Environmental Mitigation at Hydroelectric Projects

Volume II. Benefits and Costs of Fish Passage and Protection

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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

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