a total 20-year downstream fish passage/protection system cost of $48,000 and Lower Monumental has a total 20-year downstream fish passage/protection system cost of $96 million. Obviously the size of the facilities and annual operations differ significantly between the two projects, yet the objectives are identical—to safely pass downstream migrants. The annual downstream mitigation costs for Wadhams, at $2,184, and Lower Monumental, at $4.8 million, produces an average cost of $2.4 million. This is a poor summary of Lower Monumental's costs and an especially poor summary of Wadhams' costs (off by 1,000X). A summary based on averages for such diverse costs would be, if not erroneous, at least misleading.

Costs could be summarized based on a factor such as fish ladder construction costs per foot of design head. The design head implies the vertical elevation that a ladder must pass adults. Unless an individual is familiar with the types of projects in the mountains of the western United States, it might be assumed that the design head is approximately the same as the height that a fish ladder is. This can often be an incorrect assumption. The Kern River No. 3 project has a 880 foot head but the ladder is used at an upstream diversion that is only 20 feet high. The synopsis of this discussion is that the costs are summarized in this section but the reader should review the individual case studies for further understanding of the uniqueness of each case study and the different mitigation methods used.

21.2.1 Upstream Mitigation Costs. Twelve of the case studies provided mitigation costs related to upstream fish passage/protection (Table 21-1). Of the 12, the upstream mitigation costs are combined with downstream mitigation costs at three projects, Brunswick, Jim Boyd and West Enfield. The Brunswick and West Enfield costs were obtained in a format that did not allow the separation of upstream and downstream mitigation costs with confidence. The Jim Boyd costs are combined because several components of mitigation are multipurpose, such as using the training wall to control velocities to sweep the power canal fish screens and to maintain upstream passage attraction flows. At the other nine projects with upstream mitigation costs, the Little Falls project's costs are for studies that were conducted to monitor upstream migration through a nearby barge navigation lock. There is not a conventional upstream passage such as a fish ladder present.

At the remaining eight projects, seven projects use fish ladders. Conowingo uses two fish lifts, located at opposite ends of the powerhouse. The Lowell project has a ladder at the upstream diversion dam and a fish lift at the powerhouse. Leaburg, Lower Monumental and Wells all have two ladders at their respective single dams. The operational capability of one of Leaburg's ladders is degraded, and the ladder is scheduled for rebuilding during 1995. The upstream mitigation 20-year total costs range from $75,000 for the Denil fish ladder at Arbuckle Mountain to $49 million for the two ladders at the Wells hydrocombine dam on the Colombia River.

The upstream mitigation costs at the three case studies (Brunswick, Jim Boyd and West Enfield) with combined costs are described in the individual case study sections. The costs of individual mitigation components at these three projects are discussed, allowing a general picture of upstream mitigation costs. Both Brunswick and West Enfield use fish ladders. Brunswick also traps the upstream migrants and the state resource department hauls the fish upstream around other dams. The Jim Boyd project uses a notched weir and a fish gate for upstream passage.

The upstream mitigation costs per kilowatt-hour of generation range from 0.05 mills at Kern River No. 3 to 10.6 mills at Buchanan. The Kern River No. 3 Alaska steeppass fish ladder was installed in the early 1960s and does not have any annual costs. The Buchanan fish ladder was constructed by the state resource agency and it is unknown how, if at all, this influenced the costs. All of these costs include study and annually operating costs.

21.2.2 Downstream Mitigation Costs. Thirteen of the case studies provided downstream fish passage/protection mitigation costs (Table 21-1). The Brunswick, Jim Boyd and West Enfield costs are combined with the upstream mitigation costs. Brunswick and West Enfield use bypass pipes for downstream migrants. Jim Boyd uses a fish screen at the head of the power canal. The 20-year downstream mitigation costs at the 10 projects with separate mitigation costs range from $48,000 for the angled bar rack and wooden downstream sluiceway at Wadhams to $96 million for the submerged traveling screens, mined concrete tunnels within the dam, and the large concrete and metal bypass at Lower Monumental. Wells, at a cost of $35 million, uses spill flows and intake barriers for downstream mitigation. Lowell also uses a downstream bypass, which is part of the fish lift facility. Arbuckle Mountain, at a cost of $158,000, uses eight cylindrical wedge-wire screens, set on a concrete manifold, and an airburst cleaning system. Twin Falls uses two 11-foot-wide by 136 foot-long inclined wedge-wire screens and an airburst cleaning system. The Twin Falls system is completely subterranean and costs $2.5 million. The Sullivan downstream mitigation includes an Eicher screen in its Unit 13 turbine, a bypass, and an evaluator at a cost of $14 million.

The downstream mitigation costs per kilowatt-hour of generation range from 0.04 mills to 8.7 mills. The 0.04 mills cost at Kern River No. 3 is for an older screen set at the downstream end of a sand box that is used to settle-out particulates.

Table 21-1. Upstream, downstream, and lost generation mitigation costs for the 15 case study projects reporting costs. Combinations are the costs of mitigation at projects that were unable to separate upstream and downstream mitigation costs. The lost generation costs at the Leaburg project were not broken into upstream and downstream costs. Mitigation costs are presented as 20-year total costs and costs in mills per kilowatt-hour (kWh) of generation.

	Upstream passage/protection		Downstream passage/protection		Lost generation		Combination	
Project	20-year total ($ thousands)	mills/kWh	20-year total ($ thousands)	mills/kWh	20-year total ($ thousands)	mills/kWh	20-year total ($ thousands)	mills/kWh
Arbuckle Mountain	75	4.2	158	8.7	—	—	—	—
Brunswick	—	—	—	—	—	—	7,778	3.7
Buchanan	4,257	10.6	—	—	—	—	—	—
Conowingo	30,777	0.9	—	—	—	—	—	—
Jim Boyd	—	—	—	—	—	—	1,785	21.1
Kern River No.3	176	0.05	154	0.04	—	—	—	—
Leaburg	1,701	0.9	5,136	2.6	3,313	1.7	—	—
Little Falls	271	0.3	2,467	2.5	—	—	—	—
Lowell	8,176	4.8	1,057	0.6	—	—	—	—
Lower Monumental	36,226	0.6	96,238	1.7	—	—	—	—
T.W. Sullivan	—	—	14,254	5.8	—	—	—	—
Twin Falls	—	—	1,517	0.9	—	—	—	—
Wadhams	—	—	48	1.2	—	—	—	—
Wells	49,219	0.6	35,128	0.4	—	—	—	—
West Enfield	—	—	—	—	—	—	7,520	3.9

The 8.7 mills cost is for Arbuckle Mountain. The Jim Boyd costs per kilowatt-hour for both upstream and downstream mitigation is 21.1 mills. The downstream mitigation portion of this cost is probably more than half of the 21.1 mills. All of these costs included studies and annual operating costs.

21.2.3 Total Upstream and Downstream Mitigation Costs. The upstream and downstream mitigation costs for the 15 case studies reporting mitigation costs are combined and plotted against the average site flows (Figure 21-1), project capacities (Figure 21-2), and the average annual energy production (Figure 21-3). Linear regression lines are plotted in all three figures to show probable mitigation costs over ranges. However, the regression lines should be viewed judiciously as the correlation confidences are low.

21.2.4 Case Studies Costs Summary. The total mitigation costs are plotted for each project in Figure 21-4; the costs vary considerably. This variation is driven by differing mitigation methods as well as the different sizes of the respective mitigation methods. This difference in sizes is driven by the corresponding differences in the projects' water flows, dam sizes, and configurations. The Conowingo, Lower Monumental and Wells projects have the largest total 20-year expenditures, while Arbuckle Mountain, Kern River No. 3, and Wadhams all appear to have low costs (Figure 21-4). However, when the mitigation costs are viewed as mills per kilowatt-hour of generation, Jim Boyd has the highest costs (Figure 21-5). Arbuckle Mountain, which has the second lowest total 20-year cost, has the second highest (12.9 mills) cost per kilowatt-hour.

It is not difficult to define in dollars the cost of constructing and operating a fish passage/protection system. However, it would be erroneous to quantify that cost and then draw the assumption that if society spends "X" more dollars then the number of fish using the ladders will change "X" amount. The other life-cycle factors

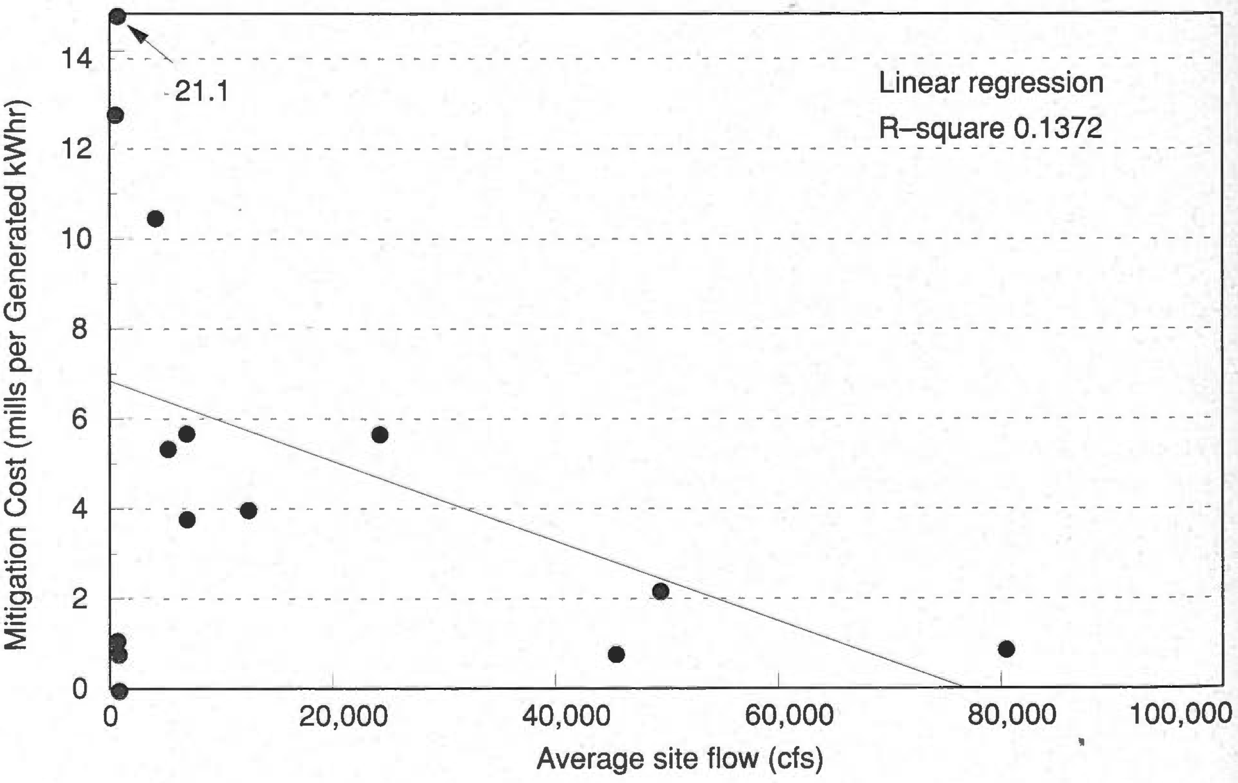


Figure 21-1. Summary mitigation costs per kilowatt-hour of generation and average site flows in cfs.

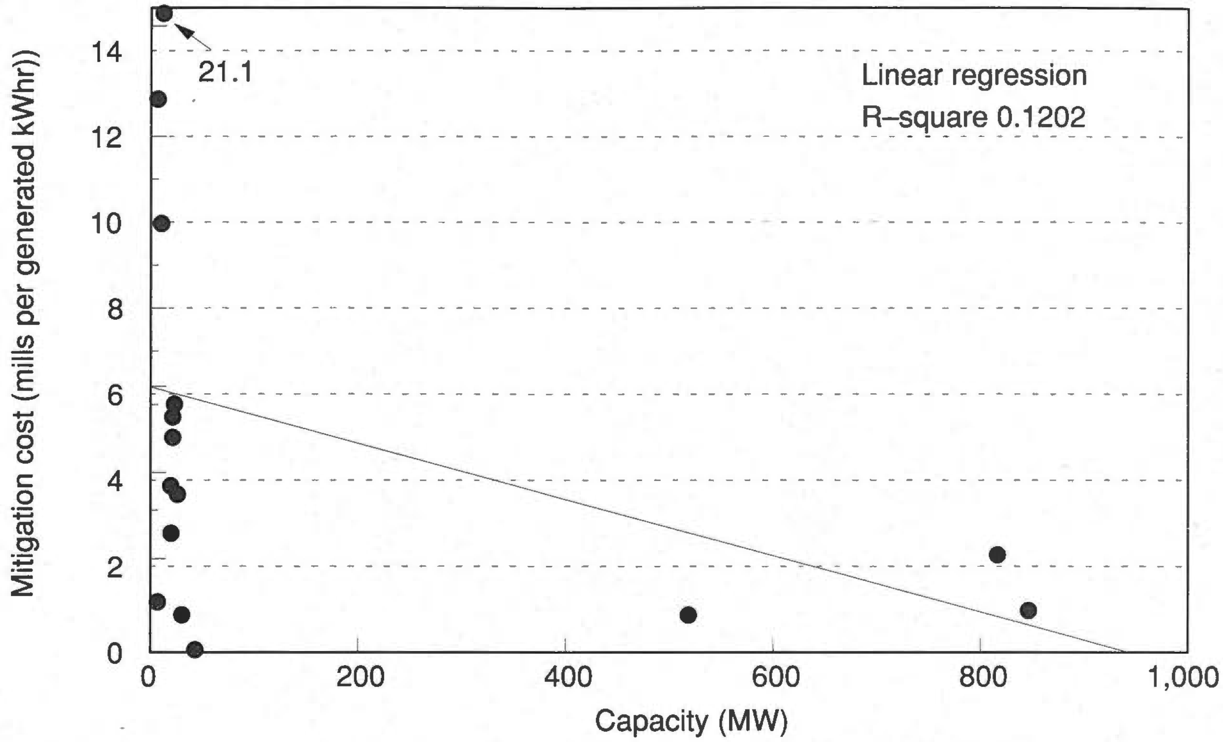


Figure 21-2. Summary mitigation costs per kilowatt-hour of generation and project capacities in megawatts (MW).

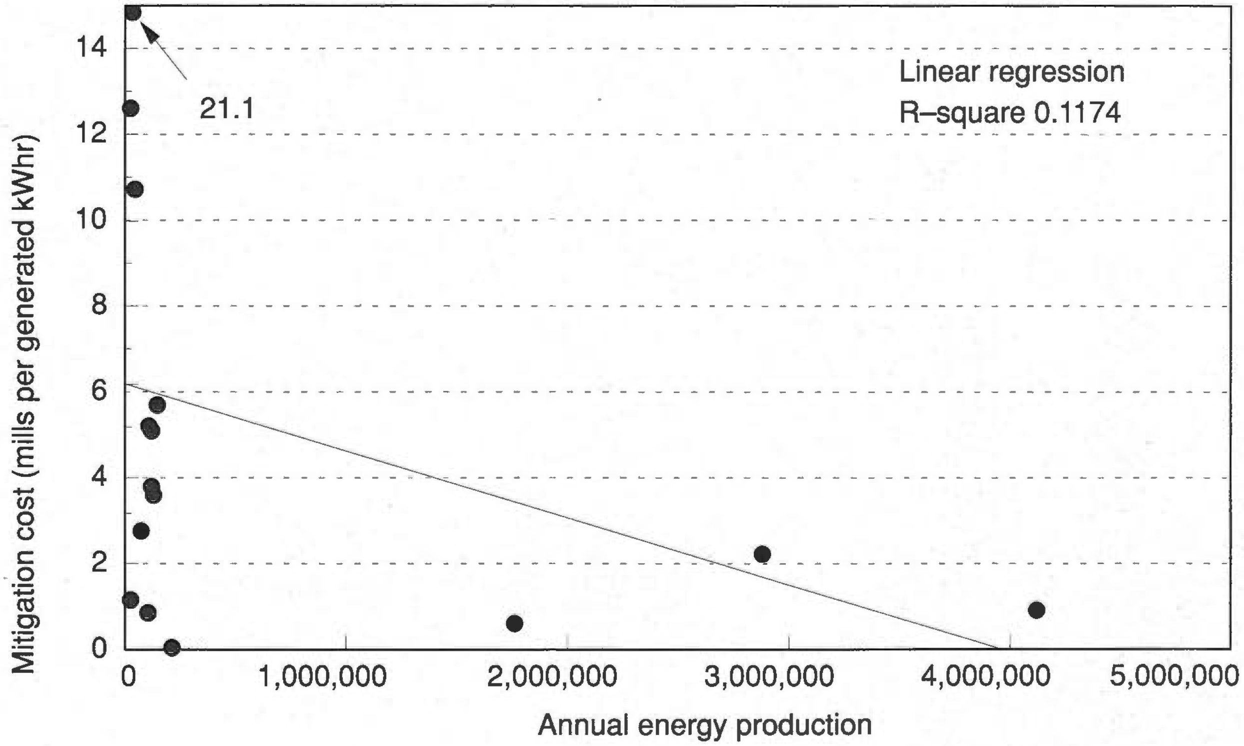


Figure 21-3. Summary mitigation costs per kilowatt-hour of generation and annual energy production.

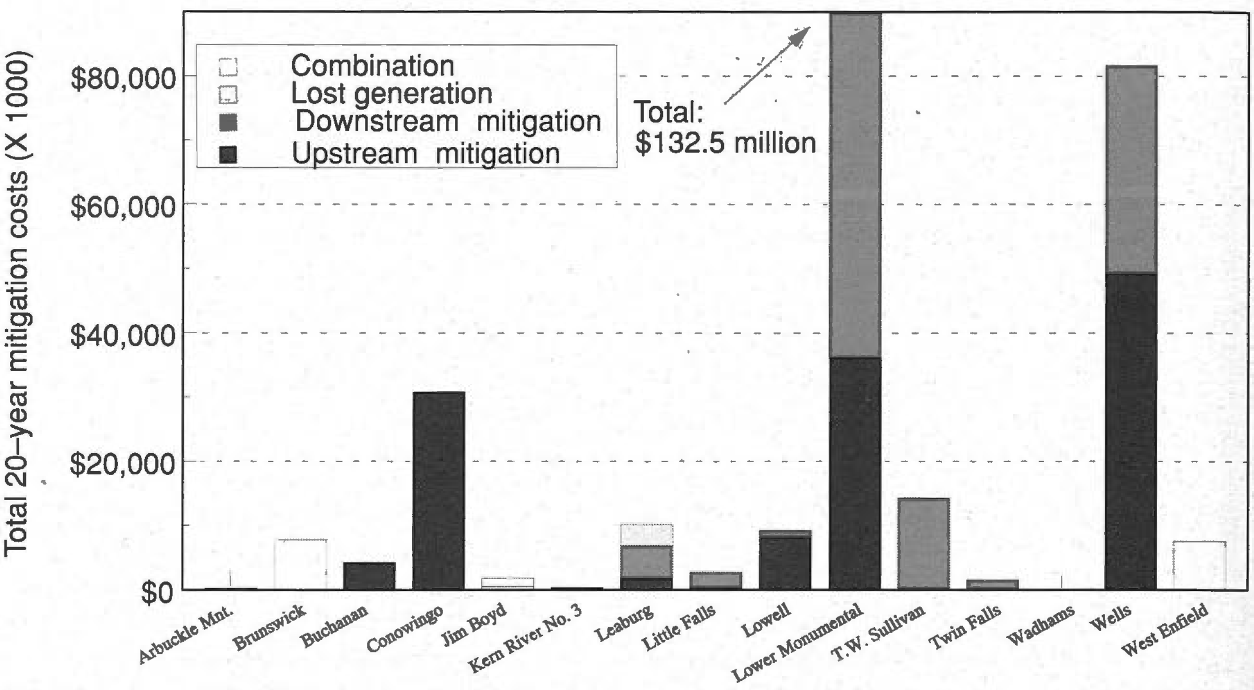


Figure 21-4. Summary mitigation costs per project as 20-year totals.

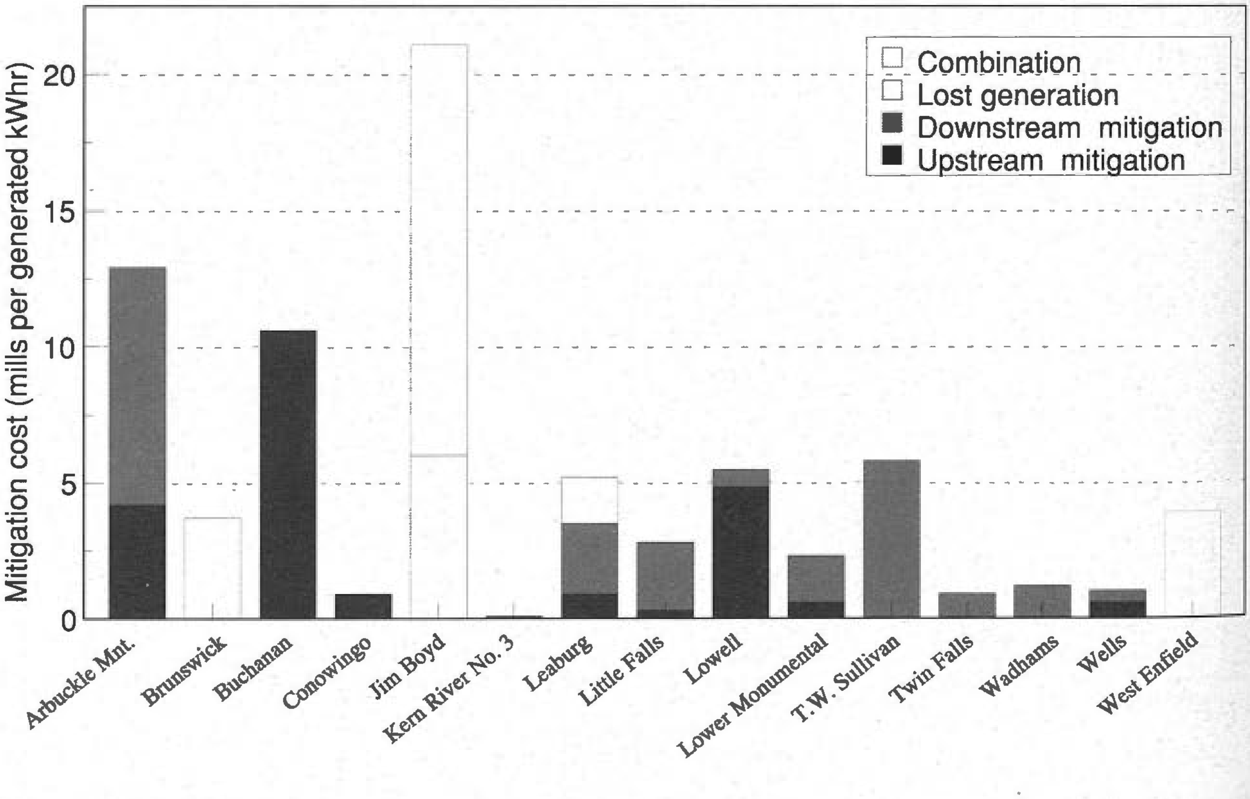


Figure 21-5. Summary mitigation costs per project as mills per generated kilowatt-hour (kWh).

that impact a species will also continue to impact passage rates regardless of how many "X" dollars are spent on mitigation at a single site. For instance, better fishing success rates downstream of a fish ladder will impact upstream passage rates at a project. Spawning habitat or downstream passage success impacts returning adult numbers, while ocean catch rates or drought may also seriously impact passage rates.

Neither the upstream or downstream mitigation systems are separate issues; both are integral components of a more complex habitat support system. Each respective mitigation method supports different aspects of the life-cycles of resident and anadromous species, either as adults when passing through fish ladders to complete the final phase of the species life-cycle, or as smolts passing downstream and starting/continuing the life-cycle. The identification and quantification of fish passage/protection system costs helps the decision-maker to understand the economic magnitudes of various passage/protection methods.

22. ESTIMATING FISH VALUES FOR INVESTMENTS IN FISH PASSAGE/PROTECTION FACILITIES

22.1 Introduction

Fish passage/protection facilities at dam sites generally contribute to the expansion of a fish population. These facilities are not without cost, and their costs can be determined. Even when the cost of these facilities is known, the question remains, "How much are the additional fish worth?" In some cases, the fish are commercially caught, and determining the value is relatively simple: it is the commercial value of the fish, at the boatside. But frequently, the fish that use fish passage/protection facilities are caught recreationally rather than commercially, and there is no price tag that can be readily attached to them. Nevertheless, these fish do have a value, as any fisherman can attest by actions and words. Several methods have been attempted to establish recreational fish values; several of those valuation methods are discussed below.

22.2 Direct and Indirect Values

If price tags are not available, how can the value of recreational fish be estimated? As suggested in the first paragraph, actions and words are the primary means: the time, travel, and equipment fishermen devote to catching fish are primary evidence from which value estimates may be derived. These verbal expressions of valuation, while not without interpretive problems, can also shed light on recreational fish values. Resource economics has developed two types of methods for estimating the values of natural resources, including recreational fish. The *direct* method is to ask people their valuations of particular resources through surveys constructed to eliminate a number of potential biases. This survey method is called the contingent valuation method, and there are a number of variants of it adapted to different situations. Survey participants may include people other than recreational fishermen, since they might, under certain circumstances, participate in recreational fishing, and even if they never chose to do so, they might still value the knowledge that certain species of fish exist on particular rivers. A second method, the *indirect* method, relies on observations of fishermen's recreational behavior—what they do rather than what they say. Indirect methods rely on the fact that to consume part of a natural resource, which has no price tag, a fisherman must spend some of his or her money (and time) on goods which are sold in markets. A fishermen's valuation of fishing and of recreational fish can be inferred from his or her behavior in these markets that are related to fishing. The most commonly used indirect method to date is the travel-cost method, which identifies travel as a market good which must be purchased in order to consume recreational fishing. Travel costs, including the value of time as well as out-of-pocket costs and any entry fees at restricted fishing sites, amount to the effective, or implicit, price which fishermen pay for their recreational fish. From information on distances and times traveled to a particular fishing site, and controlling for other influences such as income, a demand curve for recreational fishing at a particular site can be constructed. It is from such a demand curve that the recreational value of fish at the site can be estimated.

One can measure, at any particular point on a demand curve, the recreational value of a fish, *given that so many other fish are available*. This value is known as the *marginal value* of a recreationally caught fish, and it is the natural resource equivalent of the *price* of a commercially caught fish that a consumer might buy in the grocery store.

22.3 Use and Nonuse Values

Two additional concepts in natural resource valuation have become prominent in public, scientific debates in the past five years: use value and nonuse value, the latter frequently called existence value. The use value concept is clear and relatively easy to define and measure. It is the value someone will pay to consume a natural resource, whether that consumption act is catching a fish and eating it, catching a fish and releasing it, or looking at a mountain in a national park. The consumer of the natural resource is actively involved in the act of consumption and somewhere in the act of consumption pays out some real resources—money, time, wear and tear on a vehicle—for that consumption. Use values for recreationally caught fish can be estimated from observations of this consumption behavior.

Existence value is how much it is worth to a person simply to know that a natural resource exists, even though he or she has no intention of ever directly consuming it (e.g., hunting or catching it, walking through it, or even viewing it). Existence value, by its definition as a nonuse value, is more difficult—if not impossible—to observe. Its measurement is restricted to the contingent valuation method survey by the present state of science on the topic and is not subject to any other method of cross-check. Estimated existence values have been large in some cases, and reliance on the method has been the subject of intense and extended litigation in the United States court system. The estimate of use value does not fully address either current concerns natural resource economists have about the theoretical definition of existence value or the methodological concerns that have been expressed about the contingent valuation method approach to assessing economic values.

22.4 Discussion

The controversy over the reliability of the contingent valuation approach to direct valuation of natural resources is not paralleled in the indirect methods, but methodological differences do exist about different implementations of the travel-cost method, as well as an alternative approach known as the random utility model, which uses a discrete choice approach adapted from transportation demand studies to capture the relatively infrequent (discontinuous) character of recreational fishing trips. The random utility model approach, in practice, may overstate the substitutability among recreational fishing sites and consequently depress the value of those natural resources by de-emphasizing their uniqueness. In terms of the demand and supply framework introduced above, the random utility approach tends to reduce the demand for any one recreational fishing site by emphasizing how many other sites fishermen might consider to be reasonable substitutes for a site in question. For example, if the site under study were eliminated or had its availability curtailed, high substitutability indicates that fishermen would simply fish at other sites and not miss the one that becomes unavailable very much at all. What this means for the benefits of fish passage/protection is that where there are close substitutes for the fish affected by passage/protection conditions at one site, the recreational value of fish at the site in question will be lower, all other circumstances being the same.

Having discussed the principles guiding natural resource measurement in general and the techniques used to estimate recreational fish valuation in particular, what sorts of values have been derived in practice? In fact, the estimated marginal values of recreational fish vary considerably, even within a single state, primarily according to the accessibility of the site to a population of fishermen and, of course, according to species. Fish at sites which are accessible to larger numbers of fishermen will be valued by more people, which drives up their marginal values. Table 22-1, which shows marginal values for steelhead trout on 21 rivers in Oregon in 1977 (in 1993 prices), reveals this effect quite clearly. The marginal values range from a high of $456 on the Willamette River to a low of $25 on the Coos River, an 18-fold range. Table 22-2 shows marginal values of trout and salmon (1978 values at 1993 prices) at 11 counties along the Lake Michigan shoreline in Wisconsin, with a range of values from $11 to $87, an eight-fold difference. The values in these two tables clearly demonstrate variation in value between sites, and the Oregon study reports a very strong, positive relationship between estimated fish value at a site and the population within the commuting range of the site (Loomis, 1989). Fishermen's price elasticity of demand for recreational fish also is a critical parameter in determining value. Example

Table 22-1. Marginal values of steelhead trout on rivers in Oregon, 1977 (in 1993 prices) [a]

River	Marginal value ($)	River	Marginal value ($)
Alsea	31.48	Rogue	114.95
Chetco	30.11	Salmon	243.59
Clackamas	240.86	Sandy	157.38
Columbia	190.22	Santiam	253.17
Coquille	46.53	Siletz	87.58
Coos	24.63	Siuslaw	90.32
Descutes	109.48	Trask	184.75
Hood	168.33	Umpqua	134.11
John Day	56.11	Willamette	455.71
Nehalem	183.54	Wilson	172.43
Nestucca	143.69		

a. Source: Loomis (1989), Table 1, p. 189.

Table 22-2. Marginal values of trout and salmon (unweighted average) in eleven Wisconsin counties bordering Lake Michigan, 1978 (in 1993 prices).[a]

County	1	2	3	4	5	6	7	8	9	10	11
Marginal value of fish, in $	12.42	18.37	11.50	36.52	86.37	10.56	12.01	15.17	87.37	16.23	42.63

a. Source: Samples and Bishop (1985), Table 2, p. 69, pp. 70–71.

calculations indicate that a 50% difference in price elasticity of demand for recreational fish will yield close to a 50% difference in valuation, with greater elasticity (indicating greater sensitivity of demand to price) yielding smaller fish values. If fishermen frequenting different sites have substantially different price elasticities of demand for the same species of recreational fish, the valuation of fish and of the benefits of fish passage/protection facilities at the different sites would differ accordingly.

Transfer of fish value estimates from one site to another is a subject of active study, and the principal rule of thumb emerging so far is that values are more transferrable to nearby sites than to sites farther away, although measures of "near" and "far" are still rough. Sites in close proximity to one another are likely to share much the same population of fishermen and the same array of substitute sites, two characteristics that are critical to recreational fish values. However, if statistical estimation does not fully account for other characteristics of sites that fishermen value, the estimated fish values may be contaminated by some positive or negative elements of site characteristics. Consequently, transfer of fish values between sites poses a further risk of error when characteristics of both sites cannot be adequately controlled by the transfer method.

22.5 Summary

The above brief review of the various methods used in determining the value of a fish points out the complex and subjective nature of this issue. The number of fish at a site, or in a system, has a direct impact on the individual value. As the numbers of fish increase, the value per fish may decrease. Conversely, as the numbers of fish decrease the value per fish would increase. There may be a threshold where the numbers decrease to a level were the fisherman discontinues fishing or changes fishing locations. When the numbers of fish decrease to a level where the population has become threatened or endangered, then the values can become "priceless."

Determining the value of a natural resource such as a fish is not an exact science. Research and discussion continues in the attempt to develop a methodology to determine natural resource values that would be universally acceptable. In the meantime, the United States judiciary will continue to wrestle with this issue. How this will ultimately effect the develop of new sites, the relicensing of developed sites, and any affiliated mitigation requirements is unknown. However, it is likely that mitigation requirements will continue, and these requirements will not be diminished as the remaining natural resources are routinely perceived to have heighten values.

23. CONCLUSIONS

In recent years, requirements for upstream and/or downstream fish passage/protection are being imposed on hydroelectric projects with greater frequency. However, at present, the total costs and actual effectiveness of these substantial requirements are not well quantified or understood. This volume attempts to contribute new knowledge of fish passage/protection mitigation measures associated with hydroelectric projects and provide some guidance for those that may be assessing or operating such facilities.

23.1 Passage/Protection Methods

23.1.1 Upstream Passage/Protection. Almost two-thirds of the hydroelectric projects in the U. S. that presently have upstream mitigation facilities use fish ladders. About 40% of all fish ladders are located at projects in five northwestern states, and another 30% are operating in the northeast. All of the five projects in the midwest with upstream mitigation use fish ladders. Thus, the major form of bypassing fish upstream around hydroelectric projects is by fish ladder.

Accordingly, a majority of the data assessing upstream mitigation for this report concentrated on fish ladders. Preliminary data from the survey conducted for Volume I of this series (and also used for this report) represented projects where 80% with upstream mitigation use fish ladders. Of the case studies analyzed for this report, 75% of those with upstream mitigation use fish ladders.

23.1.2 Downstream Passage/Protection. Three-fourths of the hydroelectric projects in the U. S. that presently have downstream mitigation facilities use penstock or intake screens and bypass facilities (conduits or sluiceways). Another 20% use angled bar racks. Nearly half of the screen/bypass facilities are located at projects in the northeast and about half at projects in the west (a small percentage are attached to projects in the southeast). Approximately 40% of the angled bar rack installations are attached to projects in the northeast and another 40% are situated in the southeast. Thus, screen/bypass and angled bar rack systems are the primary methods used to protect fish moving downstream past hydroelectric projects.

Accordingly, a majority of the data assessing downstream mitigation for this report concentrated on screen/bypass and angled bar rack systems. Preliminary data from the survey conducted for Volume I of this series (and also used for this report) included projects where 50% with downstream mitigation use screen/bypass facilities and 30% use angled bar racks. Of the case studies analyzed for this report, 90% of those with downstream mitigation use screen/bypass systems and 10% use angled bar racks.

23.2 Costs

To aid in quantifying fish passage/protection costs, graphical representations of the available cost data were constructed. Generally, data from the preliminary survey database were plotted versus plant capacity (in megawatts) on a log-log scale for ease in delineating data scatter and trends. A graphical band across the plot was then constructed to encompass the majority of the data points to show ranges in cost for projects of various size. The case study data was then superimposed on the graph to determine if the information from this detailed study varied from the trends indicated from the preliminary survey.

Graphical analyses were conducted for installation costs (in dollars per kilowatt), total costs (in cents per kilowatt-hour levelized over 20 years), and annual operations and maintenance (O&M) costs (in cents per kilowatt-hour). Installation costs include only those capital outlays required to design and construct the facility. Total costs include outlays for facility installation, any direct studies conducted, operations and maintenance, monitoring, reporting, administration, and generation losses, and are levelized over 20 years. Annual operations and maintenance costs include outlays to operate, maintain, monitor, report, and administer the mitigation requirement each year. These costs for fish ladders (upstream mitigation), screen/bypass systems (downstream), and angled bar rack installations (downstream) are assessed.

These graphical figures should be useful as a guide in defining order-of-magnitude costs when planning new mitigation installations; however, care should be used when applying these curves, because of the site specific nature of hydroelectric projects.

23.2.1 Upstream Mitigation—Fish Ladders.

23.2.1.1 Installation Costs. Seventy percent of the projects contributing preliminary installation cost data are located in the five northwestern states and another 25% are situated in the northeast. The band across Figure 23-1 showing ranges in installation costs (dollars per kilowatt) encompasses 80% of the data points from the preliminary database. The values represented by the top and bottom of this cost range differ by a factor of three. For example, cost is shown to vary between about $30 to $100 per kilowatt for a fish ladder installation at a 10-megawatt project.

In plotting the case study data points on Figure 23-1, wide scatter with two of the nine data points was observed. If the high point (Buchanan, Michigan, the only data from midwestern projects, at $843 per kilowatt) and low point (Kern River No. 3, California, ladder 30+ years old and no accurate cost data available, at $4.80 per kilowatt) are eliminated, then the best-fit curve for the remaining points plots along the top line of the cost range. The two case study data points above the band in the range between 10 and 20 megawatts represent projects located in Maine and are a factor of two greater than cost values represented by the upper line of the range. Moreover, the only data point to fall well outside and above the range from the preliminary database also represented a project from the state of Maine. These results may indicate that unit costs for fish ladder installations are likely higher in the northeast than elsewhere.

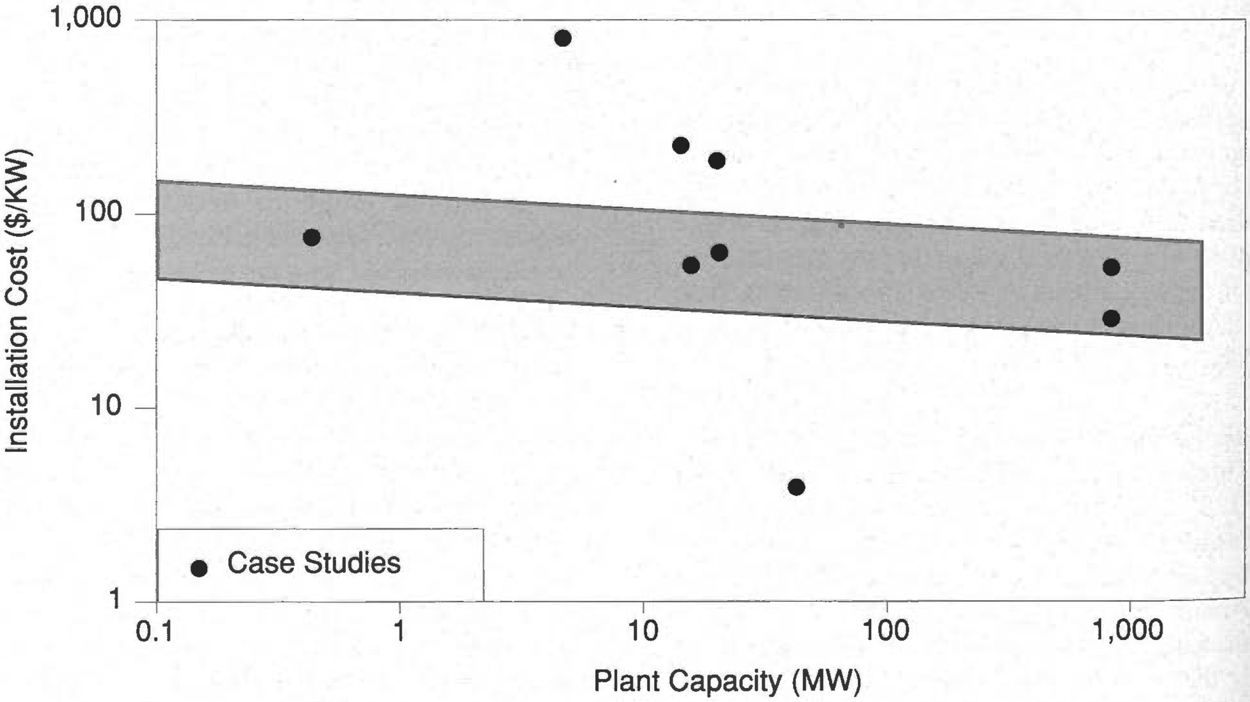


Figure 23-1. Total fish ladder installation cost versus plant size.

23.2.1.2 Total Costs. The band across Figure 23-2 showing ranges in total costs (cents per kilowatt-hour) encompasses 85% of the data points from the preliminary database. The values represented by the top and bottom of this cost range differ by a factor of four. For example, total cost is shown to differ between 0.048 to 0.19 cents per kilowatt-hour (levelized over 20 years) for a fish ladder installation at a 10 megawatts project.

When plotted, two of the case study data points again show wide scatter. If the high point (Buchanan, Michigan, 1.1 cents per kilowatt-hour) and low point (Kern River No. 3, California, not shown, 0.005 cents per kilowatt-hour) are eliminated, then the best-fit curve for the remaining points is above the top limit of the cost range by a factor of 1.25 to 1.5 times the values represented by the upper line.

The three data points above the band the range between 10 and 30 megawatts represent projects located in Maine (2) and Massachusetts (1). Again, these results indicate that total unit costs for fish ladder installations are likely higher in the northeast than elsewhere.

23.2.1.3 Operations and Maintenance Costs. The band across Figure 23-3 showing ranges in annual operations and maintenance costs was developed from case study data instead of preliminary data because these case study data exhibited substantially less scatter. Only two of the eight available data points from the preliminary survey are well below the range, and no points are greater than the range. There is a factor of three between the high and low limits of the range. For example, the annual operations and maintenance costs are shown to range from 0.018 to 0.052 cents per kilowatt-hour for a 10-megawatt project.

23.2.2 Downstream Mitigation—Screen/Bypass Facilities.

23.2.2.1 Installation Costs. Two-thirds of the projects providing the preliminary screen/bypass installation cost data are located in western states and another 30% are situated in the

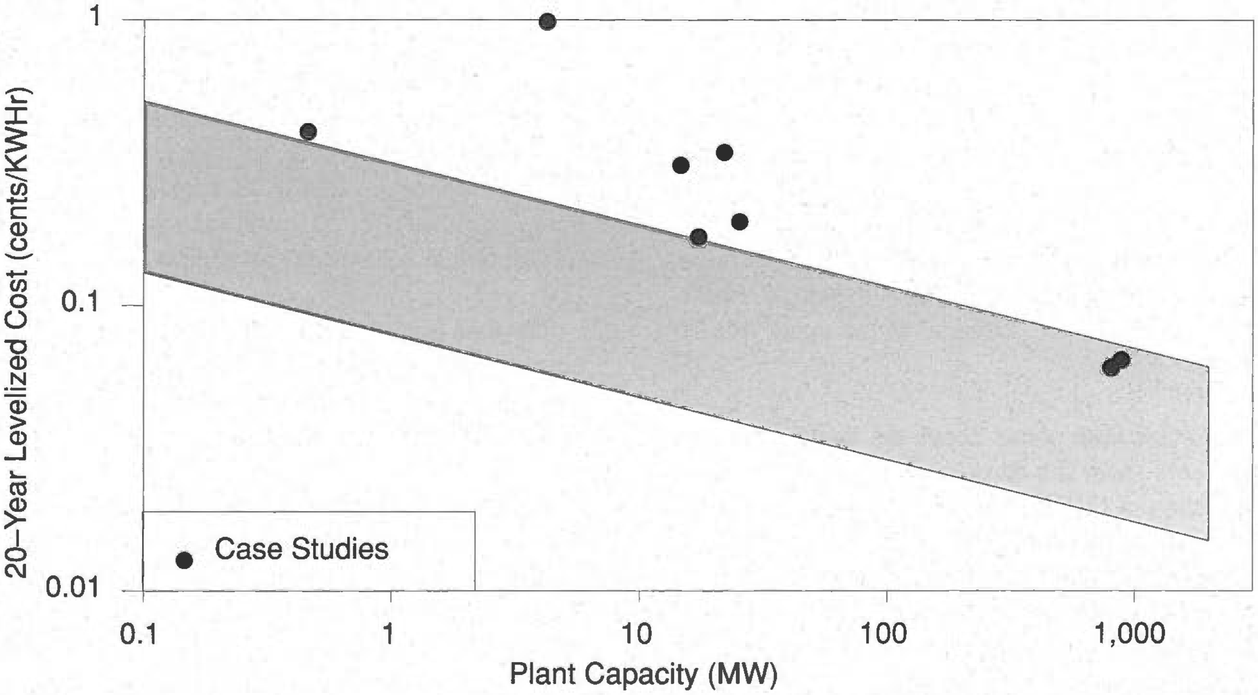


Figure 23-2. Total fish ladder costs versus plant size. Includes capital, study, administrative, operations and maintenance, reporting, and lost generation costs.

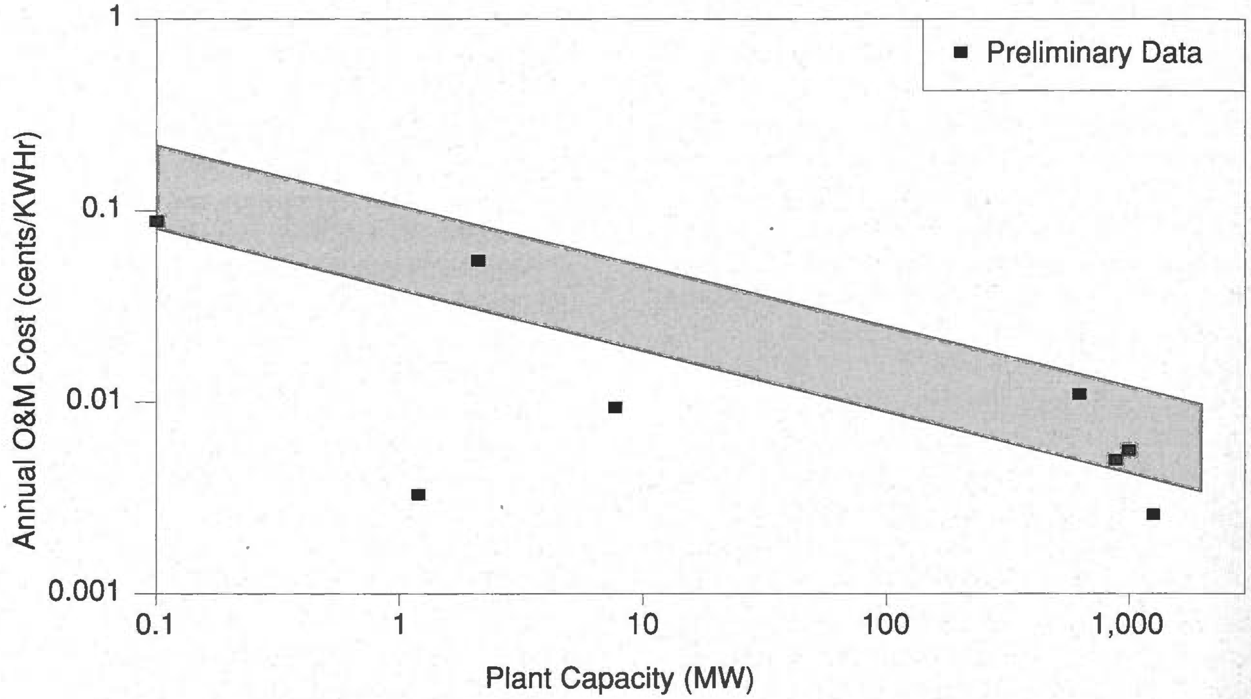


Figure 23-3. Annual fish ladder operations and maintenance costs versus plant size. Includes administrative and reporting costs. The cost range is based on the case studies information.

northeast. The band across Figure 23-4 showing ranges in installation costs encompasses 85% of the data points from the preliminary data. There is a factor of about 3.5 between the bottom and the top of the cost range. For example, cost is shown to vary between about $17 to $59 per kilowatt for a screen/bypass installation at a 10-megawatt project.

For the case study data, there is scatter above the cost range, but the best-fit curve for the case study data points is identical to the upper line of the cost range.

The five data points above the range represent projects from the northwest [Oregon (3) and Washington (2)]. These results indicate that unit costs for screen/bypass installations are likely higher in the northwest than elsewhere. The four data points from northeastern projects are grouped along the bottom line of the range (between 10 and 30 megawatts).

23.2.2.2 Total Costs. Since 85% of the preliminary survey data and all case study data were reasonably grouped in the installation cost graphical representation, the data from both sources were plotted together to develop the cost band in Figure 23-5. All retained data points are either within or in close proximity to this band. There is a factor of 10 between the bottom to the top of the cost range. For example, total cost is shown to vary between about 0.06 to 0.6 cents per kilowatt-hour (levelized over 20 years) for a screen/bypass installation at a 10-megawatt project.

The data points representing northeastern projects generally congregate along the lower line of the range, and those from western projects are within the upper half of the range.

23.2.2.3 Operations and Maintenance Costs. Since there is considerable scatter in the preliminary survey operations and maintenance data, a best-fit curve instead of a range was developed from all combined preliminary and case study data (Figure 23-6). In this instance, 70% of the points representing western projects are above the average line (one higher than the value shown on the average line by a factor of 20) and all

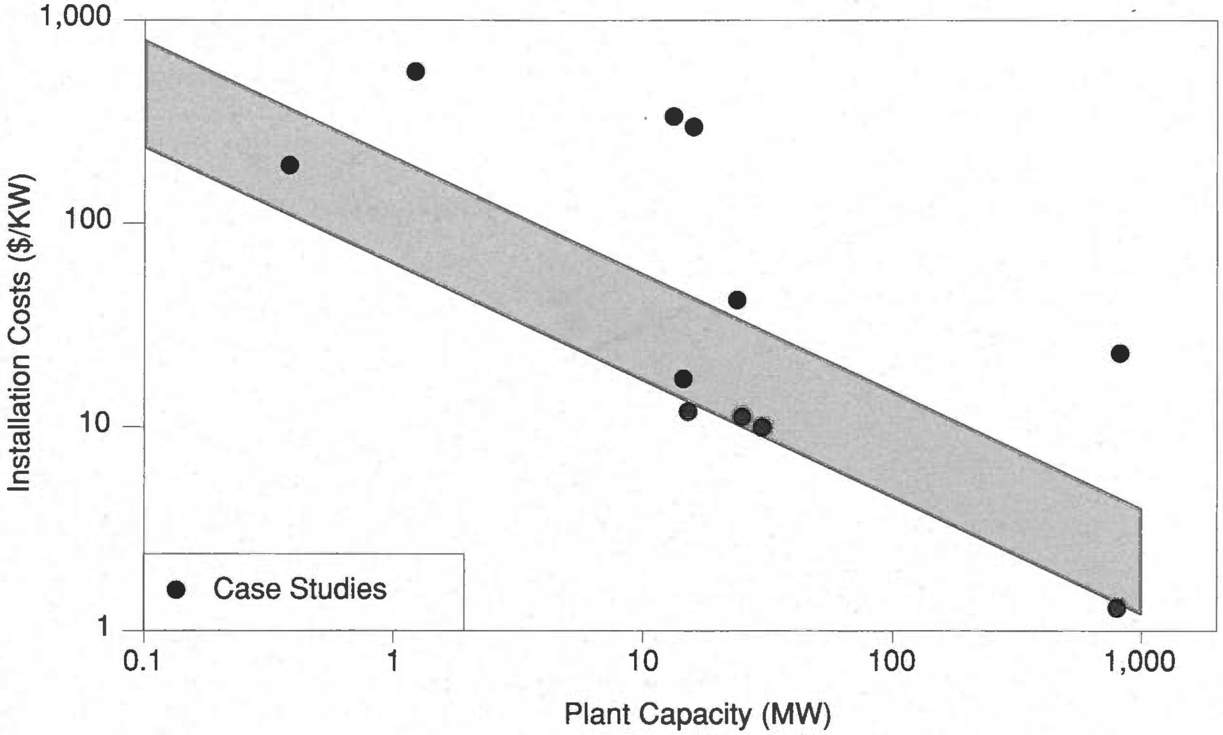


Figure 23-4. Screen/bypass installation costs versus plant size.

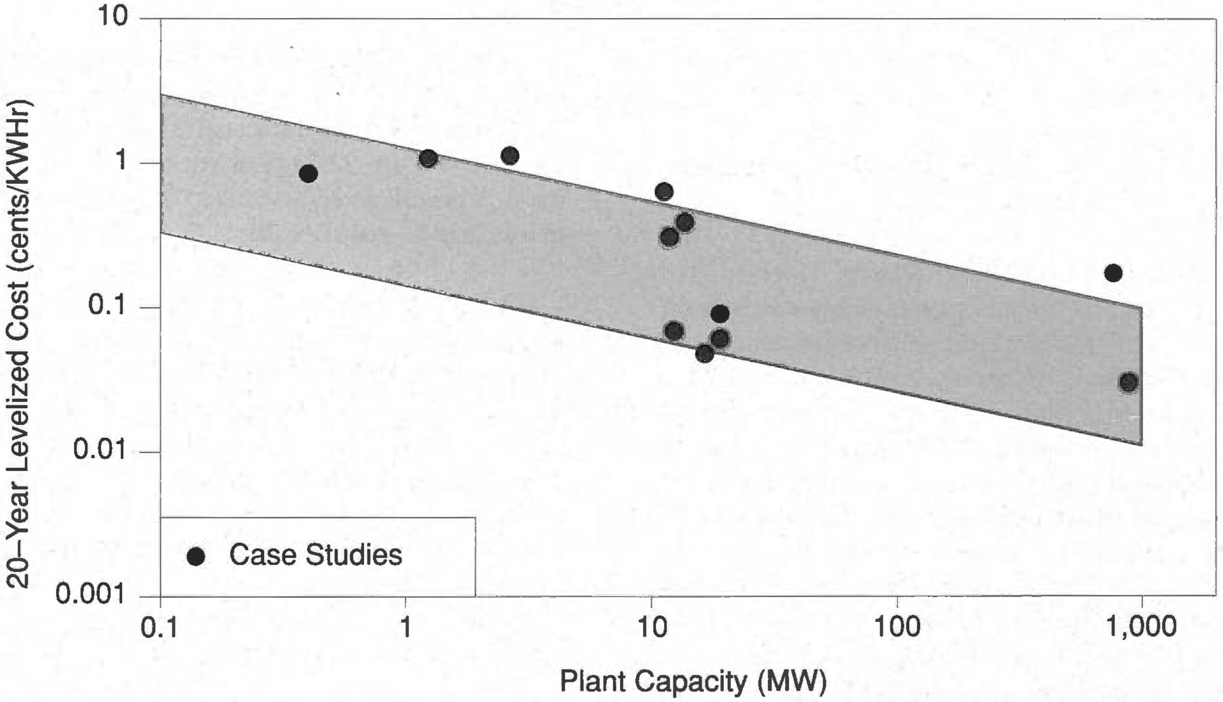


Figure 23-5. Total screen/bypass costs versus plant size. Includes capital, study, administrative, operations and maintenance, reporting, and lost generation costs.

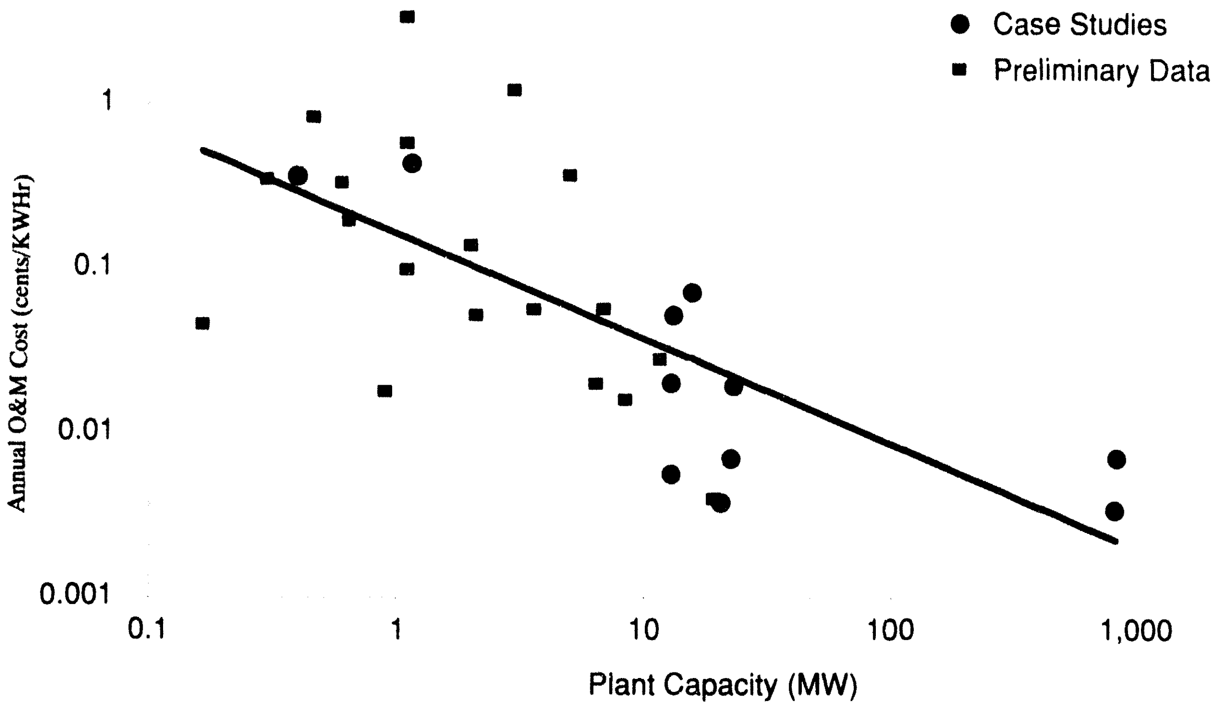


Figure 23-6. Annual screen/bypass costs versus plant size. Includes administrative and reporting costs.

points from projects in the northeast are below the line. As an example, the annual operations and maintenance costs represented by the average line for a 10 megawatts project is 0.039 cents per kilowatt-hour.

23.2.3 Downstream Mitigation—Angled Bar Racks.

23.2.3.1 Installation Costs. Three-fourths of the projects providing preliminary cost data on angled bar racks are located in northeastern states and the other 25% are situated in the west. One project with a plant capacity of 4.9 megawatts and a unit installation cost for angled bar racks of $530 per kilowatt was eliminated since the cost was orders of magnitude greater than those of all other projects. It is also noticeable that projects with angled bar racks are on the average much smaller than projects with screen/bypass facilities. Because of wide data scatter, only the best-fit line was developed and plotted (Figure 23-7) to provide some guidance for angled bar rack installation costs for projects of various size. The results show that the best-fit line is almost level at $22 per kilowatt for all plant sizes from 0.03 megawatts to 15 megawatts.

There was only one case study with angled bar racks. The data point from this project plots near the lower range of data scatter at $8.40 per kilowatt (Figure 23-7). The variation in angled bar rack installation costs ranged from almost $90 to less than $7 per kilowatt.

23.2.3.2 Total Costs. Again, because of the data scatter only the best-fit curve was plotted (Figure 23-8). This line shows a variation in average total costs over 20 years from 0.15 cents per kilowatt-hour for a 0.03 megawatts project to 0.06 cents per kilowatt-hour for a 10 megawatts project. Interestingly, the highest and lowest reported total costs were both from projects in western states (Colorado, 0.13 megawatts, 1.2 cents per kilowatt-hour; and Oregon, 1.2 megawatts, 0.01 cents per kilowatt-hour).

The data point for the single case study plots slightly above the average line at 0.56 megawatts, 0.12 cents per kilowatt-hour (Figure 23-8).

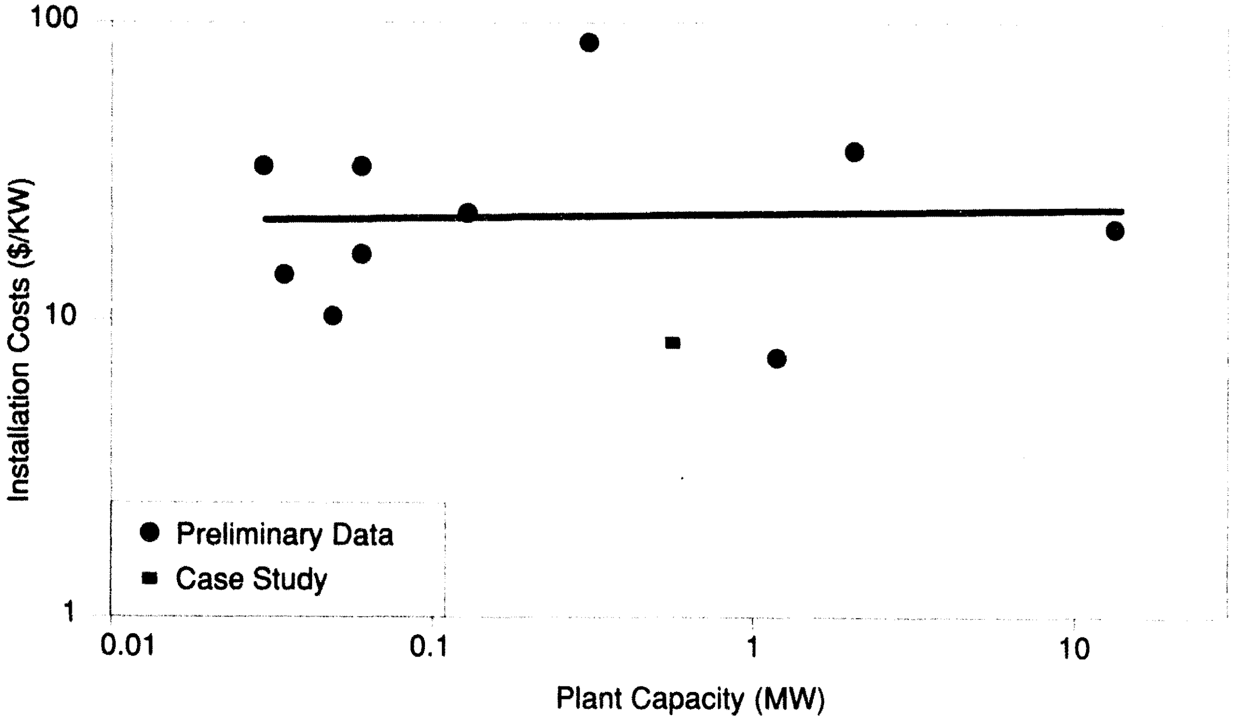


Figure 23-7. Angled bar rack installation costs versus plant size.

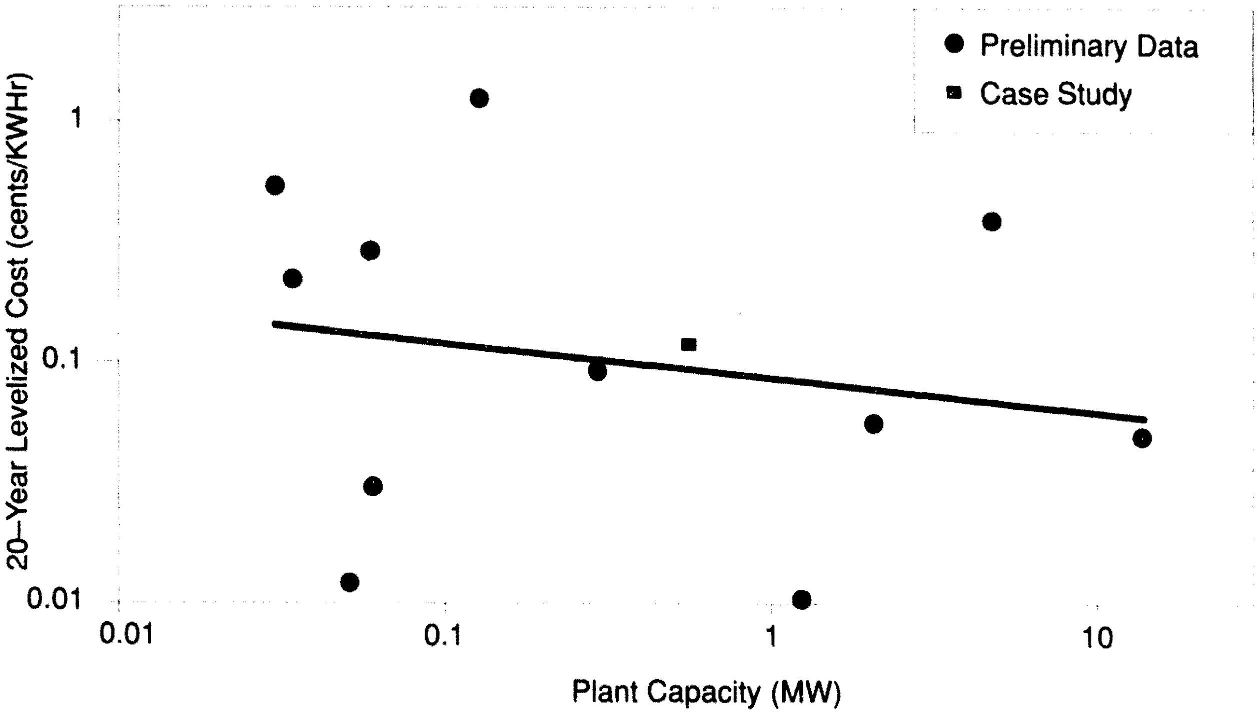


Figure 23-8. Angled bar rack total costs versus plant size. Includes capital, study, administrative, operations and maintenance, reporting, and lost generation costs.

23.2.3.3 Operations and Maintenance Costs. Annual operations and maintenance costs were developed from a limited base of five preliminary survey data points and a single case study value. The best-fit curve based on preliminary data is shown in Figure 23-9. The case study value plots well below the average line. The average curve varies from 0.15 cents per kilowatt-hour for a 0.03-megawatt project to 0.042 cents per kilowatt-hour for a 10-megawatt project.

23.3 Benefits

Based on the results of the examination of selected case studies, the benefits of most mitigation facilities can be expressed only in terms of the numbers of individual fish that use the passage/protection facility to bypass the hydroelectric project. This is the case because individual fish count is most often the only parameter monitored. And for some of the case studies, only subjective visual observations are available. In addition, the effects of mitigation facilities on fish populations are rarely studied or known. Moreover, the benefits of mitigation facilities to commercial and recreational fisheries are rarely addressed.

Various methodologies that are available to value fish and fish populations and could be used to develop economic benefits for mitigation facilities at hydroelectric projects are discussed in this report. Presently, there is wide disparity in the results produced by these methods when used to place a value on a fish, even when used to assess identical sites and species. In addition, there is little agreement among industry or agency representatives concerning an acceptable approach to the fish valuation problem. Therefore, the economic valuation of the benefits of mitigation facilities was not attempted for the case studies analyzed here.

Some mitigation practices mandated by fisheries management agencies have broad objectives (e.g., increase passage numbers, no induced mortality). However, changes in the number of

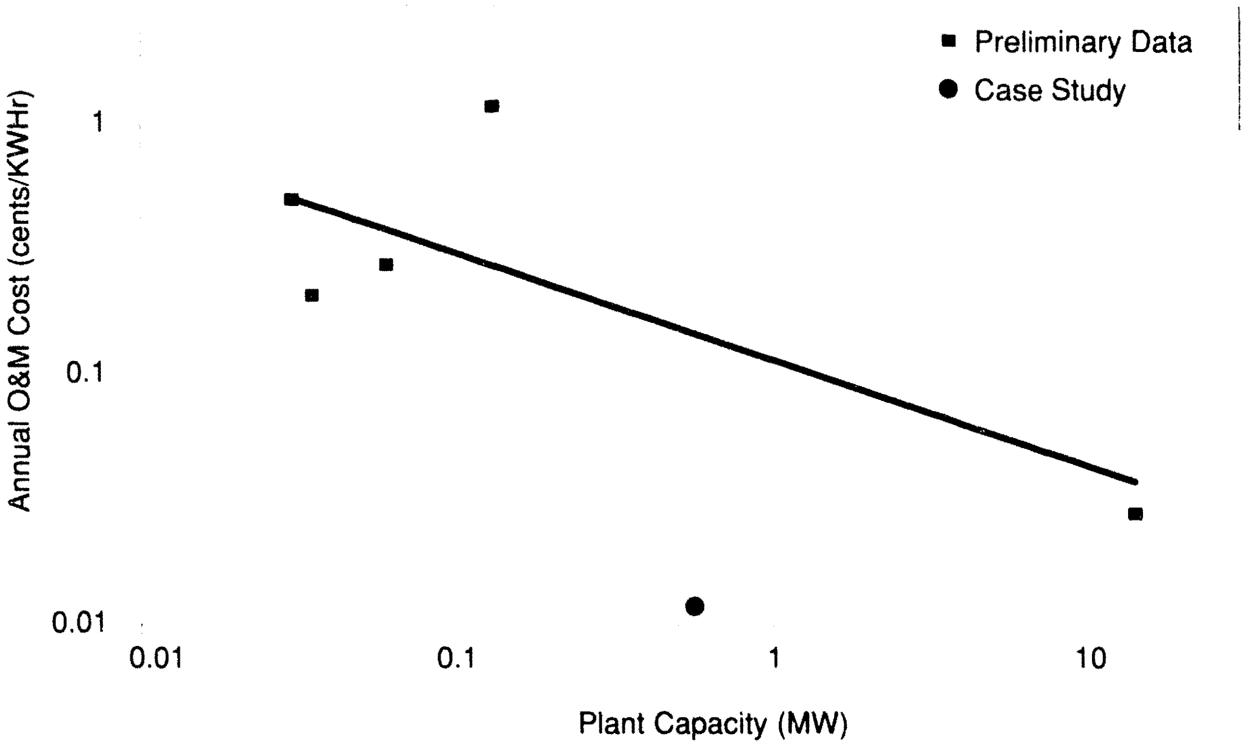


Figure 23-9. Angled bar rack operations and maintenance costs versus plant size. Includes administrative and reporting costs.

fish passing a facility can be related to many environmental factors, including available spawning and rearing habitat, harvest regulations, and hatchery practices. Consequently, most current monitoring practices, such as adult passage counts, do not provide an adequate measure of the benefits of mitigation facilities. Other more appropriate measures to monitor the benefits/impacts of an adult passage facility on migrating fish would include passage efficiency, rate/time of passage, survival rates, and other increases or decreases in population parameters. For downstream passage, total passage survival should include separate measures of the various passage routes, i.e., bypass, spill, and turbine survival. Other measurements, including migration delay or predation, may also be appropriate, depending on the type of structure being evaluated.

23.3.1 Upstream Fish Passage/Protection Mitigation. Twelve of the 16 case studies provide facilities for the upstream passage/protection of fish (ten ladders, two mechanical lifts,—one project with both a ladder and a lift, and one weir). A summary of the type of installation, objective of the agency requiring the mitigation, basic benefits of the installation operation, and annual cost of providing the facilities (levelized over 20 years) is presented in Table 23-1 for comparison.

Five case study projects with fish ladders (Buchanan, Leaburg, Lower Monumental, Wells, and West Enfield) and one case study project with two fish lifts (Conowingo) have been successful in increasing the passage rates of migrating fish. At four of the case study projects (Brunswick, Jim Boyd, Lowell, and Potter Valley), limited performance monitoring has been conducted. Although initial results from these projects are encouraging, they have not been adequately studied to determine whether upstream passage/protection measures have long term benefits to fish populations. The 30+ year old fish ladder installed at Kern River No. 3 has not been adequately monitored for effectiveness. Agencies are discussing changes in fishery management goals at Kern River No. 3 and they are considering closing the ladder to prevent undesirable hatchery fish from moving upstream into stream sections designated for wild trout populations. Finally, the ladder at Arbuckle Mountain was ordered installed in the event that anadromous chinook and steelhead runs were successfully established in the Sacramento River downstream. Thus, there are now no anadromous fish present to use the Arbuckle Mountain ladder. Moreover, monitoring the ladder for its effectiveness in passing resident rainbow trout past the project has been hampered by the severe drought in California over the past several years.

23.3.2 Downstream Fish Passage/Protection Mitigation. Twelve of the 16 case studies provide facilities for the downstream passage/protection of fish (11 screen/bypass systems and one angled bar rack installation). A summary of the type of installation, objective of the agency requiring the mitigation, basic benefits of the installation operation, and annual cost of providing the facilities (levelized over 20 years) is presented in Table 23-2 for comparison.

Three case study projects with screen/bypass facilities (Leaburg, T. W. Sullivan, and Wells) have been successful in increasing the survival rates of downstream migrating fish. At seven of the case study projects (Brunswick, Jim Boyd, Little Falls, Lowell, Lower Monumental, Twin Falls, and Wadhams), limited performance monitoring has been conducted. Although initial results from these projects are encouraging, they have not been adequately studied to determine whether protection measures for fish moving downstream have long term benefits to fish populations. As before, monitoring the screen/bypass system at Arbuckle Mountain for its effectiveness in protecting resident rainbow trout has been hampered by the severe drought in California over the past several years. At West Enfield, initial data indicate that downstream-moving fish passing through the turbines may actually have a greater survival rate than those passing through the bypass conduit.

Table 23-1. Upstream fish passage/protection benefits. The costs are levelized annual costs (1993 dollars), over 20 years.

Project	Mitigation type	Agency objective	Mitigation benefit	Annual cost (20-year average)
Arbuckle Mountain	Denil ladder	If restoration of chinook salmon and steelhead are successful downstream,then mandated ladder will be needed; also to allow movement of resident rainbow trout around the project	No anadromous fish present, restoration hindered by drought-related low stream flows; monitoring (visual observation) indicated no obstruction of resident trout	$3,770
Brunswick	Vertical slot ladder	A sustained commercial yield of: Alewife—1 million lbs/year (estimated 3.3 million fish/year) American shad—500,000 lbs/year (estimated 286,000 fish/year) Present ladder capacity: Alewife—1 million fish/year American shad—85,000 fish/year	Fish moving through ladder—6 year average: Alewife—76,000/year Atlantic salmon 47/year American shad—one fish in 6 years	$342,400
Buchanan	Vertical slot ladder	Pass large numbers of migrating fish upstream for anglers	Fish moving through ladder—1992: Chinook salmon—1,856 (92% efficiency Coho salmon—267 (100% efficiency) Steelhead—1,421 (69% efficiency)	$212,850
Conowingo	Mechanical lifts (2)	Transport maximum American eel, river herring, and striped bass upstream; Present lift design: River herring—5 million/year American shad—750,000/year	Fish moving through lift—9 year average: American shad—10,700/year (Single lift until 1991—two lifts now operating should raise this total to at least 20,000/year)	$1,538,900
Jim Boyd	V-notch weir	Assure that no induced fish mortality result from project operation (chinook and steelhead)	No established monitoring program, visual observations	$38,290
Kern River No. 3	Denil ladder	Allow upstream movement of resident rainbow trout (changing management goals may result in closing the ladder)	No established monitoring program	$8,800

Table 23-1. (continued).

Project	Mitigation type	Agency objective	Mitigation benefit	Annual cost (20-year average)
Leaburg	Vertical slot ladder	"No net loss" of anadromous fish moving past the project	Fish moving through ladder—20-year average: chinook—2,800/year (no net loss standard reportedly achieved)	$126,300
Lowell	Vertical slot ladder and mechanical lift	Restore designated fish to the following levels: Atlantic salmon—3,000 American shad—1 million	Fish using ladder/lift—7-year average: American shad—2,200/year	$408,775
Lower Monumental	Overflow weir ladders (2)	To move anadromous fish upstream past the project	Ladder efficiency: 82%—100%, spring/ summer chinook salmon	$1,811,000
Potter Valley	Pool/weir ladder	Increase movement of chinook salmon and steelhead upstream	Fish moving through ladder—21-year average: chinook salmon—220/year Steelhead—960/year	No cost data
Wells	Pool/weir ladders (2)	"No induced mortality" standard be maintained	Fish moving through ladders—20-year average: salmon—48,000/year, steelhead—7,300/year	$2,461,000
West Enfield	Vertical slot ladder	Ladder design: Atlantic salmon—10,000/year Alewife—14 million/year American shad—1.4 million/year	Fish moving upriver—10-year average: Atlantic salmon—2,650/year	$315,000

Table 23-2. Downstream fish passage/protection mitigation benefits. The costs are levelized annual costs (1993 dollars), over 20 years.

Project	Mitigation type	Agency objective	Mitigation benefit	Annual cost (20-year average)
Arbuckle Mountain	Cylindrical, wedgewire screens	Prevent fish entrainment (chinook salmon, steelhead, rainbow trout)	No anadromous fish present. Drought restricted monitoring	$7,900
Brunswick	Steel bypass pipe	Reduce mortality for downstream migrating fish (American shad, alewife)	No established monitoring program	$46,500
Jim Boyd	Perforated steel screen	"No induced mortality" standard	Reportedly achieves agency standard. Visual observations performed	$51,000
Kern River No.3	Fixed barrier screens	Protect "put-and-take" rainbow trout fishery	No established monitoring program	$7,700
Leaburg	"V" wire screens and bypass	"No net loss" standard	Meets agency standards	$381,200
Little Falls	Wire mesh screens and bypass	Protect downstream migrating blueback herring	Less than 1% turbine entrainment (>100,000 passed each season)	$123,400
Lowell	Bypass sluice	Pass American shad and Atlantic salmon	No established monitoring program but existing sluice is considered ineffective	$52,850
Lower Monumental	Submerged, traveling screens	Prevent turbine entrainment (salmon and steelhead)	Not yet monitored	$4,812,000
T.W. Sullivan	Eicher screen and conduit	Decrease turbine entrainment	Bypass efficiency between 77 and 95%	$713,000
Twin Falls	Inclined wedgewire screens	"No induced turbine mortality" standard	Reportedly effective	$75,850
Wadhams	Angled trash racks and bypass sluice	Protect downstream-moving Atlantic salmon from turbine mortality	1987 study: 8% entrainment	$2,420

Table 23-2. (continued).

Project	Mitigation type	Agency objective	Mitigation benefit	Annual cost (20-year average)
Wells	Hydrocombine bypass	Goal—"no induced mortality"; present agency criteria (passage efficiency): spring—80% efficiency summer—70% efficiency	Passage efficiency exceeds agency criteria	$1,756,000
West Enfield	Steel bypass pipe	Protect downstream migrating Atlantic salmon and alewife	Efficiency: 1990—18% 1991—62% (with attraction lighting) Mortality in bypass greater than in turbines	$61,000

23.4 Lessons Learned

For fish passage/protection facilities, the lessons that emerge from this survey and analysis include the following:

- There is widespread lack of follow-up investigation and analysis of the effectiveness of fish passage/protection facilities by developers, FERC, or resource agencies.

- Fish passage/protection facilities are sometimes imposed on hydroelectric projects without specific resource goals in place.

- For passage of fish upstream, fish ladders and lifts predominate in the Northeast and Northwest. The single case study from the Midwest uses a fish ladder to enhance the movement of anadromous species of fish for anglers.

- If properly sized and configured for the species of concern and equipped with the necessary attraction apparatus, fish ladders and lifts can be extremely effective in moving fish upstream past a hydroelectric project. These installations were near 100% effective at a number of the case study projects.

- For a typical 10-megawatt project generating 41 million kWh/Year, fish ladder installation costs would average about $1 million and total costs would average about $125,000 per year for the first 20 years of operation. The limited data on lifts indicate that the cost of these facilities could be 2.5 to 3.0 times as much as fish ladders.

- Downstream mitigation facilities comprising screens, angled bar racks, and bypass conduits predominate in all regions except the Midwest.

- Downstream mitigation facilities are not proven. Predation is a major consideration in the effectiveness of downstream passage facilities. The delivery of downstream-migrating fish from a bypass conduit below a hydroelectric plant concentrates the fish in a narrow area where they can actually experience higher mortality from predation than if they were to pass through the project's hydro-turbines.

- The case studies of fish moving downstream past the West Enfield projects indicate that downstream migrating fish moving through turbines, (particularly of recent design), may experience less mortality than those moving through spillway gates or bypass facilities.

- For a typical 10-megawatt project generating 41 million kWh/year, screen/bypass installation costs would average about $600,000 and total costs would average about $82,000 per year for the first 20 years of operation. Costs to install angled racks at an identical project would average $220,000 and total costs would average about $25,000 per year for the first 20 years of operation.

- Presently, the benefits of fish passage/protection facilities are most often measured by counting individual fish passing through the facility. Thus, decisions on fish passage/protection are based on individual fish counts and not on the effects of the facility on the overall fish population.

24. RECOMMENDATIONS

24.1 Quantifying the Effectiveness of Fish Passage/Protection Measures

Case studies of upstream fish passage have shown that both fish ladders and fish lifts can successfully transport large numbers of spawners. Where resource agency goals are expressed in terms of numbers of fish passed above the dam, effectiveness can be relatively easily determined by ladder/lift counts. If the goals are expressed as a percent of upstream migrants passed by the device, however, quantifying effectiveness is more difficult because the numbers of migrants reaching the tailrace must also be enumerated. An even more complicated situation occurs when the ladder/lift is only one part of a larger basinwide restoration program (e.g., including fish hatcheries, transport and distribution via trucks, downstream passage/protection measures, water quality and habitat improvements, harvest limitations, etc.). In cases where resource management goals are generally defined for the overall program, the benefits of a particle upstream passage/protection measure may be impossible to isolate.

Most of the monitoring studies of mitigation have dealt with anadromous salmonids or clupeids because of their commercial or recreational (use) value. Much less is known about the effectiveness of upstream passage measures for transporting resident fish, especially those with only nonuse value. Existing ladders and lifts also allow the upstream passage of nontarget fish species, although they may be less effective because they may have been designed with the behavior and size (swimming ability) of only trout and salmon in mind. Given the growing emphasis on managing natural resources to maintain biodiversity, hydroelectric facilities may eventually need to operate upstream passage measures to promote free passage of a wide variety of fish species and sizes. Alternatively, maintenance of biodiversity may argue for the closing of fishways in streams where the native fish populations may be adversely impacted by upstream movements of planted hatchery fish, or where extending the range of native fish over natural barriers is considered undesirable.

The downstream passage/protection case studies revealed fewer successes than the upstream case studies. In some instances, this is because the downstream measures were only recently installed and not yet adequately monitored. In others, the monitoring programs were apparently completed, but were too narrow in scope for results to be generalized to other sites. The most fundamental test of a mitigative measure's effectiveness, i.e., that the measure should yield better survival than the downstream passage route presumed to be most lethal (turbine passage), has rarely been rigorously examined.

In order to demonstrate the effectiveness of fish passage/protection measures and to optimize protection of the fish resources, the following recommendations should be considered:

- The regulatory and resource agencies should develop clearly defined goals for the protection or restoration of the fish resources. These goals should state the expected numbers or percentages of fish passed, and/or the projected population size. If fish passage/protection mitigation at the hydroelectric site is only part of a larger restoration effort, the expected contribution of the passage/protection measure should be estimated through such methods as sensitivity analyses of predictive models of fish population growth.

- Operational monitoring of target species should be conducted. For upstream passage/protection measures, this would include quantitative estimates of the numbers of fish reaching the dam, as well as the numbers successfully continuing upstream after accounting for losses due to fallback and mortality. For downstream passage/protection, monitoring should include quantification of both numbers and mortality of fish using all possible passage routes (e.g., turbine-passage, bypass-system, spill).

- Once the effectiveness of the fish bypass system is established, population-level studies would help address the more difficult question about the ultimate effect that improved passage or survival has on the fish populations. If the species has sport or commercial value, such studies could be extended to examine the effects of mitigation on the resultant fisheries.

- Operational monitoring should examine the influence of these measures on the movements and survival of nontarget fish species. These species might include resident fish that support a sport fishery (e.g., resident trout, bass, bluegill sunfish), fish without an identified use value (e.g., minnows and darters), and potential nuisance organisms (e.g., lampreys and carp).

24.2 Quantifying Benefits

As with population-level effects, the economic benefits of fish passage/protection measures to commercial and recreational fisheries are not known for most projects. Although recreationally caught fish are not transacted in markets, fishermen do attach values to them. Considerable effort needs to be devoted to the development of benefits assessment techniques before they can be directly compared to the costs of mitigation measures. Specific recommendations for improving the quantification of benefits include:

- Efforts should be made to develop methods for quantifying use values of recreationally caught fish, and the effect that changes in the numbers of fish (caused by the mitigation measure) have on their value.

- The theory supporting the concept and measurement of existence value (a nonuse value) is less well-developed than that for use values. None of the projects had assessed the nonuse values associated with a measure's enhancement of fish populations in the project streams. Estimates of existence values for natural resources may be many times the size of use values. Because existence values are an inadequately understood aspect of investments in natural resources, techniques for estimating them should be developed.

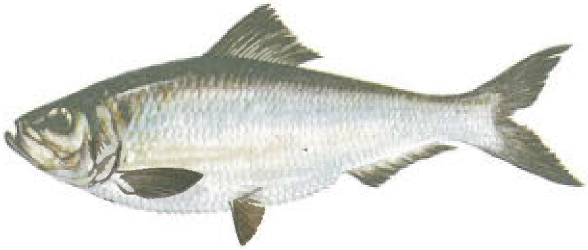
- Transfer of fish value estimates from one site to another is a subject of active study, and the principal rule of thumb emerging so far is that values are more transferrable to nearby sites than to sites farther away, although measures of "near" and "far" are still rough. Sites in close proximity to one another are likely to share much the same population of fishermen and the same array of substitute sites, two characteristics which are critical to recreational fish values. However, if statistical estimation does not fully account for other characteristics of sites that fishermen value, the estimated fish values may be contaminated by some positive or negative elements of site characteristics. Development of reliable methods for transferring benefits among nearby sites could reduce the costs of assessing benefits of individual hydroelectric projects.

25. FISH SPECIES REFERENCED

Common Name	Scientific Name
Alewife	*Alosa pseudoharengus*
American eel	*Anguilla rostrata*
American shad	*Alosa sapidissima*
Atlantic salmon	*Salmo salar*
Blueback herring	*Alosa aestivalis*
Bluegill	*Lepomis macrochirus*
Brook trout	*Salvelinus fontinalis*
Brown trout	*Salmo trutta*
Bull trout	*Salvelinus confluentus*
Carp	*Cyprinus carpio*
Channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
Chiselmouth	*Acrocheilus alutaceus*
Chum salmon	*Oncorhynchus keta*
Coho salmon	*Oncorhynchus kisutch*
Comely shiner	*Notropis amoenus*
Cutthroat trout	*Oncorhynchus clarki*
European eel	*Anguilla anguilla*
Gizzard shad	*Dorsum cepedianum*
Hardhead	*Mylopharodon conocephalus*
Largemouth bass	*Micropterus salmoides*
Largescale sucker	*Catostomus macrocheilus*
Longnose dace	*Rhinichthys cataractae*
Mountain whitefish	*Prosopium williamsoni*
Northern squawfish	*Ptychocheilus oregonensis*
Pacific brook lamprey	*Lampetra pacifica*
Pacific lamprey	*Lampetra tridentata*
Paiute sculpin	*Cottus beldingi*
Peamouth chub	*Mylocheilus caurins*
Rainbow trout (resident and steelhead)	*Oncorhynchus mykiss*
Redside shiner	*Richardsonius balteatus*
Reticulate sculpin	*Cottus perplexus*
Sacramento squawfish	*Ptychocheilus grandis*
Sacramento sucker	*Catostomus occidentalis*
Shorthead sculpin	*Cottus confusus*
Shorthorn sculpin	*Myoxocephalus scorpius*
Smallmouth bass	*Micropterus dolomieui*
Sockeye salmon	*Oncorhynchus nerka*
Speckled dace	*Rhinichthys osculus*
Striped bass	*Morone saxatilis*
Threespine stickleback	*Gasterosteus aculeatus*
Walleye	*Stizostedion vitreum*
Western brook lamprey	*Lampetra richardsoni*
White crappie	*Pomoxis annularis*
White perch	*Morone americana*
White sturgeon	*Acipenser transmontanus*

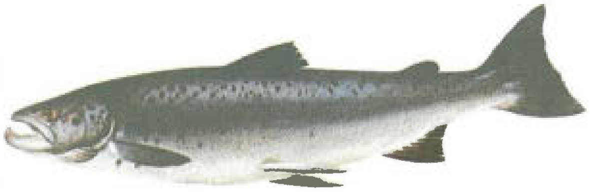
26. ILLUSTRATIONS OF SELECTED FISH SPECIES

The following figures are reproduced from *The Fresh and Salt Water Fishes of the World*, (Migdalski and Fichter, 1976).

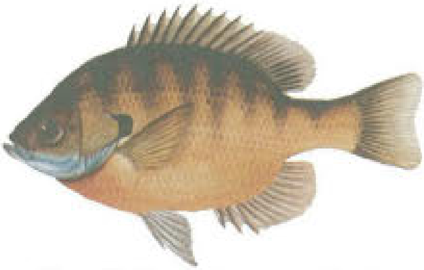


Alewife *(Alosa pseudoharengus)*

American shad *(Alosa sapidissima)*



Atlantic salmon *(Salmo salar)*

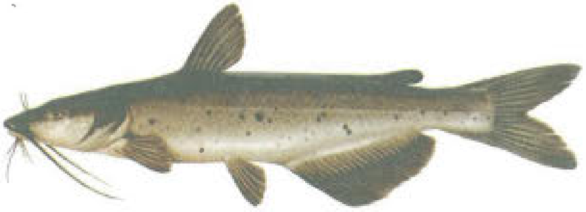


Bluegill *(Lepomis macrochirus)*

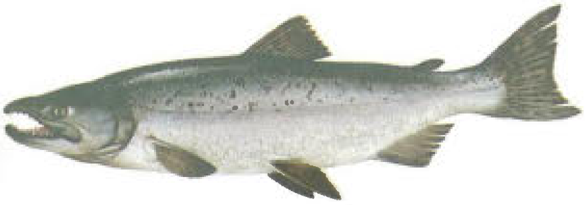
Brook trout *(Salvelinus fontinalis)*

Brown trout *(Salmo trutta)*

Carp *(Cyprinus carpio)*

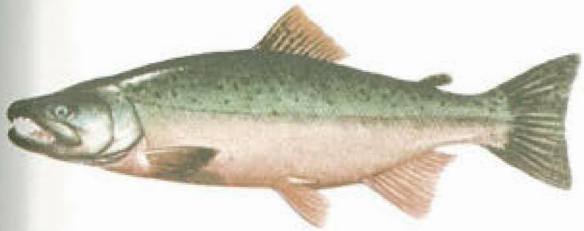


Channel Catfish *(Ictalurus punctatus)*



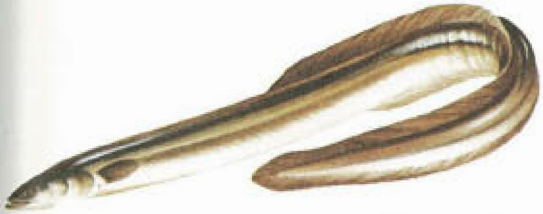
Chinook salmon *(Oncorhynchus tshawytscha)*

Chum salmon *(Oncorhynchus keta)*



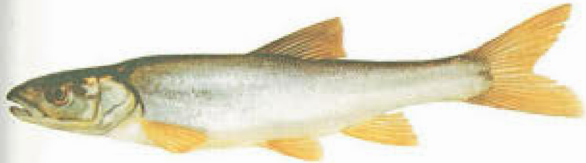
Coho salmon *(Oncorhynchus kisutch)*

Cutthroat trout *(Oncorhynchus clarki)*



European eel *(Anguilla anguilla)*

Gizzard Shad *(Dorosoma cepedianum)*

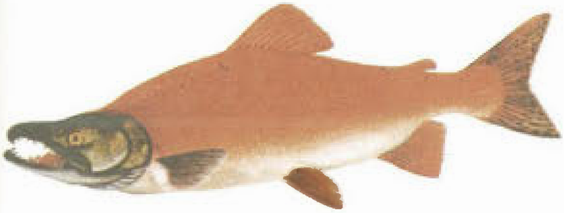


Northern Squawfish *(Ptychocheilus oregonensis)*

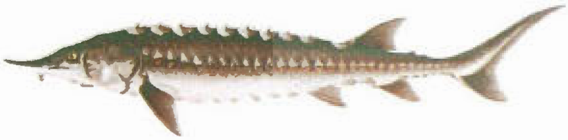
Rainbow trout *(Oncorhynchus mykiss)*

Shorthorn sculpin *(Myoxocephalus scorpius)*

Sockeye salmon—female *(Oncorhynchus nerka)*



Sockeye salmon—male *(Oncorhynchus nerka)*



White sturgeon *(Acipenser transmontanus)*

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Appendix A

Federal Energy Regulatory Commission Mitigation Frequencies

Table A-1. National mitigation frequencies. The "Plants with mitigation" columns may be lower than the sum of the columns to the left because several mitigation methods may be present at a single hydropower plant.

	Upstream fish passage					Downstream fish passage					
Plants licensed per period	Trap & hauling	Ladders	Elevator	Others	Plants with mitigation	Bypass	Angled bar rack	Screens	Light/ sound	Others	Plants with mitigation
All years											
1,825 plants	20	108	8	61	174	64	40	138	3	40	238
%	1.1	5.9	0.4	3.3	9.5	3.5	2.2	7.6	0.2	2.2	13.0
Pre-1970											
441 plants	9	25	2	12	38	14	1	21	1	8	35
24.2%	2.0	5.7	0.5	2.7	8.6	3.2	0.2	4.8	0.2	1.8	7.9
1970–1977											
79 plants	1	8	0	0	9	2	1	1	0	0	4
4.3%	1.3	10.1	0	0	11.4	2.5	1.3	1.3	0	0	5.1
1978–1985											
986 plants	9	54	6	40	100	28	27	91	0	22	143
54.0%	0.9	5.5	0.6	4.1	10.1	2.8	2.7	9.2	0	2.2	14.5
1986–1993											
319 plants	1	21	0	9	27	20	11	25	2	10	56
17.5%	0.3	6.6	0	2.8	8.5	6.3	3.4	7.8	0.6	3.1	17.6

Table A-2. Atlanta region mitigation frequencies. The "Plants with mitigation" columns may be lower than the sum of the columns to the left because several mitigation methods may be present at a single hydropower plant.

	Upstream fish passage					Downstream fish passage					
Plants licensed per period	Trap & hauling	Ladders	Elevator	Others	Plants with mitigation	Bypass	Angled bar rack	Screens	Light/ sound	Others	Plants with mitigation
All years											
204 plants	0	0	1	18	19	3	15	2	0	6	24
%	0	0	0.5	8.8	9.3	1.5	7.4	1.0	0	2.9	11.8
Pre-1970											
68 plants	0	0	0	1	1	0	0	0	0	0	0
33.3%	0	0	0	1.5	1.5	0	0	0	0	0	0
1970–1977											
12 plants	0	0	0	0	0	0	0	0	0	0	0
5.9%	0	0	0	0	0	0	0	0	0	0	0
1978–1985											
104 plants	0	0	1	14	15	2	15	2	0	5	22
51.0%	0	0	1.0	13.5	14.4	1.9	14.4	1.9	0	4.8	21.2
1986–1993											
20 plants	0	0	0	3	3	1	0	0	0	1	2
9.8%	0	0	0	15.0	15.0	5.0	0	0	0	5.0	10.0

Table A-3. Chicago region mitigation frequencies. The "Plants with mitigation" columns may be lower than the sum of the columns to the left because several mitigation methods may be present at a single hydropower plant.

	Upstream fish passage					Downstream fish passage					
Plants licensed per period	Trap & hauling	Ladders	Elevator	Others	Plants with mitigation	Bypass	Angled bar rack	Screens	Light/ sound	Others	Plants with mitigation
All years											
232 plants	0	5	0	0	5	0	0	0	0	0	0
%	0	2.2	0	0	2.2	0	0	0	0	0	0
Pre-1970											
78 plants	0	0	0	0	0	0	0	0	0	0	0
33.6%	0	0	0	0	0	0	0	0	0	0	0
1970–1977											
24 plants	0	1	0	0	1	0	0	0	0	0	0
10.3%	0	4.2	0	0	4.2	0	0	0	0	0	0
1978–1985											
77 plants	0	2	0	0	2	0	0	0	0	0	0
33.2%	0	2.6	0	0	2.6	0	0	0	0	0	0
1986–1993											
53 plants	0	2	0	0	2	0	0	0	0	0	0
22.8%	0	3.8	0	0	3.8	0	0	0	0	0	0

Table A-4. New York region mitigation frequencies. The "Plants with mitigation" columns may be lower than the sum of the columns to the left because several mitigation methods may be present at a single hydropower plant.

	Upstream fish passage					Downstream fish passage					
Plants licensed per period	Trap & hauling	Ladders	Elevator	Others	Plants with mitigation	Bypass	Angled bar rack	Screens	Light/ sound	Others	Plants with mitigation
All years											
633 plants	9	35	4	5	51	38	16	43	3	18	103
%	1.4	5.5	0.6	0.8	8.1	6.0	2.5	6.8	0.5	2.8	16.3
Pre-1970											
112 plants	3	5	1	1	10	6	0	1	1	2	10
17.7%	2.7	4.5	0.9	0.9	8.9	5.4	0	0.9	0.9	1.8	8.9
1970–1977											
18 plants	1	1	0	0	2	2	0	1	0	0	3
2.8%	5.6	5.6	0	0	11.1	11.1	0	5.6	0	0	16.7
1978–1985											
368 plants	5	22	3	3	31	18	7	33	0	9	58
58.1%	1.4	6.0	0.8	0.8	8.4	4.9	1.9	9.0	0	2.4	15.8
1986–1993											
135 plants	0	7	0	1	8	12	9	8	2	7	32
21.3%	0	5.2	0	0.7	5.9	8.9	6.7	5.9	1.5	5.2	23.7

Table A-5. Portland region mitigation frequencies. The "Plants with mitigation" columns may be lower than the sum of the columns to the left because several mitigation methods may be present at a single hydropower plant.

	Upstream fish passage					Downstream fish passage					
Plants licensed per period	Trap & hauling	Ladders	Elevator	Others	Plants with mitigation	Bypass	Angled bar rack	Screens	Light/ sound	Others	Plants with mitigation
All years											
306 plants	11	44	2	32	69	21	5	57	0	14	69
%	3.6	14.4	0.7	10.5	22.5	6.9	1.6	18.6	0	4.6	22.5
Pre-1970											
73 plants	6	18	1	8	23	8	1	10	0	6	15
23.9%	8.2	24.7	1.4	11.0	31.5	11.0	1.4	13.7	0	8.2	20.5
1970–1977											
8 plants	0	1	0	0	1	0	0	0	0	0	0
2.6%	0	12.5	0	0	12.5	0	0	0	0	0	0
1978–1985											
185 plants	4	16	1	19	34	7	4	37	0	6	42
60.5%	2.2	8.6	0.5	10.3	18.4	3.8	2.2	20.0	0	3.2	22.7
1986–1993											
40 plants	1	9	0	5	11	6	0	10	0	2	12
13.1%	2.5	22.5	0	12.5	27.5	15	0	25.0	0	5.0	30.0

Table A-6. San Francisco region mitigation frequencies. The "Plants with mitigation" columns may be lower than the sum of the columns to the left because several mitigation methods may be present at a single hydropower plant.

	Upstream fish passage					Downstream fish passage					
Plants licensed per period	Trap & hauling	Ladders	Elevator	Others	Plants with mitigation	Bypass	Angled bar rack	Screens	Light/ sound	Others	Plants with mitigation
All years											
450 plants	0	24	1	6	30	2	4	36	0	2	42
%	0	5.3	0.2	1.3	6.7	0.2	0.9	8.0	0	0.4	9.3
Pre-1970											
110 plants	0	2	0	2	4	0	0	10	0	0	10
24.4%	0	1.8	0	1.8	3.6	0	0	9.1	0	0	9.1
1970–1977											
17 plants	0	5	0	0	5	0	1	0	0	0	1
3.8%	0	29.4	0	0	29.4	0	5.9	0	0	0	5.9
1978–1985											
252 plants	0	14	1	4	18	1	1	19	0	2	21
56.0%	0	5.6	0.4	1.6	7.1	0.4	0.4	7.5	0	0.8	8.3
1986–1993											
71 plants	0	3	0	0	3	1	2	7	0	0	10
15.8%	0	4.2	0	0	4.2	1.4	2.8	9.9	0	0	14.1