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FEDERAL ENERGY REGULATORY COMMISSION
Washington, D. C. 20426

OFFICE OF ENERGY PROJECTS

To the Parties Addressed :

JUL 3 1 2002

In March 2002, we issued a report entitled, "Mitigation Effectiveness Studies at the Federal Energy Regulatory Commission: an overview" explaining that we would be evaluating various mitigation measures (such as water quality, fish passage, shoreline management) that were included in licenses issued since 1986. We indicated in the March 2002 report that once we evaluated a particular measure we would provide those stakeholders with a particular interest in the mitigative measure being examined an opportunity to participate in the process.

I am enclosing, for your review, a copy of our draft report on water quality entitled, "Mitigative Effectiveness Studies at the Federal Energy Regulatory Commission: Draft Water Quality Report." This draft report presents the results of our evaluation of the effectiveness of water quality mitigation measures implemented at projects that were licensed or re-licensed since 1986. As a recipient of this letter, you either have a project that was part of the evaluation or asked, as an interested stakeholder, to receive a copy of the report.

I invite you to review the enclosed report and provide your comments, concerns, and/or recommendations. We will be conducting a water quality workshop in the very near future to discuss these results and any comments we receive on the report. Once a date and location are established for the workshop, we will forward that information to you. In the mean time, you are welcome to send your written comments to:

Bob Fletcher
Federal Energy Regulatory Commission
Mail Code: DHAC, PJ-12.3
888 First Street, N.E.
Washington, D.C. 20426

You can also wait and provide your comments in person at the workshop or send your comments via email to robert.fletcher@ferc.gov . Once the water quality workshop has been conducted, we will take all comments received prior to and during the workshop and issue a final water quality report. If you are not interested in receiving copies of future reports, please let us know, otherwise, we will continue to send you the information as it becomes available.

Thank you for your cooperation in this matter. If you have any questions concerning this report, please contact Bob Fletcher at (202) 502-8901 or via email at robert.fletcher@ferc.gov .

Sincerely,

for George H. Taylor
Hossein Ildari
Acting Director
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EVALUATION OF MITIGATION EFFECTIVENESS AT HYDROPOWER PROJECTS : DRAFT WATER QUALITY REPORT

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Environmental Sciences Division

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Prepared for

Division of Hydropower Administration and Compliance

Office of Energy Projects

Federal Energy Regulatory Commission

July 2002

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The effectiveness of water quality monitoring and mitigation plans at hydropower projects was assessed to determine whether the license requirements of the Federal Energy Regulatory Commission (FERC or Commission) are achieving the desired result of resource protection. Water quality is the first of several mitigation areas (others include fish passage and recreation) that will be evaluated in the next few years. This activity is part of a FERC strategic plan that describes the goals and the corresponding measures of performance for meeting the intent of the Government Performance and Results Act of 1993. The assessment is based on information. such as letters. monitoring plans and annual reports. and orders. contained in the Commission's public Records of Information Management System (RIMS) database of all FERC projects that were licensed since 1986.

The most important water quality parameters at hydropower projects are dissolved oxygen (DO). water temperature. and total dissolved gases. but sufficient data were only available for DO and temperature. Of the 81 projects evaluated in this study, 79% were licensed or relicensed during a five-year period from 1994-1998. Of these. 75% had a capacity of <10 MW and 64% were operated in a run-of-river mode. Most were located in the North Central (59%) or Northeast (19%) United States.

The assessment focused on DO monitoring and mitigation. because it is the water quality parameter that is most frequently monitored at hydropower sites. and it is a significant determinant of ecosystem health. In addition. states have established DO standards to protect aquatic ecosystems. so mitigation effectiveness can be determined unambiguously by measuring DO and comparing the values to the state standard. The results of this assessment indicated that low DO in the tailwaters was not a common occurrence. Only nine of the 81 projects (11%) had

DO problems requiring mitigation. Levels of DO were successfully increased by aeration of either: intake waters or tailwaters, using diffusers, agitators, or weirs; or turbines. Although several options were usually tested and some may have been ineffective, the final mitigation measure was effective (i.e., DO levels were increased enough to meet state water quality standards).

The assessment also found that the DO monitoring plans of the 81 projects were well designed for their intended purpose: to assess compliance with state standards and to identify DO problems. More than 50% of the projects monitored DO and temperature continuously during the period when DO can be most limiting to biota (e.g., May-October), thus ensuring that any low DO problems would be detected. The majority of the projects never encountered DO problems, and many discontinued monitoring.

Several recommendations were made to enhance the effectiveness of both monitoring plans and mitigation planning. License articles that address water quality monitoring should specify the duration of the monitoring and the conditions that could result in the discontinuation and resumption of monitoring. Water quality monitoring data should be included in a central database with public access (e.g., STORET). A process for mitigation planning that includes guidance to developers on identifying and evaluating alternatives should be included in the appropriate license article. Additional information is needed on the most effective mitigation measures for various project and environmental conditions, as obtained from rigorous field tests that employ monitoring programs specifically designed to measure the success of the test. Finally, all parties must ensure that the best technical information is used in developing mitigation alternatives and in selecting and designing the preferred alternative.

1.0 Introduction

To minimize the adverse effects of energy production facilities on the environment, mitigative measures can be implemented that reduce and/or compensate for the impacts of facility construction and operation. Licenses issued by the Federal Energy Regulatory Commission (FERC or Commission), which regulates nonfederal hydropower facilities, usually contain articles that condition project design or operation to protect, mitigate, and/or enhance environmental resources and to achieve nonpower benefits. The Government Performance and Results Act (GPRA) of 1993 defines how federal agencies manage their performance and requires the development of strategic plans that describe the goals and measures of progress and performance in achieving those goals. In response to GPRA, FERC implemented an initiative in 2000 to evaluate the effectiveness of the environmental mitigation requirements incorporated in the licenses.

This report presents the results of an evaluation of the effectiveness of water quality mitigation measures implemented at nonfederal hydropower projects that were recently licensed or relicensed by FERC. Shoreline management was addressed previously (FERC 2001), and other mitigation measures, including fish passage and recreation, will be evaluated over the next few years. Finally, the report should not be considered a comprehensive review of the alternatives for mitigating water quality impacts at hydropower projects. Such reviews are provided by Sale et al. (1991) and more recently by EPRI (2002).

1.1 Background

In the 1980's, environmental protection conditions in FERC licenses were implemented based on relatively limited information that was typically collected early in the licensing process.

The effects of these measures were rarely evaluated, so little was known about whether the measures provided the level of protection intended at license issuance. By the early 1990's, but especially after 1993, most FERC licenses included requirements to develop monitoring plans for assessing significant environmental resources, such as water quality and fisheries. These plans and monitoring data have been included in reports submitted to FERC by the licensees. The reports and other compliance filings required under the various license articles and Commission orders were reviewed in this study.

1.1.1 Review of Previous Hydropower Mitigation Studies

Hydropower mitigation that provided for the maintenance of instream flows, dissolved oxygen (DO), and upstream and downstream fish passage was examined in a U.S. Department of Energy (DOE) study by Sale et al. (1991). The study used public information from Commission records and additional information obtained from a written survey of developers and state/federal resource and regulatory agencies, focusing on nonfederal hydropower projects that were licensed or exempted between January 1980 and July 1990. To supplement information from the FERC records, additional information was acquired directly from hydropower developers (Sale et al. 1991, Table 3-2).

From a target population of 707 projects that were identified in the FERC Hydropower Licensing Compliance Tracking System as having mitigation requirements for instream flow, DO, and/or fish passage, information was obtained on 280 projects. This sample, according to FERC records, included 56 projects (26%) that had implemented DO mitigation measures, of which 13 had no water quality mitigation requirements stipulated in their licenses. The 1991 study also found that compliance with state water quality standards was the most common purpose of the DO mitigation, and spill flows and turbine aeration were the most frequently implemented mitigation measures. Thirty-five of the 53 projects (66%) that provided information on mitigation methods employed spill (either alone or with other methods) to mitigate DO problems. At the time of this 1991 study, FERC commonly required continuous spill to mitigate DO problems at low-head hydropower projects during critical periods of the year (Taylor 1988). Moreover, spill was employed twice as often as other mitigation methods at projects with design heads of less than 15 m, and may be the mitigation of choice at smaller hydropower sites, where fewer alternatives are available when the constraints of cost and design are considered (Cada and Francfort 1995). For such projects, capital investments would be inappropriate when the frequency and severity of DO problems are relatively low or uncertain (Sale et al. 1991).

The 1991 study concluded that the proportion of projects with environmental mitigation requirements had increased significantly during the 1980s, but little information was available on the effectiveness of that mitigation. This earlier study had to rely primarily on surveys of licensees to obtain information on the implementation of mitigation because the availability of data to directly assess its success was limited. The present study used the data from the FERC-required water quality monitoring programs to identify DO problems and assess the effectiveness of the measures implemented to mitigate those problems.

1.1.2 Overview of Licensing Process

When a license is issued for a project, the articles contain provisions that the licensee file a monitoring plan. After consulting with the resource agencies, the licensee prepares a plan for Commission approval. In the case of water quality issues, the state water quality permitting agency or the U.S. Environmental Protection Agency (EPA) is consulted as well as other state and federal resource agencies. The state water quality agency's requirements are incorporated into the Clean Water Act (CWA) Section 401 Certification, a mandatory component of the FERC license. Commission staff review the plan and issue orders approving the monitoring. Provisions are usually incorporated into the monitoring plan to determine the goal of the monitoring and measures that need to be taken to ensure compliance with the license requirements. Authority is usually reserved by the Commission to require changes to the plan, project operation, and/or facilities during the term of the license in order to ensure compliance and environmental protection.

Once the plan is approved, the licensee begins monitoring. The type and frequency of monitoring is project-specific. Annual reports and any recommendations developed in consultation with the resource agencies usually will be filed by the licensee with the resource agencies and the Commission. These reports can identify deviations from the license requirements, problems encountered during the monitoring period, and measures taken to address any problems. Evaluating the effectiveness of these measures is the goal of the present study.

1.2 Purpose of Study

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

1.2.1 Measures of Effectiveness

The effectiveness of water quality mitigation at hydropower projects will be measured by a comparison with state water quality standards. If frequent violations characterized the project prior to the implementation of mitigation measures and no violations occur afterward, the mitigation was successful. Another measure can be the frequency and duration of exceeding state standards before and after mitigation. However, if violations continue to occur, the present mitigation may be necessary but not sufficient to always meet water quality standards.

The effectiveness of water quality monitoring plans was also evaluated to assess their ability to detect potential problems. Such factors as the frequency and duration of sampling and the effectiveness of the monitoring program in capturing worst-case conditions (i.e., low streamflow and high temperatures) were considered. A poorly designed monitoring plan that fails to adequately capture these conditions can result in undetected water quality problems. On the other hand, a well-designed monitoring program that has detected no violations of state standards for several years, yet has no provision for reviewing and/or downsizing the monitoring effort, is inefficient and may even be unnecessary.

Because the effectiveness of mitigation is linked to the monitoring plan that was developed to measure that effectiveness, both mitigation measures and monitoring plans are included in the study. Mitigation refers to those structural and nonstructural approaches that are implemented at hydropower projects specifically to increase DO. Monitoring plans are not mitigative measures. Rather, they are needed to evaluate compliance with water quality standards; determine the need for mitigation if those standards are not met; and assess the effectiveness of that mitigation.

1.2.2 Description of RIMS Database

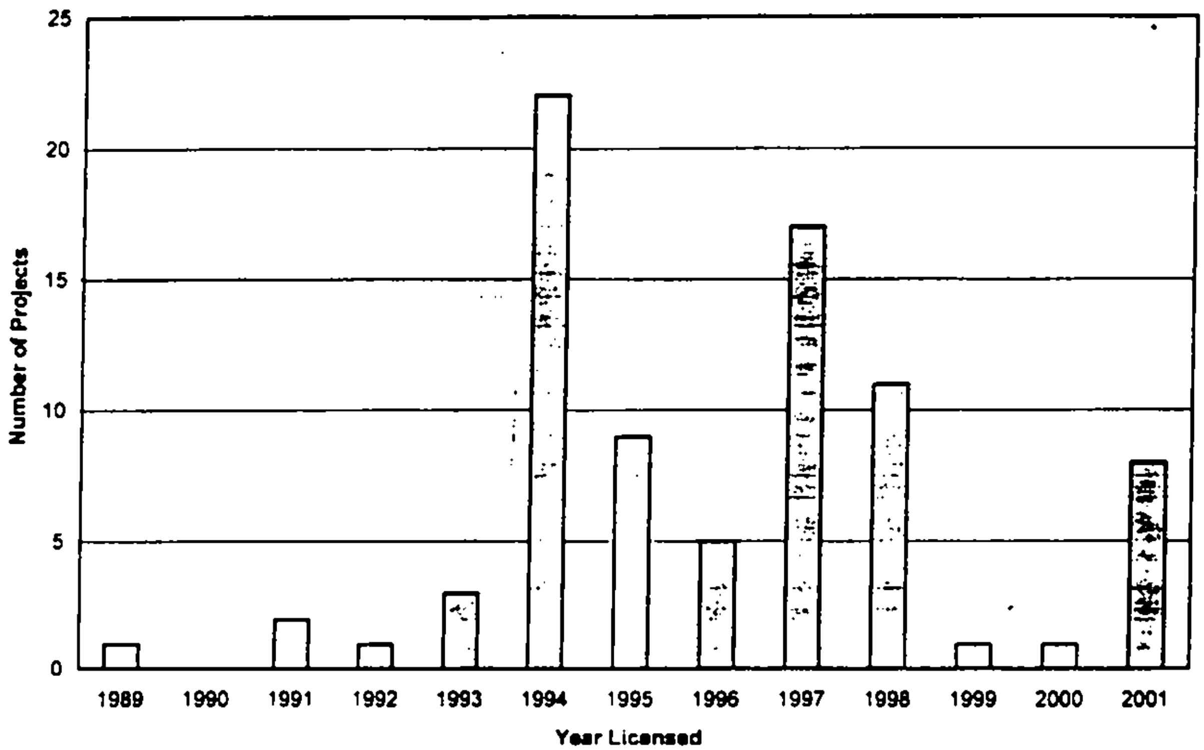
The review of the effectiveness of water quality mitigation measures utilized information contained in the public record for hydropower projects that were licensed or relicensed since passage of the Electric Consumers Protection Act in 1986. Letters, monitoring plans, and reports filed with the Commission by licensees, as well as the orders issued by the Commission based on these documents, constitute the key elements of the Records of Information Management System (RIMS) database used in this study. The database contains an index to all documents issued or received by the Commission since November 16, 1981; images of documents submitted to and issued by the Commission since November 13, 1994; and documents submitted electronically through the Commission's web-enabled filing mechanism since November 2000. A new system, the Federal Energy Regulatory Records Information System (FERRIS), will replace both RIMS and the Commission Issuance Posting System (CIPS) in 2002. Both RIMS and FERRIS can be easily accessed from the FERC website (see www.ferc.gov).

The results of the analyses presented in Section 2.0 are based primarily on monitoring data presented in annual water quality reports submitted by the licensee and monitoring plans described in either the annual reports or the orders issued by the Commission in approving the plans. These reports and plans were used in the study if they were submitted and incorporated into RIMS before April 2002. For some projects, reports were submitted to the Commission for several years following approval and implementation of monitoring, and these were included in the review. At other projects, however, reporting was required only to the appropriate regulatory or resource agency and not to the FERC. Such an outcome (i.e., no reporting of monitoring results to FERC) could occur from the inception of monitoring or after several years of monitoring and annual reporting. At some projects, no reporting to FERC was required until the conclusion of the monitoring period (e.g., five years). Consequently, the availability of monitoring data was dependent upon the reporting requirements stipulated in the license articles. Finally, licensees are required to report to the Commission any deviations from the conditions stipulated in the license article. This requirement is usually stated in an ordering paragraph of the Commission order approving the water quality monitoring plan. Deviations related to water quality were reviewed in this study.

For most of the hydropower projects included in this study, the most important water quality parameters are DO, water temperature, and total dissolved gases. Several projects had monitoring programs that included other chemical parameters, and a few projects were required to conduct limited biological monitoring. These monitoring elements reflected either site-specific needs, as identified by Commission staff who prepared the documents to comply with the National Environmental Policy Act (NEPA), or by regulatory or resource agencies. Only the data on DO, temperature, and dissolved gases were reviewed in this study.

A group of 134 hydropower projects constituted the initial database used in this study. Of these, 53 projects had no monitoring data available and were not used in the analysis (see Sect. 2.0). The remaining 81 projects, which comprised the actual database used in the study, were licensed or relicensed during the period 1986-2001. Of these, 91% were licensed after 1993 and 79% were licensed during the five-year period from 1994-1998 (Fig. 1-1).

Figure 1-1. Histogram of the licensing years for 81 hydropower projects that comprised the database used in the analysis of mitigation effectiveness.



The capacities of these 81 projects is summarized in Table 1-1 and compared with the capacities of projects included in a previous DOE mitigation study (Sale et al. 1991). Only one of the 81 projects in the present study could have been included in the earlier study, which was based on projects that were licensed or exempted between 1980 and 1990. The present study is characterized by a majority of projects with generating capacities between 1 and 10 MW; the proportion of projects in this category was more than twice that reported in the DOE study. On the other hand, the present study was proportionately underrepresented in the <1 MW and 10 to <50 MW categories; the proportion of the projects in both categories in the earlier study was about twice that of the present study. However, in both studies, more than 90% of the projects were <50 MW.

Table 1-1. Numbers of hydropower projects with DO requirements for each of five capacity categories included in an earlier DOE mitigation study (Sale et al. 1991) and the present FERC study.
Percentages are given in parentheses.

	CAPACITY CATEGORY (MW)					
	<1	**1 to <10**	**10 to <50**	**50 to <100**	**>100**	**Total**
DOE Study[a]	13 (23)	17 (30)	21 (38)	2 (4)	3 (5)	56 (100)
Present FERC Study	7 (9)	53 (65)	17 (21)	3 (4)	1 (1)	81 (100)

[a]Included projects that were licensed or exempted between January 1, 1980 and July 1, 1990.

Comparisons between the two mitigation studies of the regional distribution of sites and the modes of project operation (e.g., run-of-river, peaking) were not possible, because quantitative, tabular information was not presented in Sale et al. (1991). From the information that was presented, however, the DOE study had a substantial proportion of sites in New England, possibly as high as 65%, assuming that the FERC-defined "New York region" geographically approximates the Northeast. No information was presented on the mode of operation.

The majority of the 81 hydropower projects included in the present study were less than 10 MW (74%). Although this capacity category also characterized the projects included in the Sale et al. (1991) study, the earlier study had a substantial number of very small (<1 MW) projects (Table 1-1). Also unlike the former study, most of the projects in the present study were located in the North Central United States (59%), primarily Wisconsin and Michigan (Tables 1-1 and 1-2), respectively). Although most projects operated in a run-of-river mode (64%), peaking constituted the major operational mode of the facilities in the Southeast.

Table 1-2. Regional summary of the mode of operation and water quality monitoring parameters at 81 projects for which monitoring data were available in the RIMS database. ROR = run-of-river; P = peaking; SS = seasonal storage; DO = dissolved oxygen; TDG = total dissolved gases

Region	No. of Projects	Mode of Operation			Water Quality Parameters			
		ROR	P	SS	DO+ Temp	DO Only	Temp Only	TDG Only
Northeast (ME, NH, MA, VT)	15	12	2	1	14[a]	1	-	-
Southeast (NC, SC, GA, AL, TX)	8	1	7	-	5	3	-	-
North Central (WI, MI, MN)	48	31	17	-	46	2	-	-
Midwest (IL, WV, IN, IA)	5	4	1	-	5	-	-	-
West (ID, CA, AK)	5	4	1	-	1	-	3	1

[a]Includes one project that also required TDG monitoring.

2.0 Data Analysis

A total of 134 projects were reviewed to assess the effectiveness of measures implemented to mitigate adverse effects on water quality, including DO, temperature, and total dissolved gases (TDG). Of these projects, 53 (40%) were excluded because no monitoring data were available with which to evaluate the projects. Many of these licensed hydroelectric facilities are not operating because they are under construction or construction has not yet started. Others that are operating have not submitted a report on the results of their water quality monitoring program or, in some cases, the monitoring plan itself because they are not yet due to be filed with the Commission (Table 2-1). Nevertheless. a review of this group of projects does provide information on the type of water quality monitoring required by FERC, as stipulated in the license articles. Because these requirements guide the development of the monitoring plans that are developed by the licensee and submitted to FERC for approval. they can provide a reasonable approximation of the plan that would be developed.

2.1.1 Summary of Monitoring Requirements

More than 80% (44 of 53) of the water quality monitoring plans and license articles for the projects in Table 2-1 include DO monitoring. but <10% (4 of 53) of them include TDG monitoring. These results suggest that low DO could be a much greater or more widespread potential problem than gas supersaturation. Although the magnitude of the problem in both cases is dependent upon site-specific attributes of the project. low DO has other, nonhydropower-related causes. such as wastewater loading from point sources and nutrient enrichment from nonpoint sources. An alternative explanation for the low occurrence of TDG monitoring is the underrepresentation in the RIMS database of hydroelectric projects in the Northwest where the incidence of gas bubble disease from waters supersaturated with oxygen and nitrogen is more common.

A more detailed and comprehensive assessment of water quality monitoring requirements at FERC-licensed hydroelectric facilities can be conducted based on the 81 projects that submitted and implemented monitoring plans and reported the results (Table 1-2). For most projects. the monitoring was either stipulated in the 401 water quality certification (41 of the 81 projects or 51%) or required by the FERC (44%). Dissolved oxygen monitoring was a requirement at 77 (95%) of these projects, and most of these (71 or 92%) also required temperature monitoring. Only one project required the monitoring of TDG. Interestingly, just one of the five projects in the West that was included in this review required DO monitoring. Although the sample size is small, the results suggest that temperature was more important than DO, possibly reflecting the importance of coldwater fisheries, especially salmonid fisheries, in western streams.

Table 2-1. Summary of the status and type of water quality monitoring plans required for 53 projects for which no monitoring data were available in the RIMS database. DO = dissolved oxygen; TDG = total dissolved gases

Status		No. of Projects	Water Quality Monitoring Parameters[a]			
			DO and Temp	DO Only	Temp Only	TDG Only
Operating Projects						
-	First report pending	13	10	3	-	-
-	No monitoring plan submitted	14	8	3	2	1
-	No monitoring required	3	1	1	1	-
-	No reporting to FERC required	3	2	1	-	-
	Total	33	21	8	3	1
Non-Operating Projects						
-	Preconstruction	8	4	1	1	2
-	Under construction	4	3	1	-	-
-	License surrendered/revoked	8	6[b]	1	-	1
	Total	20	13	3	1	3

[a]Monitoring parameters are those included in license articles, Commission orders, or monitoring plans submitted by the licensee.
[b]Includes one project that requires DO, temperature, and TDG monitoring.

In addition to the parameters measured, the water quality monitoring programs were reviewed with regard to the sampling period and the frequency and duration of monitoring (Table 2-2). Most of the programs were characterized by continuous monitoring (72%) during a specific time of year, most often within the period from May to October, for a duration of three years or less (63%). Monitoring continuously and reporting the DO and water temperatures at

Table 2-2. Regional summary of the water quality monitoring programs and monitoring results for 81 projects for which monitoring data were available in the RIMS database. A regional summary of the number of projects, mode of operation, and monitoring parameters is presented in Table 2-2. The monitoring period is approximately May-October unless noted otherwise. DO = dissolved oxygen

Region	No. of Projects	Monitoring Frequency				Worst-Case Conditions Defined[a]	Monitoring Duration				Monitoring Results			
		Continuous	Daily	Weekly	Other		Indefinite	≤3 yrs	5 yrs	Once every 5 yrs	DO Problems Identified	Mitigation Implemented	Monitoring Reduced	Monitoring Terminated
Northeast (ME, NH, MA, VT)	15	6[b]	-	2	7[c]	8	4	10	1	-	-	-	1	9
Southeast (NC, SC, GA, AL, TX)	8	6[d]	-	2	-	-	8	-	-	-	6	6	-	-
North Central (WI, MI, MN)	48	40[e]	1	-	7[f]	1	2	39	3	4	9	5[g]	9	4
Midwest (IL, WV, IN, IA)	5	2	3	-	-	3	2	1	-	2	-	-	-	2
West (ID, CA, AK)	5	4[h]	1	-	-	-	1	1	3	-	-	-	-	2

[a]Monitoring conducted only when stream flow was less than a specified value and water temperature exceeded a specified value (usually 20°C).
[b]Includes four projects that monitor continuously for 72 h (3 consecutive days) in each of three periods between late June and early September.
[c]Twice daily for three consecutive days in each of three periods between late June and early September.
[d]Includes one project that monitors continuously for 48 h (2 consecutive days) in each month throughout the year.
[e]Eleven projects monitor continuously throughout the year via subcontract with the U.S. Geological Survey.
[f]Includes three projects that monitor monthly throughout the year, two that monitor monthly in June-August, one that monitors monthly for 24 h, and one that monitors biweekly.
[g]The other four projects with DO problems will evaluate/implement mitigative measures in 2002.
[h]Includes one project that monitored temperature continuously throughout the year.

hourly intervals provides assurance that monitoring occurred during worst-case conditions (combination of low streamflow and high water temperatures) for a given year. Although equipment problems leading to extended periods of no data occurred at some projects, these problems were encountered primarily during the early stages of monitoring. Remedies ranged from better lightning protection to more frequent cleaning/replacing of probes. Finally, downloading of data at weekly or biweekly intervals was most effective in detecting low DO concentrations that were approaching the state water quality standard and minimizing the length of data gaps due to an undetected equipment malfunction.

In contrast to the continuous monitoring that characterizes most of the water quality programs in Table 2-2 is the short-term (three consecutive days) monitoring that occurs during three specified periods between June and September at most of the projects in the Northeast. Also characteristic of this region's water quality monitoring is the requirement that sampling occur during worst-case conditions, often defined as water temperatures >20°C and streamflows that are below a specific value, which varies with site. The intent of both a continuous monitoring strategy and one that focuses specifically on the infrequent periods of low flow and high temperature is the same—to measure the minimum concentrations of DO at the site. The same rationale explains why most programs limit monitoring, whether continuous or instantaneous (i.e., grab sampling), to a specific period of the year when minimum DO values are expected to occur.

Another common attribute of the water quality monitoring programs summarized in Table 2-2 is their limited duration. Most licensees are required to monitor for three years or less, at which time a final report is prepared with recommendations for future monitoring, including the options of reducing or terminating the monitoring programs. Only 21% of the 81 projects did not specify the duration of the monitoring programs. Even more significant was the finding that 33% of the projects either reduced the scope of monitoring or terminated the program based on the results of monitoring.

Finally, summarizing project characteristics by region revealed several significant trends. For example, the strategy of monitoring for three years or less and then reassessing the need and scope of future monitoring is most characteristic of the Northeast and North Central regions. Operating in run-of-river mode is common in both regions (80% and 65% of projects, respectively). In contrast, peaking is characteristic of the projects in the Southeast (88%), where all eight projects have monitoring programs of indefinite duration. Such a trend suggests that the potential adverse impact on DO from the mode of operation was a factor in determining the duration of the monitoring program. Because impacts on DO can potentially be greater at peaking facilities with large, stratified reservoirs, designing a monitoring program that will assure the detection of those impacts becomes critical. In such cases, the requirement for continuous, indefinite monitoring seems appropriate. Conversely, run-of-river projects (often with small reservoirs that stratify only weakly or not at all) might be expected to have no significant adverse impact on DO levels downstream of the project. Thus, it seems appropriate that the Northeast with a high proportion of run-of-river projects (80%) would have an equally high proportion of projects where DO monitoring was terminated after a few years.

2.1.2 Compliance with Criteria

With few exceptions, monitoring is conducted to determine compliance with state water quality standards. Consequently, the effectiveness of a monitoring program is measured by its ability to achieve compliance and document that achievement. A program of appropriate duration that measures water quality at the appropriate sites and frequency, including efforts to bound worst-case conditions, will be the most effective. When low DO or other problems are encountered, mitigation must be considered and, if necessary, implemented in order to achieve compliance with state standards. In other words, monitoring identifies the need for mitigation, and mitigation becomes the mechanism leading to compliance.

Dissolved Oxygen

State standards for DO generally range from 4.0 – 7.0 mg/L, depending upon the state, stream, and water use designation. In some states, the standard is based on the percent oxygen saturation (e.g., no less than 75% saturation in New Hampshire) rather than a specified concentration. Occurrences of DO not meeting state standards were identified by monitoring at 15 of the 81 projects (18%). Mitigation has been implemented at 11 of these 15 projects (Table 2-2), and data are available to evaluate the effectiveness of the mitigation at eight projects (see Sect. 2.1.3). Of the four projects for which specific mitigation has not been implemented, all will evaluate and/or implement mitigative measures in 2002. Sixty-six of the 81 projects (81%) with monitoring data have complied with the state standards for DO or otherwise met the monitoring requirements in the license articles, and monitoring for DO has been terminated at 15 of these 66 projects (23%).

Monitoring data were also used to confirm model predictions of DO concentrations. For example, DO data obtained near five small hydroelectric dams on the Androscoggin River in New Hampshire were used to verify the predictions of a water quality model for that reach of the river. Three years of data confirmed the prediction that no violations of DO standards are likely to occur with the present mode of project operation (i.e., run-of-river) and the present pollutant loading to the river. The modeling results, together with no violations of state standards, provided a basis for terminating the monitoring program at these projects. For guidance on the use of modeling and site-specific monitoring data to predict DO, see Railsback (1988).

Water Temperature

State standards for water temperature can include an absolute maximum that can not be exceeded (e.g., 89°F for projects on the Wolf and Menominee Rivers in Wisconsin) and/or a mean temperature for each month that can not be exceeded (e.g., 80°F in June, 83°F in July, 81°F in August, and 74°F in September for projects on the Michigamme River in Michigan). Of the 74 projects with water quality monitoring plans that included temperature as one of the parameters to be monitored (Table 1-2), 50 projects (68%) were required to monitor and meet state standards. With the exception of the Holyoke Project (FERC No. 2004) on the Connecticut River in Massachusetts, where water temperature exceeded the state standard of 28.3°C for a limited period of time in August 2001, no violations of state temperature standards were reported for these projects. The other 24 projects (32%) were required only to monitor and report water temperatures: compliance with state water quality standards was not stipulated in the license articles or the CWA Section 401 water quality certification issued by the state. For at least one project included in this review, monitoring was used to verify the predictions of a river temperature model. At the Tule River Project (FERC No. 1333), six years of data collected just prior to the renewal of the license in 1993 was sufficient to validate the stream temperature model and no further monitoring was required.

Dissolved Gases

Only two of the 81 projects were required to monitor dissolved gases. Measurements of dissolved nitrogen were required by article 404 of the license for the Holyoke Project. However, monitoring of this parameter is no longer required by the Massachusetts Department of Environmental Protection (MADEP) due to the limited benefit of the data (letter from MADEP, August 7, 2001), and the monitoring plan was modified by deleting the requirement for dissolved nitrogen testing. At the Dworshak Small Hydro Project (FERC No. 10819), which is located on water supply lines to two hatcheries in Idaho, limited dissolved gas monitoring was required to ensure that gas levels do not increase as a result of project operation, which could require additional degassing facilities at the hatcheries. In a report submitted to FERC in January 2002, the monitoring results indicated that (1) project operations had no adverse effect on dissolved gas levels or nitrogen gas saturation in the water supply flow to the hatcheries and (2) no further monitoring was required. With the exception of the projects included in Table 2-1, no other projects included in this review had water quality monitoring plans that included dissolved gas or dissolved nitrogen testing.

2.1.3 Assessment of Mitigation Measures

The majority of the hydroelectric projects included in this review had water quality monitoring plans that were approved and implemented, and no water quality problems, defined as the failure to meet state standards, were encountered at most projects. Low concentrations of DO were observed in the tailwaters of some projects, however, and various mitigative measures were employed to increase DO levels. Of the 81 projects with water quality monitoring data, 11% (nine projects) have installed devices to increase DO (Table 2-3). These measures include turbine venting, headrace and tailwater aeration systems, and weirs. Their site-specific effectiveness was evaluated by comparisons of DO levels before and after the implementation of mitigative measures and comparisons of current DO levels downstream of the project with state standards. The results of these analyses are summarized in Table 2-4.

Table 2-3. Location, capacity, operational mode, and license/relicense date of nine hydroelectric projects where mitigative measures were implemented to increase downstream concentrations of dissolved oxygen or enhance temperatures (Prickett project).

ROR = run-of-river

Project Name[a]	River	State	Capacity (MW)	Operational Mode	Date of Issuance of License
Abbeville (11286)	Rocky	SC	2.8	Peaking	12-24-97
Buzzards Roost (1267)	Saluda	SC	15.0	Peaking	12-18-95
Caldron Falls (2525)	Peshtigo	WI	6.4	ROR	6-26-97
High Falls (2595)	Peshtigo	WI	7.0	ROR	6-26-97
Lloyd Shoals (2336)	Ocmulgee	GA	18.0	Peaking	3-22-93
Morris Sheppard (1490)	Brazos	TX	22.5	Peaking	10-14-89
Prickett (2402)	Sturgeon	MI	2.2	ROR	8-29-95
Stevens Creek (2535)	Savannah	GA	18.8	Peaking	11-22-95
Yates (2407)	Tallapoosa	AL	64.0	Peaking	2-3-94

[a]FERC project (docket) number in parentheses.

Table 2-4. Description of water quality monitoring plans and mitigation at nine hydroelectric projects where mitigative measures were implemented to increase downstream concentrations of dissolved oxygen or enhance temperatures (Prickett project).

N/A = no data available

Project Name	Water Quality Monitoring Plan			Mitigation			
	Date of Approval	**Monitoring Frequency[a]**	**Monitoring Period[a]**	**Required By License rticle?**	**Type**	**Increased DO?**	**Meets State Standards[b]**
Abbeville	10-28-98	Weekly	May – Oct	Yes	• Stoplog weir	Yes	N/A
Buzzards Roost	11-14-96	Continuous	Jun – Aug (3-day period in each month)	Yes	• O_2 injection (forebay)	Yes	Yes
Caldron Falls	9-14-98	Continuous	Jun – Sep	No	• Aeration (tailwaters)[c] • Aeration (4 intake agitators) • Increased flow (via sluice gates)	Yes	Yes
High Falls	9-14-98	Continuous	Jun – Sep	No	• Aeration (tailwaters)[c] • Aeration (5 intake agitators) • Venting turbine no. 5[c] • Increased flow (via taintor gates) • Reservoir drawdown (October)	Yes	No
Lloyd Shoals	6-30-94	Continuous	May – Oct	Yes	• Labyrinth weir[d]	Yes	No[e]
Morris Sheppard	12-14-90	N/A	N/A	Yes	• Tailrace aeration (19 diffusers) • Turbine venting	Yes	Yes
Prickett	10-13-98	Continuous	May – Oct	Yes	• Selective withdrawal system (installed September 2000)	N/A	No
Stevens Creek	7-18-96	Monthly Biweekly	Nov – May Jun – Oct (twice daily for two consecutive days)	Yes	• Turbine runner aeration (to be installed)	N/A	No
Yates	11-25-94	Continuous	Jun – Oct	Yes	• Turbine draft tube aeration	Yes	Yes[e]

[a]Tailwater monitoring stations.
[b]Yes = >99% compliance.
[c]Not employed in 2001.
[d]Aeration occurs as water spills over the crest of the weir, plunging into a pool similar to a waterfall.
[e]No data after 1997.

With the exception of the two projects on the Peshtigo River in Wisconsin, the possibility of DO problems (i.e., failure to meet state standards) was recognized in the Environmental Assessment (EA) or the Environmental Impact Statement (EIS) that was prepared to comply with NEPA. As a result, articles that specifically addressed the need for mitigation were included in the license. These articles required either the implementation of specific mitigative actions [e.g., the Morris Sheppard (FERC No. 1490) and Prickett (FERC No. 2402) Projects] or an evaluation of various options for mitigation prior to implementation [e.g., the Abbeville (FERC No. 1286) and Buzzards Roost (FERC No. 1267) Projects].

For projects in which no specific mitigation was required, such as the Caldron Falls (FERC No. 2525) and High Falls (FERC No. 2595) Projects on the Peshtigo River (Tables 2-3 and 2-4), the licensing articles usually stipulated the need to consider mitigation should DO levels fail to meet state standards. Although the licensee operates six projects on the Peshtigo River, only two have had DO problems. At Caldron Falls, DO levels did not meet state standards on two days (estimated total duration of eight hours) in 2000 and on three days (19 hours) in 2001. Air compressors (14 cfm) were used from mid-June through September in 2000 to aerate the tailwaters, but were replaced in 2001 by four agitators located in front of the trash racks to enhance mixing of the surface water that has a higher DO with deeper, low-DO water near the turbine intake. The trash sluice gate flow was increased from August to mid-September in both years. To mitigate low DO conditions in the tailwaters in the future, the licensee will increase the sluice gate flow annually from July 15-September 1 and to agitate the water in front of the trash tracks annually from June 1-September 1.

A more significant DO problem was encountered at the High Falls Project where DO was below the state standard on 18 days (maximum duration of 201 hours) in 2000 and 9 days (75 hours) in 2001. Turbine venting by opening the vacuum breaker on one of the turbines, increasing flow through one of the taintor gates, and injecting air (7 cfm) to the flume of one of the turbines were all employed in 2000 to increase DO levels below the dam. Actions taken in 2001 included operating five agitators in front of the trash racks from June through mid-September, opening the taintor gate to provide an aeration flow, and initiating a six-foot drawdown of the reservoir in mid-October to control Eurasian milfoil and reduce diurnal DO fluctuations. The licensee installed a real-time DO monitor in 2001 that will provide a continuous monitoring capability through the summer (June-September). If DO levels fall below the state standard, corrective actions to include spill will be initiated.

Clearly, identification of the need for mitigation in the EA or EIS, which resulted in licensing articles that stipulated the implementation or evaluation of mitigative measures to increase the DO content of the tailwaters, significantly reduces the duration of low DO problems following project licensing. However, even when potential DO problems can not be accurately predicted, the licensing/relicensing process adequately addresses the issues through monitoring programs that can detect problems and provide a basis for evaluating various remedial actions (e.g., the Peshtigo River projects).

In this review, the number of nonfederal hydroelectric facilities with DO problems requiring mitigation is relatively small. Even so, the data in Tables 2-3 and 2-4 are indicative of trends that are useful in the early, accurate assessment of potential DO problems. For example, most of the projects that must install measures to increase downstream DO concentrations operate in a peaking mode and are located in the Southeast (Table 2-3; Ashby et al. 1999). The higher water temperatures at lower latitudes contribute to this regional DO issue. A study by Cada et al. (1983) noted a higher probability for noncompliance with DO standards at hydroelectric sites in the Southeast where the warmer climate results in an earlier and longer period of reservoir stratification. The elevated temperatures reduce the oxygen saturation of water and can contribute to the thermal stratification of the upstream impoundment(s). Moreover, peaking facilities operate intermittently, so non-generation periods occur frequently, usually on a daily basis. During these periods, streamflow below the dam is limited to leakage and/or required minimum flows. These low flows during non-peaking periods can increase the retention time in the reservoir, thereby enhancing stratification. If the reservoir is deep enough and/or stratification is strong enough, the hypolimnion (i.e., the colder, noncirculating bottom layer of water in a stratified reservoir) can have significantly lower DO than the epilimnion (i.e., the warmer, circulating upper layer) at and near the surface. In worst-case conditions of low reservoir inflow and outflow, the hypolimnion becomes anoxic. Consequently, for projects with impoundments that stratify, the elevation of the water intake can be an important factor in determining the magnitude and frequency of low DO episodes downstream of the project.

Most of the mitigation for low DO described in Table 2-4 is directed toward minimizing the adverse effects of impoundment stratification. Effective approaches include aeration of intake waters by oxygen injection via diffusers or by agitators that enhance aeration by mixing oxygen-poor, hypolimnetic waters with surface waters. The oxygen injection system installed in the forebay of the Buzzards Roost Project successfully increased DO levels, which consistently meet or exceed state standards, and contributed to the delisting of the Saluda River downstream of the project from the CWA, Section 303(d) list.

Aeration of tailwaters has also been employed with varying success. It contributed to the effective mitigation of low DO levels below the Morris Sheppard Project in Texas, but the tailwater aeration system (14 cfm using two air compressors) installed in 2000 at the Caldron

Falls Project was replaced the following year by four intake agitators. The labyrinth weir below Lloyd Shoals Dam Project (FERC No. 2336) was of limited success, also. The licensee investigated seven methods to enhance DO, and a labyrinth weir was selected as the most cost beneficial alternative (Hendricks 1997). On average, the weir recovered 50% of the daily mean oxygen deficit (i.e., the difference between the observed DO and saturation), an aeration rate similar to that of the labyrinth weir at the Tennessee Valley Authority's South Holston Dam, which also uses turbine venting to provide supplemental aeration (EPRI 2002). Levels of DO downstream of the weir were below the state standard of 4.0 mg/L about 6% of the time in 1996 (Hendricks 1997), the last year for which data were available. However, the weir did significantly increase DO in both 1995 and 1996, and the Ocmulgee River downstream of the project was recognized for the first time to be in full support of its designated uses in 1995 by the Georgia Department of Natural Resources (GDNR 1996). Additional mitigation, including turbine venting, was under consideration in 1997.

The Abbeville Project on the Rocky River in South Carolina utilized a stoplog weir to improve DO levels downstream of the dam. Preliminary testing with removable steel stoplogs in the existing stoplog slot of the intake structure indicated the weir was effective in obtaining more surface water with a higher DO content. Permanent stoplogs were to be installed in 2000, but no monitoring reports were available in RIMS to assess their effectiveness.

The DuBay Project (FERC No. 1953) on the Wisconsin River installed a skimmer weir that was ineffective in raising DO levels. In this case, a license article required installation and evaluation of the weir during low DO episodes in the tailrace. The article was deleted from the license after concluding that the weir was ineffective and possibly detrimental to downstream DO levels under certain conditions. The weir caused upwelling of low DO, hypolimnetic water that was entrained into the turbines. In the future. if low DO occurs for more than eight hours. the licensee will operate one of the turbines continuously to increase the DO downstream.

Although the data are limited. turbine aeration may be effective in increasing the DO content of tailwaters. It was successful at both the Morris Sheppard and Yates (FERC No. 2407) Projects and was selected as the mitigation of choice for installation at the U.S. Army Corps of Engineers (COE) Thurmond Dam. which is located upstream of the Stevens Creek Hydroelectric Project (FERC No. 2535). The EA for the latter project analyzed water quality monitoring studies conducted from July 1990 through September 1992 and concluded that low DO in the Savannah River arm of Stevens Creek Reservoir resulted from the stratification of Thurmond Reservoir. The COE is preparing to install aerating runners on the seven main turbines at Thurmond Dam. which should significantly improve DO levels in Stevens Creek Reservoir and tailrace. When this approach was evaluated for its applicability to the turbines of the High Falls Project on the Peshtigo River in Wisconsin. the consultant reported that the draft tubes were too short. resulting in less than 2 s of contact time between the air that is admitted and the water (vs. 8-10 s for most projects with air admission systems).

The DO mitigation measures implemented at the hydropower projects in this study differed significantly from those in an earlier mitigation study by Sale et al. (1991). In that DOE study. spill had been reported as the only. or one of several. mitigation measures employed at 66% of the projects that provided information on DO mitigation methods. In addition. a recent review by EPRI (2002) noted that changes in project operation were included as mitigation measures in 88% of the FERC licenses issued since 1986 that contained specific DO requirements. Although spill was mentioned in the license articles or monitoring plans as a possible mitigation measure for several projects in the present study, it was rarely implemented and therefore could not be evaluated. Although spill was utilized in 2001 at the Way Dam Project (FERC No. 1759) on the Michigamme River in Michigan, article 418 of the new license requires that permanent corrective measures be addressed by a special study. The study by Sale et al. (1991) was based on a 1990 survey of hydropower developers (Sect. 1.1.1), whereas water quality monitoring plans and annual reports were used in this study. Nevertheless, the 1990 survey is consistent with FERC policy at that time of emphasizing continuous spill flows to mitigate DO problems at low-head projects (Taylor 1988). The recent trend away from spill, if it is real and not biased by the different sources of information used in the two studies, may reflect the availability of less costly but equally effective alternatives and/or less emphasis by Commission staff on spill as the preferred alternative.

The only mitigation implemented for temperature was the installation of a dual siphon, selective withdrawal system at the Prickett Project on the Sturgeon River in Michigan. The purpose of the system is to enhance downstream temperatures during May-October. Monitoring of both DO level and water temperature is required to ensure that the withdrawal of cooler water from approximately 30 feet below the surface meets the state standards for these two water quality parameters. Installation of the system at the Prickett Project was completed in December 2000, and monitoring was initiated the following year. The project did not meet the state standard for DO (7.0 mg/L) or water temperature (maximum increase of 2°F above the temperature upstream of the reservoir) during much of August and September, when the reservoir was stratified. Both onsite observations and modeling indicated inadequate mixing at the tailwaters monitoring station, so monitoring will be continued at a new station in 2003 after construction is completed in 2002 on a cap of the plunge pool area. Although a selective withdrawal plan is also required by an article in the license of the Lake Cushman Project (FERC

No. 460) on the North Fork Skokomish River in Washington. the plan has not been submitted to FERC for approval.

No mitigation for excess dissolved gases was implemented and evaluated at any of the 134 projects included in this review. Although some license articles require submittal of water quality enhancement plans that address dissolved gases (e.g., Lake Cushman Project) or gas supersaturation mitigation plans [e.g., Cabinet Gorge Project (FERC No. 2058) on the Clark Fork River in Idaho], no plans had been submitted to FERC for review.

3.0 Summary and Conclusions

Eighty-one hydropower projects newly licensed or relicensed between 1986 and 2001 were reviewed in a study to assess the effectiveness of their water quality monitoring plans and any mitigative measures that were implemented. The review focused on DO monitoring and mitigation, because it is the most frequently monitored water quality parameter and is a significant determinant of ecosystem health. Consequently, states have established clearly defined DO standards to protect aquatic ecosystems. The ability to detect periods of low DO levels and implement effective mitigation, as appropriate, is an important expectation of both the licensee and the Commission staff.

3.1 Value of Monitoring to Identify Problems

Ensuring that hydropower projects do not adversely affect water quality requires adequate background information that can support an analysis of potential water quality impacts in the EA or EIS required by NEPA. This pre-licensing characterization of water quality is a critical component of the assessment process. Several projects are operating with DO mitigation that was specifically required in a license article, implying that potential DO problems had been accurately assessed in the NEPA document. Clearly, good data are needed to make the best decisions regarding water quality monitoring needs and mitigation requirements. Good background data can also be used to design effective monitoring plans that can detect DO problems even though none were anticipated at the licensing stage. The duration of DO problems and the cost to mitigate them affect project feasibility, so careful monitoring of DO levels is essential (Railsback 1988). Finally, an effective monitoring plan is needed to properly assess mitigation success.

Most of the DO monitoring plans included in the review of the 81 projects were well designed for their intended purpose: to determine compliance with state standards, including periods when worst-case conditions occur (i.e., low streamflow and high water temperature). They often required monitoring only during periods of the year when DO levels could be most limiting to biota and usually included a provision for re-evaluation of the program after a specified period of time. Most (72%) of the 81 projects included in this study employed continuous monitoring, which supports the observation in EPRI (2002) that the trend continues to be toward continuous monitoring. While most projects required continuous monitoring over several months, usually May/June through September/October, others required daily or twice-daily grab samples for several consecutive days during specified periods between May and October. The latter strategy was sometimes accompanied by specific thresholds of flow and temperature that defined when the sampling should occur. For example, at the Gilman Project (FERC No. 2392) in Vermont, DO sampling was to be conducted when the flow of the Connecticut River at Dalton, New Hampshire was less than 800 cfs and the water temperature exceeded 20°C. Similarly, worst-case conditions were applied to the DO monitoring program for the Ayers Island Project (FERC No. 2456) on the Pemigewasset River in New Hampshire (e.g., flow <500 cfs and water temperature >20°C). Both strategies offer reasonable approaches for meeting the monitoring objectives.

Most of the water quality monitoring programs specified a duration for the monitoring; that is, data were collected and reported for a defined period of time, usually several years, after which time the program was reviewed and resumed without change, modified, or discontinued. To be effective, monitoring programs must include an opportunity to review the results and make revisions, as appropriate. Most, but not all, of the monitoring programs in this study included a specified time for this critical review of the data and the program.

There were differences among monitoring programs that were, in part, based on different agency requirements and policies. For example, sampling twice daily for several consecutive days in three periods between May and September was characteristic of some New England states. The variation observed in the structure of the monitoring plans at individual projects is not problematic; most plans included provisions for capturing worst-case conditions and for revising the plan based on the sampling results. No significant benefits would be derived from a greater standardization of monitoring plans. However, year-round monitoring or measuring DO at monthly intervals are probably not effective strategies for most projects and ecosystems.

In conclusion, the monitoring plans required by the Commission, as implemented by the licensees in consultation with the appropriate state/federal regulatory and resource agencies, were effective in identifying DO problems. Although most problems requiring mitigation were identified in the licensing process, some were encountered at projects where no specific mitigation has been incorporated in the license articles. Instead, the articles required a mitigation plan should DO levels violate state standards. These plans were required to consider various options and to select one (or more) for implementation. after consultation with the regulatory and/or resource agencies and approval by the Commission. This mechanism seems to be functioning well for the few projects that are currently engaged in that process. The vast majority of the 81 projects never encountered DO problems. and many have discontinued monitoring.

3.2 Mitigation Effectiveness

Only nine of the 81 projects (11%) included in the review had water quality problems requiring mitigation. and eight of those were due to low DO in the tailwaters. The other project employed a selective withdrawal system to enhance downstream temperatures from May to October but could not meet state standards for temperature and DO during the first year of operation (2001). No mitigation was implemented to reduce gas supersaturation at any of these 81 projects.

The eight projects with low DO occurrences addressed the problem by aeration of either intake waters or tailwaters. using diffusers. agitators. or weirs: or turbines. Although several options were tested initially. the final mitigation measure selected was usually effective. That is. the DO levels were increased enough to meet state water quality standards. The review indicated that most of the DO problems were associated with peaking facilities in the Southeast. Having a well-designed monitoring program to assess the effectiveness of the mitigation was a key element to the successful solution of the DO problems.

Most of these eight projects had a monitoring and mitigation requirement as a stipulation of their license. This condition implies that the problem was identified during the environmental review of the project prior to issuance of a license. Early detection of potential problems resulted in the preparation of license articles that outlined the requirements for mitigation. Again, adequate background data and a thorough analysis to assess water quality impacts are needed for this approach to be successful. The predictive capabilities of the analyses can be strengthened by the inclusion of water quality models of stream reaches or watersheds. A water quality model was developed and used during the licensing process for five hydropower projects within a 10-mile reach of the Androscoggin River in northern New Hampshire. Data on DO and temperature obtained in the post-licensing monitoring program were used to verify the model predictions that DO levels in the river would meet state standards. As illustrated by this example, modeling can be an especially useful tool for assessing the effects of multiple projects in a river basin.

3.3 Recommendations

The process established by the FERC to address potential water quality problems at hydropower projects emphasizes monitoring and is effective. Moreover, the mitigation that was implemented at projects with DO problems has been successful. Good monitoring plans will provide data that adequately characterize water quality at the site and identify potential problems which can be addressed in the licensing process. A well-designed monitoring program is also needed to properly evaluate the effectiveness of any mitigative measures that are implemented, and detect any problems should they occur. Successful mitigation begins with development of effective monitoring plans, as required by the license articles and based on the technical review provided in the EA or EIS.

To further enhance the effectiveness of these monitoring and mitigation plans, the following recommendations should be considered:

1. Ensure all license articles that address DO monitoring specify the duration of monitoring (i.e., number of years). At the end of this period, the monitoring program should be reviewed by the regulatory and resource agencies to decide if it should be revised or discontinued. The conditions that must be met for discontinuing the monitoring program should also be described, to the extent possible. In addition, the conditions that could initiate a resumption of monitoring after some period of absence should be identified. For example, increased urbanization that results in higher consumptive water use, which would reduce streamflow, or higher wastewater loading, which could reduce DO, could justify the resumption of water quality monitoring at hydropower sites. Limited monitoring to verify the predictions of an existing water quality model could be a very cost-effective approach in this situation.
2. Consider submitting the water quality data presented in annual reports for all FERC-licensed projects to a central database (e.g., STORET, which is managed by EPA). In this way, data obtained at those projects required only to report to regulatory or resource agencies and not to FERC would become available for public use. The benefits of providing public access to this information outweigh the costs associated with entering this information in the database.
3. Consider including a mitigation planning process that addresses unanticipated DO problems (e.g., recurring violations of state standards) in the appropriate license article. The process could include submittal of a plan that considers various mitigation alternatives (see EPRI 2002), including cost evaluation,

and provides an implementation schedule that includes the option of field testing, as necessary, prior to full. long-term implementation.

4. Obtain additional information on the most effective mitigation measures. Especially important are field applications with associated monitoring programs specifically designed to test the success of the applications. This recommendation is not intended to be an assessment of aeration technologies. but rather an evaluation of how well water quality problems at hydropower sites can be mitigated. A similar recommendation made more than 10 years ago by Sale et al. (1991) remains valid. More information from rigorous field testing is required in order to significantly increase the deployment of new technology for environmental mitigation.

5. Ensure that the best technical information is used in developing mitigation alternatives and in selecting and designing the preferred alternative. This information would be important to the alternative licensing process. especially the development of settlement agreements. This and the preceding recommendations would contribute to the goal of implementing the most effective mitigation measures.

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