Attachment 9

United States Department of Energy Dissolved Oxygen Hydropower Report

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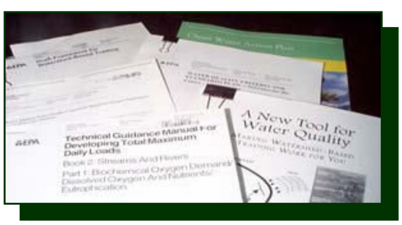
DOE/ID-11071

Regulatory Approaches for Addressing Dissolved Oxygen Concerns at Hydropower Facilities

Biocriteria

Negotiation of site-specific limits



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Regulatory Approaches for Addressing Dissolved Oxygen Concerns at Hydropower Facilities

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SUMMARY

Low dissolved oxygen (DO) concentrations are a common water quality problem downstream of hydropower facilities. At some facilities, structural improvements (e.g. installation of weir dams or aerating turbines) or operational changes (e.g., spilling water over the dam) can be made to improve DO levels. In other cases, structural and operational approaches are too costly for the project to implement or are likely to be of limited effectiveness. Despite improvements in overall water quality below dams in recent years, many hydropower projects are unable to meet state water quality standards for DO.

Regulatory agencies in the U.S. are considering or implementing dramatic changes in their approach to protecting the quality of the Nation's waters. New policies and initiatives have emphasized flexibility, increased collaboration and shared responsibility among all parties, and market-based, economic incentives. The use of new regulatory approaches may now be a viable option for addressing the DO problem at some hydropower facilities. This report summarizes some of the regulatory-related options available to hydropower projects, including negotiation of site-specific water quality criteria, use of biological monitoring, watershed-based strategies for the management of water quality, and watershed-based trading. Key decision points center around the health of the local biological communities and whether there are contributing impacts (i.e., other sources of low DO effluents) in the watershed. If the biological communities downstream of the hydropower project are healthy, negotiation for site-specific water quality standards or biocriteria (discharge performance criteria based on characteristics of the aquatic biota) might be pursued. If there are other effluent dischargers in the watershed that contribute to low DO problems, watershed-scale strategies and effluent trading may be effective.

We examine the value of regulatory approaches by reviewing their use in other contexts (e.g., for other types of facilities or effluent dischargers, or for other water quality issues), by reviewing recent regulatory policy, by summarizing evaluations in the literature of their potential value, and by use of hypothetical examples. Future research needs are also summarized. This report provides a basic understanding of the situations where regulatory approaches may be most applicable and of information that may be useful in considering the relative costs and benefits.

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Regulatory Approaches for Addressing Dissolved Oxygen Concerns at Hydropower Facilities

1. INTRODUCTION

One of the major environmental issues associated with hydroelectric power production is the effect of project operations on water quality, particularly dissolved oxygen (DO) concentrations in the water released from the dam (Cada et al. 1983, Railsback et al. 1991). DO problems in the discharges from hydroelectric reservoirs most often occur as a result of seasonal warming and the consequent thermal stratification of impounded waters (Figure 1). During the summer, this natural process can divide the reservoir into distinct vertical strata, i.e., a warm, well-mixed upper layer (epilimnion) overlying a cooler, relatively stagnant lower layer (hypolimnion). Plant and animal respiration, bacterial decomposition of organic matter, and chemical oxidation can all act to progressively remove DO from hypolimnetic waters. This decrease in hypolimnetic DO is not generally offset by the renewal mechanisms of atmospheric diffusion, circulation, and photosynthesis that operate in the epilimnion (Hutchinson 1957, Wetzel 1975). In temperate regions, the decline in hypolimnetic DO concentrations begins at the onset of stratification (spring or summer) and continues until either anaerobic conditions predominate or reoxygenation occurs during the fall turnover of the water body.

The chemically reducing conditions resulting from reservoir stratification and the absence of DO in the hypolimnion may have an effect on other water quality parameters. For example, decomposition of sulfur and nitrogen compounds in the absence of DO may result in the buildup of toxic hydrogen sulfide and ammonia (Smalley and Novak 1978). In some cases, the quality of hydropower discharges may be adequate but the quantity is not, resulting in stagnant below-dam conditions that can adversely affect oxygen budgets downstream. In other cases, low DO in the discharge is ultimately caused by upstream sources of nutrient-rich or deoxygenated water independent of reservoir characteristics. For example, water entering the hydroelectric reservoir may carry high levels of oxygen-consuming materials, often expressed as Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), from

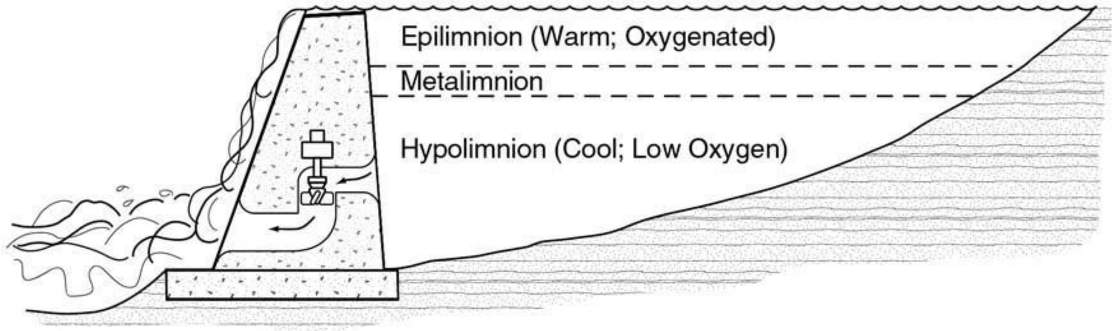

Figure 1. Thermal stratification of a hydropower reservoir

the watershed upstream. Regardless of the specific cause of low DO, adequate DO levels downstream of hydroelectric facilities are necessary to maintain a variety of benefits, including aesthetic qualities, balanced communities of aquatic organisms, assimilative capacity of tailwaters, and disinfection efficiency of chlorination.

There are numerous structural, operational, and regulatory techniques that a hydropower operator can use to resolve a low DO issue. Turbine aeration, for example, has successfully increased DO concentrations (Harshbarger 1987, March et al. 1992; Voith Hydro 1997; Hopping et al. 1999; March and Fisher 1999). Injection of air or oxygen in the forebay and tailrace weir aeration have proven effective at particular sites. Thorough reviews of such structural options for improving DO below dams are available (EPRI 1990, Sale et al. 1991, EPRI 2002, FERC 2002).

Levels of DO can also be increased through modifications in dam operations (EPA 1993). These include such techniques as fluctuating the timing and duration of flow releases, spilling or sluicing water, increasing minimum flows, and flow mixing (Figure 2).

The timing and duration of flow releases can substantially enhance water quality below dams. In both natural and artificial aquatic systems, DO levels can fluctuate widely on a daily and/or seasonal basis. Release of oxygenated surface waters during low DO periods or when critical life history stages of aquatic organisms are present (e.g., during fish spawning or recruitment) can be highly beneficial to instream biological resources. In some cases, small adjustments in reservoir storage rates or water release schedules can have significant ecological benefits. A thorough understanding of the DO cycle and the limnological

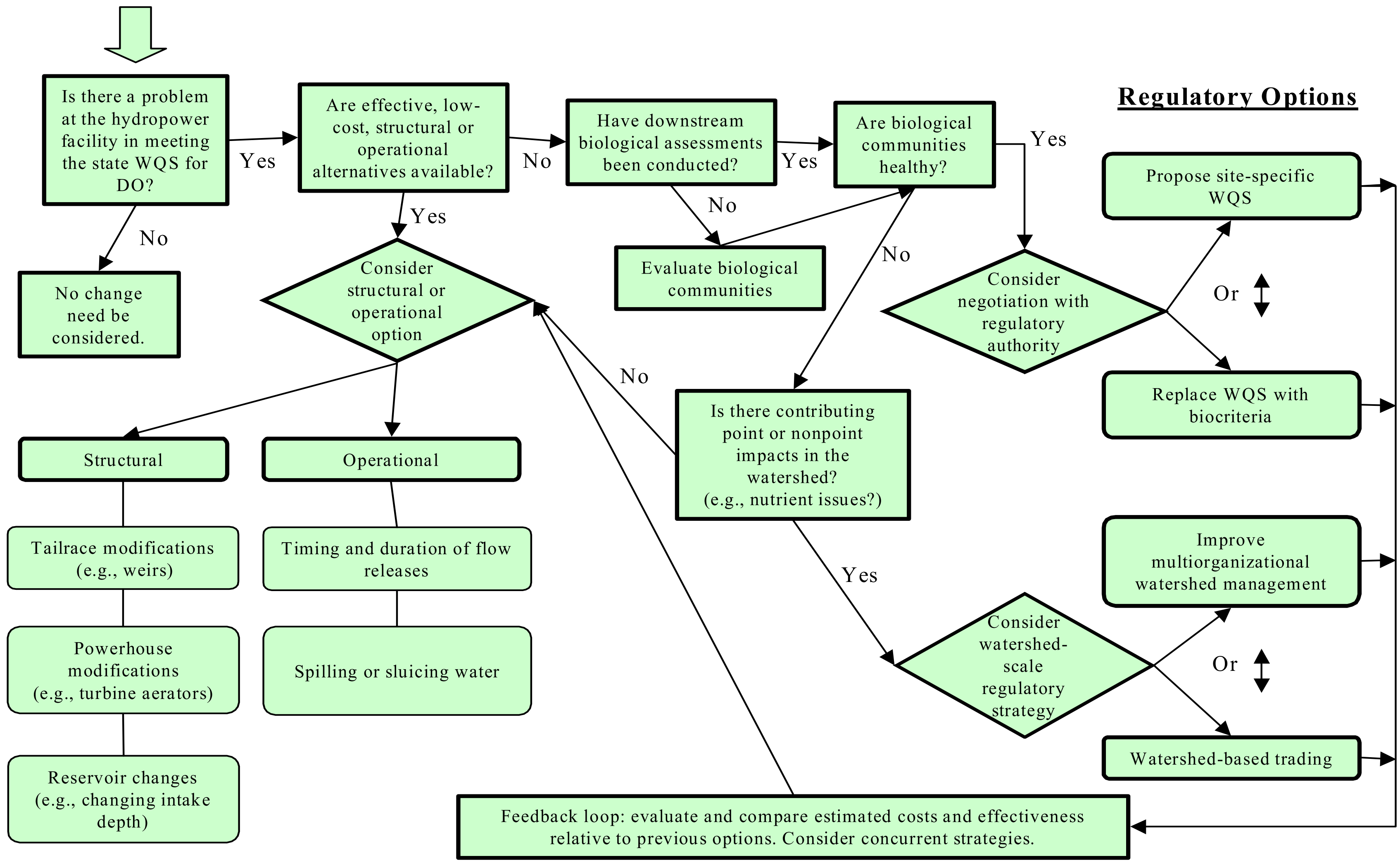

Figure 2. Decision-based flowchart for consideration of regulatory approaches to addressing the dissolved oxygen (DO) problem at hydropower facilities. **WQS = water quality standard**

characteristics of the aquatic system can provide the information necessary to optimize flow releases for enhancing DO levels in the tailwaters. Water quality and/or water balance models may be particularly useful tools in this regard.

Spilling of water can produce agitation and mixing with air, increasing the saturation of water released below the dam. Release of epilimnetic (surface) waters (generally higher in DO than hypolimnetic waters) via sluicing or bypass valves can also be beneficial. Mixing of these well-oxygenated auxiliary flows with generation flows that withdraw from poorly oxygenated bottom waters is also a viable option.

Maintaining a constant minimum flow could ensure that water does not stagnate below the dam and promote algal blooms that create anoxic conditions. For dams with multilevel intake devices, operators can minimize the withdrawal of low-DO hypolimnetic water or of surface water high in blue-green algae. Another operational tool for minimizing DO problems is the implementation of turbine start-up procedures that enlarge the zone of withdrawal to include higher-quality epilimnetic waters (EPA 1993).

Operational changes often require releasing stored water at times that may be undesirable economically. For example, in a review of the cost/benefit of spilling water to improve DO conditions, EPRI (1990) found only one example (Kingsley Dam in Nebraska) that was economically viable. In general, it appears that modest structural techniques that improve aeration while allowing hydroelectric generation are more economical than spilling water. Operational changes that modify the timing and duration of flows have a greater potential of increasing DO at a lesser cost. However, operational changes to improve DO conditions must to be balanced against the needs for power generation and those of upstream and downstream water users. Hydropower operators may have only limited capability to alter releases because of license conditions. If additional structural changes are required to implement operational changes (for example, if control structures or bypass valves are needed), the costs would increase dramatically.

Even with structural or operational changes, DO concentrations below dams may not comply with regulatory standards, and further modifications can be costly. This report addresses the use of alternative, regulatory strategies for addressing DO problems. Regulatory agencies in the U.S. are considering or implementing dramatic changes in their approach to protecting the quality of the Nation's waters. New policies and initiatives have emphasized flexibility, increased collaboration and shared responsibility among all parties, and market-based, economic incentives. This report summarizes some of the non-structural, regulatory-related options available to hydropower projects, including negotiation of site-specific water quality criteria, use of biological monitoring, watershed-based strategies for the management of water quality, and watershed-based trading. We examine the value of regulatory approaches by reviewing their use in other contexts (e.g., for other types of facilities or effluent dischargers, or for other water quality issues), by reviewing recent regulatory policy, by summarizing evaluations in the literature of their potential value, and by use of hypothetical examples.

2. REGULATORY APPROACHES TO ADDRESSING DO ISSUES

There have been a number of recent changes in the regulations for protecting water quality, particularly with regard to controlling nonpoint-source pollutants, and there is considerable uncertainty about how the new regulations will be implemented. In general, water quality regulation is moving away from "one-standard-fits-all" approaches toward more comprehensive, watershed-wide strategies with greater site-specific flexibility. Some regulatory options for addressing DO issues at hydropower facilities include the use of (1) site-specific water quality standards; (2) biocriteria; (3) watershed-based strategies; and (4) watershed-based trading (Figure 2). The first two options will require negotiations between the utility and the water quality regulators, much as presently occurs when such aspects of a permit as the size of a mixing zone or the dates at which particular numerical values for DO apply are established. The latter two, watershed-based options are likely to include negotiations with other parties as well. For example, determining the sources (and magnitudes) of low DO or high BOD/COD water that may share responsibility for low DO discharges from the hydroelectric power plant may require input from other point-source and nonpoint-source dischargers. The following sections describe alternative approaches to "one-standard-fits-all" water quality regulation that will require additional information and negotiations. The key assumption for all of these approaches is that the currently applied regulatory limits may not be an effective measure of water quality impacts (or lack of impacts). The hydropower facility may be able to provide a convincing argument that a healthy aquatic community could be maintained at lower numerical limits, or, if impacts are occurring, that the costs of enhancing DO levels in the river should be shared with other water users.

2.1 Site-Specific Water Quality Standards

The Clean Water Act (CWA) prohibits the discharge of pollutants into most waterways of the U.S. without a National Pollutant Discharge Elimination System (NPDES) permit issued by the Environmental Protection Agency (EPA) or the state water quality permitting agency. A discharge permit issued under the NPDES provides conditions and establishes allowable levels for the discharge of pollutants to surface waters. In the case of DO, the NPDES permit specifies minimum concentrations needed to protect water quality and other instream uses. Under Section 401 of the CWA, an applicant for a Federal Energy Regulatory Commission (FERC) hydroelectric project license must obtain certification from the state or interstate pollution control agency verifying compliance with the CWA. FERC's three-stage agency consultation requires an applicant for a hydropower project to consult with the certifying agency under Section 401 of the CWA (FERC 2001).

Application of water quality regulations can vary at hydropower facilities, depending on the type of facility (federal or private) and the regional, state, and federal laws that apply to the facility at that location. For example, federal hydropower projects comply with requirements of the CWA directly, whereas DO limits at non-federal, FERC-licensed facilities are based on license articles that are established by FERC in consultation with state water quality agencies. In general, however, hydropower facilities must comply with numerical state water quality criteria for DO, which in most cases are based on EPA guidance. Many FERC-licensed hydroelectric projects are required to monitor for compliance with state DO standards (FERC 2002).

For many years a single minimum allowable DO concentration of 5 mg/L was the established criterion that was deemed adequate to protect the diversity of aquatic life in fresh waters (EPA 1976). In 1986, EPA established new criteria that included various mean and minimum values for cold water and warm water systems (EPA 1986). In addition, separate criteria were established for protection of early life stages of fish and for inter-gravel water.

Depending on the test method, life stage, and water temperature (cold or warm), DO criteria can be as low as 3.0 mg/L (1-day minimum for warm-water "adult" life stages) or as high as 9.5 mg/L (7-day mean for inter-gravel water to protect cold-water early life stages). Stricter limits were established for cold water systems because of the greater sensitivities of salmonids to low DO conditions. Some states have DO limits that exceed the EPA criteria, and many hydropower facilities struggle to comply with these standards.

Despite DO noncompliances at hydropower facilities, there are many cases of clearly viable aquatic communities and successful fisheries below the dams. A potential approach to compliance for these facilities is to document that the aquatic community downstream is not affected by occasional DO noncompliances (e.g., through the application of a bioenergetics model) and to negotiate less stringent limits (See Section 2.2). Although such an approach depends upon regulatory flexibility and site-specific conditions, some states (e.g., Pennsylvania) already include such site-specific policies in their regulatory code. Moreover, recent EPA guidance suggests that biological assessments will be considered, for example, in establishing DO criteria in saltwater (EPA 2000a). In these waters, the new criteria combine features of traditional numerical water quality criteria with a new biological framework that integrates time (replacing the concept of an averaging period) and establishes separate limits for three different life stages (larvae, juveniles, adults).

Hydropower operators with DO problems should contact the appropriate water quality regulatory authority to discuss site-specific standards. The costs associated with negotiating a site-specific standard include data collection to support a different standard and the time and effort to conduct potentially protracted negotiations.

2.2 Biocriteria and Bioassessments

The objective of the CWA is to restore the physical, chemical, and biological integrity of the nation's waters. During the last two decades, increasing emphasis has been placed on measuring the biological status of surface waters as a supplement to criteria that are based on chemical water quality. As noted by Yoder (2001), the ability of a water body to sustain a balanced, integrated, adaptive assemblage of aquatic organisms is one of the best overall indications of the suitability of that water body for many other beneficial uses.

Although monitoring for compliance with state DO standards is the norm for FERC-licensed projects (FERC 2002), monitoring the response of biological communities to DO levels in the water discharged from the power plant has been rare. Depending on the particular situation, it may be appropriate to negotiate the replacement of numerical limits for DO with biocriteria. *Biocriteria* are defined by the EPA as numeric or narrative expressions that describe the reference biological integrity (structure and function) of aquatic communities inhabiting waters of a designated aquatic life use (http://www.epa.gov/ost/biocriteria/basics/). They are developed as measures to directly assess the overall condition of an aquatic community in surface waters. Examples of biocriteria include measures of species diversity (particularly among the fish or aquatic macroinvertebrate communities), species abundance, fish growth and mortality, and instream habitat measures.

Bioassessments are evaluations of the biological condition of a water body that use biological surveys and other direct measurements of the resident biota. There is increasing recognition in the scientific and regulatory community of the advantages of biological assessments of receiving waters (EPA 1998a,b), several of which are outlined on a comparative basis with numerical DO criteria in Table 1.

Although DO measurements are necessary for acquiring source-specific information, a watershed-based biomonitoring program can provide a better understanding of actual effects of hydropower discharges on the biological integrity of receiving waters. Biological assessments can integrate impacts of all sources (point and nonpoint) over space and time (biota are exposed to all upstream contributors over their lifetime), in contrast to chemical measures that often represent a single location and time (e.g., grab sample). Often, biological assessments are based on comparing the fish or aquatic macroinvertebrate communities in the potentially affected river reach (e.g., dam tailwaters) with the aquatic communities in nearby, similarly sized reference sites. If the aquatic communities in the tailwaters are not significantly different from those in the unimpacted reference sites (in terms of insect species richness, diversity, fish growth rates, etc.), it can be inferred that DO non-compliances are not adversely affecting the designated uses of the water.

Table 1. Relative merits of numerical DO criteria versus biocriteria/bioassessment approaches for protection or restoration of aquatic resources. Modified from Peterson et al. 2000.

Numerical Criteria (Water Chemistry Measurements)	Biocriteria (Biological Measurements)
• Provide data on specific concentrations of dissolved oxygen over time and space	• Provide data on cumulative biological/ecological responses to environmental conditions over time and space
• Data are intermittent/non-continuous (grab samples) or are flow-weighted and pooled	• Data are cumulative and integrative; organisms are continuously exposed to all substances in water or sediments and integrate the effects of this exposure.
• Data reflect shorter temporal scales and near-field effects; measurements can quickly detect changes in DO concentrations; well-suited for reflecting rapid changes resulting from specific events or remedial actions	• Data reflect longer temporal scales and far-field effects; data are well suited for reflecting watershed-scale, cumulative ecosystem responses
• Data applicable to human welfare and ecological risk estimates via models/extrapolation	• Data reflect actual exposure to and biological impact of DO levels; i.e., data reflect actual responses rather than theoretical (often worst case) impacts extrapolated from chemical data
• Yield numerous data points per sampling location, relatively inexpensive per data point, but have low information value per data point	• Yield fewer data points per sampling location, relatively laborious and expensive per data point, but data are highly integrative, so there is high information value per data point
• Data are affected by flow variations (storms, seasonal, wet *vs* dry years, etc.)	• Data are affected by flow and other environmental factors (temperature, habitat) over time, but they are normalized by long-term data records and monitoring of reference sites
• Can provide an endpoint; e.g., when DO concentration regime complies with environmental standards	• Can provide an end-point; e.g., when the biological community is equivalent to reference sites

A biocriteria approach could be advantageous to those hydropower facilities with tailwaters that have healthy aquatic communities despite occasional DO noncompliances. Figure 3 shows the relationship of DO concentrations and the Index of Biotic Integrity (IBI), a commonly used statistic that summarizes information on abundance, species richness, and habitat needs of the fish assemblage. The IBI concept was originally developed to assess impacts to fish communities in Midwestern streams, and it has since been expanded to include benthic communities and modified for different biogeographic regions. Generally, higher values of IBI corresponded with higher values of DO. However, at some sites DO values of less than 5 mg/L are associated with relatively high IBI values (greater than 30).

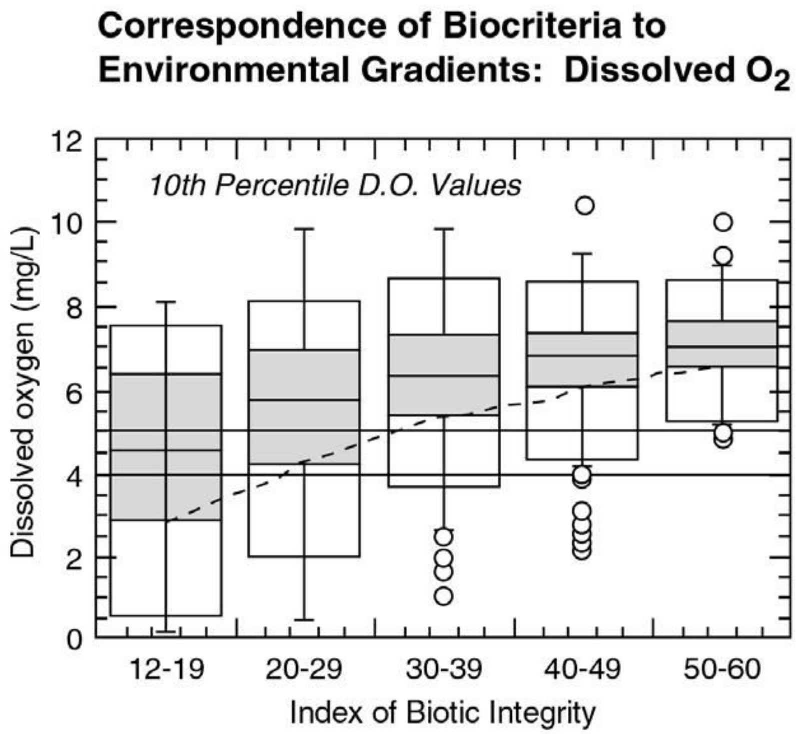

Figure 3. Relationship of dissolved oxygen concentrations to Index of Biotic Integrity values for Ohio streams. From Yoder (2001).

While the value of using the aquatic community to reflect the long-term effects of water quality is clear, there are several constraints associated with this approach. For example, there may be substantial year-to-year variation in specific biological measures (e.g., growth rate) that are not related to water quality and may overshadow any effects of reservoir discharges. In addition, it can be difficult to find similar-sized, unimpaired reference sites that can be compared to the tailwater site; often a group of reference sites must be used that

encompass the range of natural variability in streams (and aquatic communities) in the geographic region. If not clearly defined, biocriteria can be qualitative, subjective indicators, and measures such as species richness may be difficult to interpret. For example, if an unimpacted reference site supports 44 insect species and the tailwater site supports 41, does it indicate that low DO releases from the hydroelectric reservoir have had an adverse impact? How significant is a reduction in fish growth rate in the tailwaters of 5 percent (compared to growth of the same species in a nearby reference site)? Is an IBI value of 36 at one site significantly different from an IBI value of 33 at another? Finally, costs of this approach can be high; biological measurements can be expensive, and data analysis and interpretation can require a high level of expertise.

The Oak Ridge Biological Monitoring and Abatement Program (BMAP) has successfully used a biocriteria/bioassessment approach since the mid-1980s to evaluate the condition of receiving streams on the Oak Ridge Reservation (http://www.esd.ornl.gov/BMAP/). Table 2 summarizes the most common biomonitoring methods, organisms sampled, and parameters measured in this program. In many cases, the BMAP has been able to demonstrate that "biological integrity" of the streams can be restored even though National Ambient Water Quality Criteria are exceeded.

As of 1995 a total of 29 states had included narrative biocriteria in their water quality regulations (EPA 1995, 1999). Only one state (Ohio) has adopted numeric biocriteria, whereas 41 states have opted to use bioassessments to meet their resource management responsibilities. EPA (1999) encourages all states and Tribes to use biocriteria and bioassessments in concert with chemical and physical measurement for development of standards for protection of water quality. In support of these efforts, EPA continues to develop guidance documents related to the development and implementation of biocriteria (e.g., EPA 1996b; 1998c).

European Union (EU) Use of Bioassessments. Water quality is one of the most comprehensively regulated areas of EU environmental legislation, and the EU's newly established approach to water quality management may have lessons for the U.S. Formulation of water policy and the regulation of water quality in the member countries of the EU began in the 1970s and has been periodically revised since then. While these regulations resulted in considerable progress in dealing with water pollution issues, it was recognized that water policy was fragmented and that there was a need for a single piece of framework legislation. Accordingly, a Water Framework Directive (WFD) was proposed with the following key aims (http://europa.eu.int/comm/environment/water/index.html):

Table 2. Summary of the most common biomonitoring methods, organisms sampled, and parameters measured for the Oak Ridge Biological Monitoring and Abatement Program (BMAP) tasks, with citations providing additional information.

Tasks	Methods	Organisms	Major Parameters	Citations
Toxicity Testing: Effluents and ambient waters	3-brood, survival and reproduction test	cladoceran (*Ceriodaphnia*)	survival and fecundity; water chemistry	Kszos et al. 1997; Kszos et al. 1996; Stewart et al. 1996; Lewis et al. 1994; Stewart et al. 1990
	7-day, larval survival and growth test	fathead minnow	survival and growth; water chemistry	
Bioindicators: Fish health	electrofishing; dissection, measurement, and analysis of individual fish	redbreast sunfish; largemouth bass; catfish	suite of biochemical and physiological parameters	Adams et al. 1999 Adams and Ryon 1994; Adams et al. 1993
Reproduction	electrofishing; gonadal and radioimmuno-assays	redbreast sunfish; largemouth bass; catfish	reproductive condition and fecundity	Hinzman 1998; Greeley et al. 1994
Bioaccumulation: Aquatic	electrofishing; contaminant analysis of resident fish tissue	primarily sunfish, bass, catfish, and minnow species	primarily Hg and PCBs, also other metals and organics	Peterson et al. 1996; Southworth et al. 1994; Southworth 1990
Terrestrial	trapping; contaminant analysis of tissue; visual observations	mink, kingfisher, starling, waterfowl	Hg, PCBs and pesticides; population survey	Stevens et al. 1997; Kendall et al. 1989
Instream monitoring: Periphyton	periphyton on natural substrates	periphyton taxa	biomass and productivity; contaminant uptake	Hill et al. 1996; Boston et al. 1991
Benthic macroinvertebrate community	replicate Surber or Hess samples	benthic macroinvertebrate taxa	abundance (richness, EPT richness); diversity	Smith and Beauchamp 2000; Hinzman 1998
Fish community	electrofishing; 3-pass removal method	fish taxa	species richness, population densities, growth, Index of Biotic Integrity	Ryon and Carrico 1998; Stewart and Loar 1994; Ryon and Loar 1988

- expanding the scope of water protection to all surface and groundwaters;
- achieving “good” status for all waters by a set deadline;
- basing water management on river basins, rather than political or administrative boundaries;
- using a “combined approach” of emission limit values and water quality standards;
- incorporating overall water costs in the price of water, reinforcing the “polluter pays” principle and confronting users with the real costs of providing water.

The WFD was agreed to by the European Parliament, the European Council, and the European Commission and came into effect on December 22, 2000. The member countries have 3 years to transpose the requirements of the WFD into their particular legal administrative systems (a process called approximation) and implement them.

Two goals of the WFD are of particular relevance to the issue of DO concentrations in water discharged from hydropower facilities: the determination of status of the surface waters and the desire to employ a “combined approach” to address water pollution.

The WFD requires that all surface waters be categorized as either “high,” “good,” or “fair” in terms of their *ecological* status, and that all waters be brought to at least a “good” status. That is, the assessment will be based on the structure and function of ecological systems, rather than just chemical contamination. Surface waters which differ only slightly from what would be expected under conditions of minimal anthropogenic impact (in terms of the biological community, hydromorphological and physico-chemical characteristics) are considered to have high ecological status. The definitions for ecological status are based on changes in structural and functional characteristics of the aquatic ecosystems (e.g., abundance and composition of benthic invertebrates, concentration of chlorophyll-a, and obstructions to fish migrations), compared to “natural” reference sites. Some of these ecological parameters will be difficult to express quantitatively and to categorize, and the significance of deviations from the reference conditions will be difficult to judge. Nonetheless, such an approach recognizes the limitations of relying solely on chemical water quality standards to determine the status of surface waters. Determining the ecological status takes into account those surface waters that don’t meet chemical water quality standards yet could still support a balanced, normative aquatic ecosystem. Conversely, waters that meet standards for chemical contaminants may still be impaired because of habitat degradation, undetected pulses of contaminants, or the cumulative effects of low levels of chemical contaminants. Hydropower facilities could be evaluated on whether or not they support a normative aquatic ecosystem in the tailwaters, rather than strictly on the basis of compliance with DO standards.

The WFD recognizes that there are two general approaches to regulating water quality. The Water Quality Objective (WQO) approach defines the minimum quality requirements of a water body in order to limit the cumulative impacts of multiple effluents. On the other hand, the Emission Limits Value (ELV) approach focuses on the maximum allowed quantities of pollutants discharged from a particular source into the aquatic environment. The WQO and ELV are analogous to water quality standards and National Pollutant Discharge Elimination System (NPDES) permits used in the U.S., respectively. The WFD notes that an approach which combines WQO and ELV is needed; the two approaches will reinforce each other, and in any particular situation, the more rigorous approach will be applied. All existing technology-driven source-based controls must be implemented as a first step (ELV approach). But over and above this, the requirement for good ecological status may call for implementation of additional water pollution control measures (WQO approach).

Details of the implementation of the WFD have to be worked out on both an EU and country-by-country basis, so the effects of this new legislation on hydropower production in Europe are not yet known. The first required activity is that EU Member States identify and assign waterbodies to River Basin Districts based on hydrological catchments, i.e., they must regulate water quality using a watershed-based strategy (Griffiths 2002). One of the member states, Scotland, sees the new directive as an opportunity to improve the regulation of water abstractions (withdrawals), including those from approximately 1,000 hydropower projects, many of which remove all the water during low river flows. The quality of water discharged from reservoirs will be judged not only by the level of chemical parameters (e.g., DO concentrations), but also by the status of the aquatic ecosystem downstream from the dam. Bringing the ecological status of surface waters up to the “good” category may require the provision of fish passage and minimum flow releases at hydroelectric power plants. Exceptions to the requirement to achieve good ecological status are allowed for some essential activities (e.g., flood protection and essential drinking water supply). Power generation is subject to three tests before the requirement is relaxed: alternatives are technically impossible, are prohibitively expensive, or would produce a worse overall environmental result. The intention to combine the

WQO and ELV approaches will improve water quality. However, because the most rigorous of the two will be applied in any particular situation, the Directive's combined approach does not support tradeoffs, and lacks the flexibility of the watershed-based strategies now being developed in the U.S.

2.3 Watershed-Based Strategies

Watershed management has been found to be a cost effective means for improving tailwater quality (TVA 1988). Nutrient and organic material sources (BOD and COD) in the upstream watershed can be a major factor contributing to low DO concentrations below dams. Consequently, actions such as land use planning, erosion control, groundwater protection, and animal and septic waste control can be effective ways to improve both DO levels and overall water quality. Other watershed management practices can help maintain riparian habitat in the areas around the impounded reservoir and downstream from the dam. Examples of downstream aquatic habitat improvements include maintaining minimum instream flows, providing channel scouring when and where needed, providing alternative spawning areas or fish passage, protecting streambanks from erosion, and maintaining wetlands and riparian areas. While not improving DO concentrations in the reservoir discharges, these measures enhance habitat for aquatic organisms, reduce the input of organic matter and nutrients, or increase the stream's waste assimilative capacity. Consequently, biological communities, DO concentrations, and overall water quality will be improved.

An example of a watershed-based strategy is the Total Maximum Daily Load (TMDL) program, which is an EPA regulatory framework by which states identify polluted waters, determine the sources of pollution, and design basin-wide clean-up plans (EPA 2000b). Impaired water bodies are listed by the states, after which the process begins for identifying and assessing waste loads, and allocating source contributions of those wastes.

Section 303(d) of the CWA requires states to identify all waters that do not meet water quality standards even after pollution controls required by law are in place. For these waters, the state must calculate how much pollution the water can receive without violating the standard, and then distribute that quantity to all the sources. The Total Maximum Daily Load (TMDL) is the maximum amount of a pollutant that a water body can receive and still meet water quality standards. The TMDL is the sum of all pollutant contributions from point-source discharges (e.g., sewage treatment plants, industries), nonpoint sources (runoff from forest, agricultural lands, feedlots, abandoned mine lands, etc.), plus a safety factor (called the Margin of Safety, MOS).

How hydropower operations would be considered within this process is still not well defined. Key elements in this process are a shared approach to water quality problems and local/regional flexibility in how water quality goals are achieved. As presented in the TMDL final rule: “States have maximum flexibility to make their own choices about which sources of pollution to clean up, and in what manner, and to produce their own plans for local cleanups to ensure the full protection of public health.”

While sources, loadings, and allocations are relatively easy to understand for pollutants that are added to the aquatic system (e.g., phosphorus, suspended sediments, or metals), applying the TMDL approach to DO deficits is not straightforward. Sufficient levels of DO may be present initially in water entering a river or reservoir, but because of in-stream and in-reservoir processes (e.g., decomposition of organic matter), DO may be consumed within the water body. Consequently, it may be useful to evaluate the sources and loadings of oxygen-consuming materials, i.e., the Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Appropriate models can be used to identify the sources of nutrients and organic matter (BOD and COD) in the watershed and reservoir, evaluate the fate of these materials in the river/reservoir system, and predict the extent to which oxidation of these materials within the hydropower reservoir contributes to low DO problems.

Application of the TMDL approach involves mathematical modeling, including the use of models to identify pollutant sources, evaluate loadings, examine impacts on receiving waters, quantify loading capacity, evaluate the linkage between loading and response, and allocate the pollutant loading in a way that ensures achievement of water quality standards (Donigian 2001). Numerous watershed and nonpoint source water quality models can be employed in the TMDL process, ranging from simple, inexpensive applications to complex approaches such as the Watershed Analysis Risk Management Framework (WARMF) model. WARMF was developed by Systech Engineering, Inc. to study fate and transport processes at a watershed scale, so it is a useful tool for developing TMDLs (EPRI 2000; Weintraub et al. 2001).

While TMDLs have been part of the CWA since 1972, until recently there has been little effort to promote this approach. EPA issued regulations in 1985 and 1992 that implemented Section 303(d) (the TMDL provisions) of the CWA. Changes to EPA's TMDL regulations were finalized on July 13, 2000. However, concerns about the new regulations were expressed by many organizations (e.g., WEF 2001), and a recent report from the National Research Council (NRC 2001) recommended changes to the TMDL program. Consequently, EPA published a notice in the Federal Register to delay the effective date of the new TMDL rules until April 30, 2003. EPA is reconsidering some of the choices made in the July 13, 2000 rule, and at this writing has proposed to withdraw the rule (67 FR 79020; December 27, 2002). The existing 1992 regulations under which the TMDL program now operates, as well as the status of future changes in the regulations, may be found at http://www.epa.gov/owow/tmdl/

Although the TMDL remains a promising approach for addressing water pollution problems on an appropriate, watershed-based scale, application of the process is highly variable from state to state. Numerous legal actions both for and against the listing of waters, calls for greater scientific rigor in the implementation of TMDLs, and the recent announcement delaying the effective date of new TMDL regulations all diminish the present value of this watershed-based strategy for addressing dissolved oxygen problems.

Another example of a watershed-based strategy is the Clean Water Action Plan, a U.S. Executive Branch initiative that focuses on a collaborative effort by state, tribal, federal, and local governments, the private sector and the public to restore watersheds not meeting clean water, natural resource, and public health goals (EPA 1998b). As an outgrowth of this initiative, all federal agencies have agreed to use a watershed management approach to protect and restore watersheds (Federal Register 2000). Federal hydropower operators, such as the Tennessee Valley Authority (TVA), have long embraced watershed-wide strategies for addressing water quality issues like the DO problem (TVA 1985). TVA's Lake Improvement Plan, a 5-year, $44 million program for improving DO and minimum flows below 16 hydropower projects, targeted DO levels lower than state water quality standards in the discharges from hydropower reservoirs that were impacted by excessive loads of nutrient and organic matter from the watershed.

Regardless of the regulatory considerations, hydropower facilities may benefit from considering DO limits in the context of watershed-wide goals and best management practices.

For example, EPA and the National Oceanic and Atmospheric Administration (NOAA) have published a guidance document for states to use that describes "management measures” that can be applied to dam operations in coastal areas (EPA 1993). Although these measures do not supersede federal requirements set forth in FERC licenses and do not apply to projects under NPDES jurisdiction, FERC licensing proceedings may be less protracted if water quality assessments are consistent with EPA and NOAA guidance.

2.4 Watershed-Based Trading

A variation of the watershed management approach is watershed-based trading. Like the watershed management strategy described above, watershed-based trading also involves an evaluation of pollution sources in a watershed. However, with this option, costs and market incentives are more formally considered, and a procedure for trading pollution credits is established in an effort to achieve overall watershed-wide clean water goals (much like recent modifications to Clean Air Act requirements). Again, the focus is on improving water quality in the watershed as a whole and placing less emphasis on individual source contributions (although trading does not substitute for existing regulation). EPA envisions watershed-based trading occurring within, or in conjunction with, the TMDL process (EPA 1996c). Watershed-based trading has been explored, developed, or implemented at a few locations across the nation in recent years (NWF 1999). Although we have been unable to find examples of trades that involve hydropower facilities (EPA 1996a), it is a focus area that has received some attention as possible demonstration projects.

The principles of watershed-based trading are described in the *Draft Framework for Watershed-Based Trading* (EPA 1996c). Different types of trading are allowed within this framework, including intra-plant, pretreatment, point/point-source, point/nonpoint-source, and nonpoint/nonpoint-source trading. The greatest potential benefit to hydropower facilities is in point/nonpoint-source trading, where the hydropower plant is considered a nonpoint source for low DO. The basic premise consists of an industry paying (or obtaining credits from) hydropower facilities to improve DO and water quality below dams (using aeration, etc.), at a potentially lower cost than remediation options at the industrial point source.

On January 13, 2003, EPA announced a new Water Quality Trading Policy to provide guidance on how trading can occur under the Clean Water Act and its implementing regulations (EPA 2003; http://www.epa.gov/owow/watershed/trading.htm). Water quality trading is a market-based approach that is intended to provide greater efficiency in achieving water quality goals in watersheds by allowing one source to meet its regulatory requirements by using pollutant reductions created by another source that has lower pollution control costs. For example, a farmer or wastewater treatment plant owner would be able to generate pollution "credits" by reducing pollutants in the effluents beyond what is required by law. The credits could then be sold to other pollution sources, allowing those sources to discharge more than their share of the pollutants.

The objectives of water quality trading include achieving early reductions and progress towards water quality standards pending development of TMDLs for impaired waters, reducing the cost of implementing TMDLs and complying with water-quality requirements, establishing economic incentives for voluntary pollutant reductions from point and nonpoint sources within a watershed, and offsetting new or increased discharges resulting from growth. Under the policy, all water quality trading should occur within a watershed or a defined area for which a TMDL has been approved. EPA supports trading that involves nutrients (e.g., total phosphorus and total nitrogen) or sediment loads. In addition, EPA also supports cross-pollutant trading for oxygen-related pollutants where adequate information exists to establish and correlate impacts on water quality. (Examples of cross-pollutant trading are reducing upstream nutrient levels to offset a downstream BOD or to improve a depressed instream DO level.) Potentially, the Water Quality Trading Policy would allow a hydropower operator to receive credits for oxygenating water that is at least partially degraded by other water users in the watershed. The policy provides incentives for all water users in the watershed to work together to clean up sources of nutrients and organic matter before they reach the river (e.g., through the use of buffer strips to capture soil, manure, and chemical runoff from fields).

An analysis of the South Fork Holston River in East Tennessee provides an example of how point/nonpoint-source pollutant trading within a watershed might be implemented (Podar et al. 1985, Hauser and Ruane 1985, Bender et al. 1991). In this case, an industrialized stretch of the river downstream from the Tennessee Valley Authority's Fort Patrick Henry Dam did not meet water quality standards, even after the City of Kingsport and local industries installed new wastewater treatment facilities and met their technology-based treatment and NPDES permit requirements. Although several hundreds of millions of dollars had been invested in waste treatment facilities in the 1970s, DO levels in the South Fork Holston River dropped to 2 mg/L under low flow conditions. Further, DO concentrations were predicted to range from 0-1 mg/L if industrial and municipal facilities discharged to the limits of their permitted waste loads (Ruane et al. 1998). As a result, the State of Tennessee declared the river “water quality limited.” The TVA investigators considered a number of options for improving DO conditions in the river, including advanced waste treatment for the dischargers, turbine aeration at Fort Patrick Henry Dam, various levels of flow augmentation at the dam, and instream aeration.

The results of this exploratory analysis indicated that DO standards of 5.0 mg/L in the South Fork Holston River could not be attained with the advanced effluent treatments that were considered by the industrial and municipal dischargers. Further, the costs of these treatments exceeded those for river management options at the dam by at least two orders of magnitude (Ruane et al. 1998). For example, it was predicted that state water quality standards could be met by augmenting flow releases from the dam, coupled with additional aeration by the hydroelectric project, either at the dam or downstream. The annual cost of this option ranged from $298,000 to $395,000, compared to an estimated annual cost of $44 million for the industrial and municipal dischargers to operate advanced (but insufficient) waste treatments. A situation like this presents the point source dischargers with a clear opportunity to reduce their waste treatment costs by helping to defray the electric utility’s cost of aeration and flow augmentation. Ruane et al. (1998) noted that by including a hydropower project in a watershed-based trading program, it may be possible to (1) secure a new source of revenue for the hydropower project; (2) maximize water resource benefits when power generation has less value; (3) improve water quality in “water quality limited” stream segments; (4) provide for continued economic growth where river assimilative capacity is currently limited; and (5) enhance river habitats. In other words, this can be a “win-win-win” situation, for the hydroelectric project, municipal and industrial dischargers, and the environment. In order for this approach to be used, trades must be covered by TMDL or similar watershed-based analyses and all point sources involved with a trade must be in compliance with applicable technology-based limits (EPA 1996a).

Encouraged by the potential of this approach, EPA supported an assessment of the potential role that hydropower projects could play in improving water quality in the Mississippi River Basin through EPA’s Watershed-Based Pollutant Trading Program (Crossman et al. 2000;

John Crossman & Associates 2001). Fourteen of the 31 Mississippi River Basin states had at least one candidate trading project (i.e., a DO-relevant TMDL site that is influenced by a hydropower project). In all, 55 candidate trading projects were found by this survey. Of the hydropower projects that were involved in these 55 candidate trading sites, 35 had "high-volume" reservoirs with greater than 103,813 acre-feet of storage. The majority of the TMDL sites were found upstream of the dam. The initial findings of the EPA-sponsored study indicated that many hydropower projects are being adversely affected by pollutant loadings from the watershed upstream (John Crossman & Associates 2001). These pollutant loads are transformed by reservoir processes, which can contribute to poor-quality hydroturbine releases. The report noted that these hydropower projects have the potential to make a significant contribution to national water quality objectives if technological advances to improve water quality are employed in a watershed-based trading program.

The intent of trading is to use the flexibility allowed in clean water regulation to achieve pollutant reductions in the watershed at a lower overall cost. In addition to the benefit of low cost, the process encourages communication between water users/dischargers and other stakeholders and fosters a better appreciation of the overall value of the watershed. Like other watershed management strategies, it may be difficult to achieve amicable inter-party communication and committed involvement of multiple contributors and stakeholders. In a watershed trading program in North Carolina, half of the industrial point sources in the watershed were not involved because the regulators did not provide strong enough economic incentives for trading (Jarvie and Solomon 1998). In particular, nonpoint sources that are currently subject to less government regulation may have little incentive to follow through with real source reductions. This situation could change if TMDL enforcement is strengthened and the new Water Quality Trading Policy is implemented. Watershed-based trading that provides additional income to facilities that are marginally cost-effective may be beneficial. In cases where hydropower facilities operate in a contentious environment with other water users, these facilities need to consider the potential level of assessment, modeling, and regulatory negotiation that might be required to ensure equitable trades and overall improved water quality.

3. CONCLUSIONS AND RECOMMENDATIONS

The use of nonstructural approaches is one of the options for addressing DO concerns at hydropower facilities. Structural modifications may be the most effective option, especially in cases where there are severe DO problems, but costs are high. Modifying operational procedures can also improve DO, without the need for structural changes. However, in cases where operational changes involve spilling water or increasing generation during times of the day when power is less valuable, the operational approach to DO enhancement can also be costly. The use of more flexible regulatory approaches to the DO issue (e.g., development of site-specific water quality standards) is an option available to hydropower facilities. Bioassessments are being increasingly recognized as the most appropriate and direct means for determining whether biological integrity of the receiving waters is maintained. Bioassessments not only ensure that discharge limits in the water quality permits are having the desired effects, but they can also be used to determine whether healthy aquatic communities can be supported in the tailwaters despite occasional non-compliances with chemical (numerical) water quality standards. There is still considerable uncertainty as to how watershed-based strategies (e.g., the TMDL program) will ultimately be implemented, but such approaches may warrant further investigation at many sites. If water quality problems in a hydropower reservoir or its releases can be attributed to watershed point source or nonpoint source loads, there is a high likelihood that the hydropower operator can convince the water quality regulatory agencies to reduce these loads in the watershed or to assist in the implementation of water quality improvements in the reservoir. Notwithstanding uncertainties about the TMDL program, if a hydropower operator has a reasonably well-defined water quality problem that can be attributed to watershed sources, the issue can probably be resolved in a site-specific, state-by-state process.

Implementation of these alternative approaches would benefit from further research and the development of regulatory guidance. For example, whereas conventional sampling techniques can be used to conduct bioassessments, interpreting the results to determine whether the tailwaters support a balanced and healthy aquatic community may not be straightforward. It may not be possible to find a nearby, appropriately sized, unimpacted site in order to establish a reference against which to compare measurements of the biological community in the tailwaters. Often there is substantial year-to-year variation in the measured biological parameters that can obscure effects of the hydropower project or DO-enhancement measures. The significance of small differences in biological parameters between impacted and reference sites may be difficult to discern.

Watershed-based strategies for dealing with low DO problems could benefit from new or refined water quality models, as well as easily applied methods to identify and quantify all the sources within the watershed of low DO or high BOD/COD effluents. Implementation of watershed-based trading has the same needs as watershed strategies. The most equitable solutions to DO problems are those in which both the parties responsible for incoming nutrients and organic matter (non-hydropower dischargers) and the parties responsible for limnological processes that transform these inputs into low DO discharges (hydropower dischargers) participate and share costs. The costs of correcting low DO problems for each of the point-source and nonpoint-source dischargers need to be quantified and assigned, so that tradeoffs can be developed to achieve the greatest DO enhancement for the lowest cost.

All of these approaches could benefit from additional research and development (e.g., new/refined water quality models, cost-benefit models, or statistical approaches for comparing bioassessment results). In addition, it would be valuable for the regulatory agencies charged with furthering these innovative water quality protection approaches to provide additional regulatory guidance. Layman et al. (2000) suggested that a Net Environmental Benefits Analysis (NEBA) approach may be a useful way to deal with contentious natural resource issues in hydropower licensing. Most often used for oil spill responses or contaminated land cleanup, NEBA is a set of techniques and tools for comparing the benefits of alternative actions that affect the environment. The goal of NEBA is to rank the environmental benefits of alternative actions, measured in terms of ecological units instead of dollars. Coupled with a conventional cost-benefit analysis, a NEBA could help guide negotiations for watershed-level DO enhancement activities. That is, NEBA and cost-benefit analyses could identify actions that will produce the highest water quality and ecological benefits for the lowest costs.

Of course, the most effective strategy for addressing the DO problem is dependent on the site-specific situation. Before making costly structural or operational changes at hydropower facilities, a thorough assessment of the specific DO problem, using modeling or other tools, should be conducted. As much as possible, this assessment should quantify sources of water to the reservoir that contain high concentrations of nutrients and organic materials. It is possible that other point- and nonpoint-source dischargers are having difficulty complying with CWA regulations, and they may find it most economical to help defray to costs of DO-enhancing modifications by the hydropower project. A combination of mitigation techniques, including structural, operational, and regulatory approaches, may be the most effective way to address DO problems at hydropower projects.

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