by Sale et al. (1991), development of standardized valuation criteria would benefit utilities and regulatory agencies.

APPENDIX. REFERENCES

Levy, D. A. (1992). "Potential impacts of global warming on salmon production in the Fraser River watershed." *Can. Tech. Rep. Fisheries and Aquatic Sci.*, Vancouver, BC, Canada, 1889.

Lewis, A. F., Mitchell, A. C., and Prewitt, C. M. (1994). "Evaluation of the effectiveness of water release as a mitigation to protect fish habitat." *Rep. 9118 G878*, Can. Electrical Association, Montreal, Quebec, Canada.

Rosenberg, D. M., Bodaly, R. A., Hecky, R. E., and Newbury, R. W. (1987). "The environment assessment of hydroelectric impoundments and diversions in Canada." *Canadian aquatic resources*, M. C. Healey and R. R. Wallace, eds., Dept. of Fisheries and Oc., Ottawa, Canada.

Sale, M. J., et al. (1991). "Environmental mitigation at hydroelectric projects, Volume 1: Current needs for instream flow needs, dissolved oxygen, and fish passage." *Rep., DOE/ID-10360*, U.S. Dept. of Energy, Idaho Field Office, Idaho Falls, Idaho.

Walters, C. J., Collie, J. S., and Webb, T. (1989). "Experimental designs for estimating transient responses to habitat alteration: is it practical to control for environmental interactions?" *Proc., of the Nat. Workshop on Effects of Habitat Alteration on Salmonid Stocks, Can. Spec. Publ. Fisheries and Aquatic Sci.*, C. D. Levings, L. B. Holtby, and M. A. Henderson, eds., Ottawa, Ontario, Canada, 105, 13–20.

2970 AL

EFFECTIVENESS OF WATER RELEASE AS MITIGATION FOR HYDROELECTRIC IMPACTS TO FISH

By Adam F. Lewis,[1] and A. Clyde Mitchell[2]

ABSTRACT: Utility companies release water to mitigate the effects of hydroelectric projects on fish habitats. Utility companies, government agencies, and research communities in Canada, the United States, Europe, New Zealand, and Australia were surveyed as part of a Canadian Electrical Association study to evaluate the effectiveness of water release as a mitigation. Respondents identified only 28 projects in which water was released specifically to protect fish habitats. Fewer than half of these projects (12) were judged as being effective. Six case histories with preimpact assessment and postimpact monitoring were reviewed. In four cases fish habitat or fish populations or both were maintained; in two cases they were not. The effectiveness of water release differed among rivers and fish species, and was greatest when designed to meet the habitat requirements of each life-history stage. A review of the literature did not support the theory that a particular fraction of the mean annual flow provides the best fish habitat. Although smaller changes in the flow regime had smaller effects, increasing minimum flows above those historically observed did not necessarily increase fish production.

INTRODUCTION

Background

The extent of hydroelectric development in Canada creates the potential for a widespread impact to fish habitat. The Department of Fisheries and Oceans (DFO) may require that utilities meet instream-flow needs for fish habitat and thereby forego some revenue from electricity generation. The effectiveness of water released for fish habitats is of concern to utility companies, regulatory agencies, and the public, because allocation of water between competing needs determines resource values and social costs. This paper evaluates the effectiveness of water releases from hydroelectric projects as a mitigation strategy to protect fish habitats, and is based on a study sponsored by the Canadian Electrical Association (Lewis et al. 1994).

Objectives

The objective was to identify and report on the findings of earlier studies on the effectiveness of water release as mitigation. Methods of prescribing water-release regimes were identified, along with measures required to maintain the effectiveness of water release. To achieve this, sites were identified at which water release has been used by utilities and other developers to maintain fish habitats in Canada, the United States, Europe, Australia, and New Zealand. Basic data on these sites, such as rate of flow, species involved, and type and quantity of habitat protected, were collected. The methodology used to prescribe the flow release and to assess the effects of flow regulations was identified, and the effectiveness of the resultant flow-

---

[1]Mgr., Fisheries Consulting, Triton Environmental Consultants Ltd., #120-13511 Commerce Parkway, Richmond, BC, Canada V6V 2L1.

[2]P.E., Vice Pres., Triton Environmental Consultants Ltd., #120-13511 Commerce Parkway, Richmond, BC, Canada V6V 2L1.

Note. Discussion open until January 1, 1996. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on April 18, 1995. This paper is part of the *Journal of Energy Engineering*, Vol. 121, No. 2, August, 1995. ©ASCE, ISSN 0733-9402/95/0002-0081–0088/$2.00 + $.25 per page. Paper No. 10564.

release prescription was noted. To increase the usefulness of this study to Canadian utilities, studies with data pertaining to Canadian anadromous and freshwater species were targeted.

METHODS

To evaluate the effectiveness of fish water-release sites relevant to Canadian situations and species, and to identify methods of assessing instream flow needs, data were collected in a stepwise approach. The published literature was searched by computer for information on water-release protocols and monitoring programs. This literature was reviewed and summarized as an annotated bibliography. From the review of the published literature, key representatives from within utility companies, government agencies, and research communities were identified and contacted via questionnaire for specific details (anecdotal and unpublished literature) of water-release protocols and monitoring programs associated with hydroelectric developments for which they were responsible. Following receipt and review of the questionnaires, data gaps and deficiencies were filled by conducting telephone interviews with the questionnaire respondents, and other professionals involved in these projects, as necessary. Although projects in several countries were reviewed, the focus of data collection was on Canadian projects.

RESULTS

Survey

A total of 35 questionnaires were distributed by mail to representatives of hydroelectric utility companies, government agencies, and researchers. There were 39 projects with water releases to protect fish habitats. The objective of water-release programs was most commonly to protect fish habitats (92% of the projects). Of the 39 projects with a water release designed to protect fish habitats, 21 (54%) had monitoring programs following construction, but in only 12 (31%) projects were fish, fish habitat, or both monitored both prior to and following project operation. Even though pre- and postdevelopment studies were made for just 12 studies, 28 studies reported on the effectiveness of flow release. Detailed information was lacking on monitoring at most of the projects identified from the questionnaire survey, limiting our selection of case studies to be examined to those with substantial monitoring data.

In-river projects and projects with storage had a higher percentage of effective releases than diversion projects or run-of-river projects (Table 1). Of the 35 projects within Canada, 23 projects evaluated water release, and

TABLE 1. Projects with Effective Water Release—Effect of Project Type on Effectiveness

Project type (1)	Diversion: Effectiveness (%) (2)	Diversion: Sample size (3)	In River: Effectiveness (%) (4)	In River: Sample size (5)	Both: Effectiveness (%) (6)	Both: Sample size (7)
Run of river	0	2	50	4	33	6
Storage	38	13	63	8	48	21
Both	33	15	58	12	44	27

al. (1991). The assessment of effects will require additional monitoring over several years, perhaps decades. In the short term, some answers may come from the analysis of existing data on fish population size and habitat status. These data have been collected for other purposes, but may serve to assess water-release effectiveness.

Defensible monitoring will follow an experimental approach that can assess the impacts of hydroelectric developments without bias. This would necessarily require a rigorous design to monitor several projects simultaneously with adequate controls (Walters et al. 1989). Monitoring efforts on systems with relatively unimportant fish-bearing streams or reaches should also be encouraged. The current study was biased by the tendency for preimpact studies and monitoring data to be collected from streams with relatively important fisheries resources. As a whole, lesser streams may provide a large proportion of the fish production within a region and thus should not be ignored.

Study Life History Requirements

Intensive studies of the life-history requirements of fish species affected by water releases are required. Where possible, life history and behavior studies should be made on the stream where water is being released as a mitigation for fish habitat.

Define Productive Capacity

Productive capacity is used as an assessment criterion, but is not well defined. As a result, utilities are faced with using water releases to achieve an ambiguous goal. At present, habitat is the key evaluation criterion. However, habitat protection may not protect productive capacity, because habitat is an indirect measure of fish-population health. Both habitat and population have strengths and weaknesses as measures of productive capacity. By studying the relationships between these measures it may be possible to get a more accurate estimate of how water releases affect productive capacity.

Assess Peak Flows

The need for flushing flows should be examined wherever a flow release is prescribed. Flushing flows may not always be available for release; however, the consequence of not providing one should be predicted and monitored. Trade-offs between provision of a continuous low flow and a periodic flushing flow should be identified in terms of fish habitat and fish production.

Define Objectives

The effectiveness of water releases should be evaluated against well-defined objectives. The objective of a water release must be explicitly defined in terms of which species are to be protected or optimized. If diversity of species is a goal, this too should be explicitly stated. Any monitoring effort must be designed to measure variables important to fish and address fish survival and the ecological differences between streams.

Value Fisheries Resources and Mitigation

The efficiency of water releases can be assessed only if common, meaningful units of value are available to compare water- release mitigation costs, other mitigation costs, and fisheries resource values. As previously noted

Sediments accumulated in both rivers and have had negative impacts on spawning gravel quality in the Big Qualicum River. Sufficient time has not elapsed since the Upper Salmon River Project began to determine the effect of sediment accumulation on the fish habitat.

Notwithstanding concerns about inadequate flushing flows, the case histories showed that methods of instream-flow prescription are effective. Discharge methods (e.g., the Montana Method) appear to have been sufficient to protect fish resources at the Upper Salmon and Wreck Cove Projects. A discharge method was also applied at Daisy Lake, but the recommended flows were not implemented and so the effectiveness of the method cannot be evaluated. Only at Terror Lake was the instream-flow incremental methodology applied, and it appears to have successfully protected and enhanced habitats on two rivers.

Conclusions

The effectiveness of water release at projects examined in this study varied between project type. In-river projects tend to have more effective water releases because they have the capability to release flows at critical life-history periods. No general statement regarding the effectiveness of a magnitude of flow or percent of mean annual flow could be made on the basis of the projects evaluated here. Although smaller changes in the flow regime had smaller effects, increasing minimum flows above those historically observed did not necessarily increase fish production.

The most detailed monitoring programs evaluated in this study assessed the effectiveness of water releases in maintaining both habitat and populations. The monitoring programs did not address all of DFO's goals of sustainable fisheries development: avoiding irreversible habitat damage, maintaining genetic diversity, maintaining habitat diversity, and providing a net gain in productive capacity (Levy 1992). The evidence of effectiveness is equivocal for some projects because of confounding effects and the short period of time elapsed since projects began. None of the studies examined had data on the cost of the water release and the value of the fish resource protected specifically by the water release.

The case histories showed that methods of prescribing instream flows were effective. Professional judgment performed well in the case histories examined—two of the three case histories in which water releases were set based on professional judgment were effective. These releases were higher than required by standard setting techniques, demonstrating the conservative effect of professional judgment. Standard setting approaches (discharge methods) were applied in two case histories but were not able to predict the direction and magnitude of impacts for some species. A common flaw among the case histories was the failure to account for changes in channel morphology and streambed composition that result from changes in the flow regime. Damage to habitat from sedimentation was common to projects lacking flushing flows.

RECOMMENDATIONS

Additional Monitoring

Sufficient information was identified for detailed review at only 15% of the projects where water was released to protect a fish habitat. This confirms the need for more intensive monitoring of the effectiveness of water released as a mitigation, as earlier observed by Rosenberg et al. (1989) and Sale et

TABLE 2. Projects with Effective Water Release within Canada—Distribution between Provinces Reporting Water Releases

Location (1)	Projects where Water Release was Evaluated: Number (2)	Projects where Water Release was Evaluated: Percentage of total (%) (3)	Effective Releases: Number (4)	Effective Releases: Percentage of total (%) (5)	Percentage effective within province (%) (6)
Newfoundland	2	9	2	22	100
Nova Scotia (Cape Breton)	1	4	1	11	100
New Brunswick	1	4	1	11	100
Quebec	0	0	0	0	—[c]
Ontario[a]	5	22	4	44	80
Manitoba	2	9	0	0	0
Saskatchewan	0	0	0	0	—[c]
British Columbia[b]	12	52	1	11	8
Total	23	—	9	—	

[a]Includes three projects on the Nipigon River.
[b]The Big Qualicum Development Project (nonhydroelectric) was excluded.
[c]Not applicable.

Table 2 shows the number of projects reporting effectiveness among the provinces. The breakdown of responses further demonstrates the bias in this survey, and the responses do not accurately represent the frequency of water-release effectiveness across the country.

Case Histories

The preceding reviews identified six projects for which sufficient information existed to justify a detailed case history analysis. The six projects are: Upper Salmon River—Newfoundland; Wreck Cove—Nova Scotia; Ragged Rapids—Ontario; Daisy Lake—British Columbia; Big Qualicum—British Columbia; and Terror Lake—Alaska. The Big Qualicum River Project is a fisheries-enhancement project in which water is stored and released solely to benefit fish production. The project does have all the elements of a power-storage project (except power generation), and therefore provides information of use in this study.

The case histories showed that water releases partly protected fish habitat at all six case projects. In two of the case histories studied (Wreck Cove and Terror Lake), populations and habitats for which data were available were protected. In two of the case histories (Upper Salmon and Big Qualicum), protection was complete except for an increase in sedimentation caused by reduced flushing flows. In one case history the recommended flow was not released (Daisy Lake) and fish habitat was lost. In the last case history the release provided minimal protection (Ragged Rapids). The case histories are summarized in Tables 3 and 4.

None of the case histories provided an experimental test of the effectiveness of flow release, and the extent of inference involved in the evaluations varied between assessments. The Big Qualicum and Upper Salmon River case histories demonstrated that even conservative minimum-flow prescription may fail to protect habitat if flushing flows are not provided.

TABLE 3. Case Histories Reviewed to Assess Water-Release Effectiveness

Characteristic (1)	Upper Salmon Project (2)	Wreck Cove Project (3)	Ragged Rapids Project (4)
Province	Newfoundland	Nova Scotia	Ontario
Generation Capacity (MW)	84	220	8
Type	Storage/diversion	Storage/diversion	Storage/diversion
River impacted	West Salmon River	Cheticamp River	Moon River
Year completed	1982	1978	1938
Preproject MAF (m^3/s)	6.40	11.0	50.0
Water release	Continuous	Summer low flow period	During walleye spawning and incubation
Water-release characteristic	Growing season flow held at 2.6 (41% PMAF). Peak flows reduced.	Flow of 0.72 (7% PMAF) released in upper watershed during the critical flow period. Mean annual flows have not changed following impoundment, but minimum flows have increased and spring flows have decreased.	No flow specifically for fish until 1967—flow then released during walleye spawning and incubation. This increased the median mean monthly flow in June from 5% to 14% of the preimpoundment value.
Year of monitoring (preconstruction/postconstruction)	1979/1985, 1987, 1988, 1992	1974, 1975/1982, 1983, 1984	none/1955–1974
Species monitored	Ouananiche, brook trout	Atlantic salmon	Walleye
Parameters monitored both prior to and following operation	Density and size of juvenile Ouananiche and brook trout	Juvenile Atlantic salmon density, adult angling catch statistics	Angler catch, commercial trapping, study trapping
Control	Southwest tributary & Dog Pond Brook	Robert Brook	None
Impacts to fish and fish habitat	Negligible change in fish density, biomass, or growth. The control stream had lower abundances during drought years. Evidence of increased sedimentation.	Negligible change to the flow regime in the anadromous section of the Cheticamp River (the monitored section). Habitat increased during critical flow period in July.	Attenuation of high flows during the spring is correlated with low year class strength.
Flow effectiveness	Effective at providing rearing habitat. Spawning habitat at long-term risk due to sedimentation.	Effective at providing rearing habitat for Atlantic salmon.	Ineffective at protecting walleye.
IFN methodology	Discharge method: Montana Method	DFO required 30% surcharge on consultant's proposed July low flow with a return period of 1 in 4 y (a discharge method).	Professional judgment
IFN method effectiveness	Effective at providing flow to maintain rearing habitat. Did not consider need for flushing flow.	Effective at providing flow to maintain rearing habitat. Has enhanced rearing habitat.	Ineffective because flow provided was insufficient. High flows during early life history improve survival.

Note: MAF = mean annual flow and PMAF = preproject mean annual flow (all flows in m^3/s).

TABLE 4. Case Histories Reviewed to Assess Water-Release Effectiveness

Characteristic (1)	Daisy Lake Project (2)	Big Qualicum River Project (3)	Terror Lake Project (4)
Province	British Columbia	British Columbia	Alaska
Generation capacity (MW)	140	0 (storage only)	20
Type	Storage/diversion	Storage	Storage/diversion
River impacted	Cheakamus River	Big Qualicum River	Terror and Kizhuyak River
Year completed	1957	1963	1984
Preproject MAF (m^3/s)	64.0	8.10	8.21
Water release	Continuous	Continuous	Continuous
Water-release characteristic	Postdevelopment mean annual flow reduced to 31.5 (49% PMAF), but minimum flow as low as 6 (10% PMAF). Flushing flows maintained.	Mean flows from June to October increased from 2.7 (33% PMAF) to 4.6 (57% PMAF), and peak winter flows decreased from 90.6 to 26.8.	Mean annual flow of the Terror River decreased 12%, whereas in the Kizhuyak River it increased 20%. Minimum flow doubled in the Terror River and quintupled in the Kizhuyak River.
Year of monitoring (preconstruction/postconstruction)	1951–1957/1958–1992	1959–1963/1963–1982	1982–1984/1985–1991
Species monitored	Pacific salmon and steelhead trout	Pacific salmon and steelhead trout	Pink and chum salmon
Parameters monitored both prior to and following operation	Escapement, commercial catch, angler catch	Escapement and commercial catch, angler catch, gravel and water quality	Escapement and catch, alevin and egg density, water and intragravel temperature
Control	None	None	Uyak and Uganik Rivers
Impacts to fish and fish habitat	Loss of rearing and spawning habitat. Escapement of two species down by 30 to 39%: two other species are up 30 and 77%.	Increased egg-to-fry survival due to reduced scouring by floods. Increased juvenile size. Increased sedimentation of gravel (is mitigated by annual mechanical scarification of gravels).	Negligible change in water temperature in Terror River. Negligible change in habitats for spawning in Terror River. Increase in egg-to-fry survival inferred in both terror and Kizhuyak Rivers.
Flow effectiveness	Effective at maintaining predicted levels of habitat (a loss was predicted). Assessment confounded by fishing mortality and the effects of other industrial developments.	Effective at protecting against floods as predicted. Rearing of juvenile salmonids has not shown a clear improvement because larger juvenile size has not increased marine survival. Sedimentation was not predicted to be an impact.	Effective. Habitats key to critical life history phases were identified and studies were focussed to determine best flow for these sites.
IFN methodology	Discharge method: lowest daily recorded flow for both the spawning and rearing period.	Professional judgment based on empirical data on relationship of gravel porosity and egg survival.	IFIM plus knowledge of critical life history phases and biological sampling to confirm these.
IFN method effectiveness	Ineffective because low flows limited rearing and spawning habitat.	Effective for life history stages and habitats that were considered. Did not predict increased sedimentation.	Effective at protecting key habitats. Allowed project to be designed to manage flow releases to enhance fish production.

Note: MAF = mean annual flow and PMAF = preproject mean annual flow (all flows in m^3/s).