Urban Issues: Hydrologic Modification and Septic Tanks

NATIONAL PERSPECTIVE ON ENVIRONMENTAL CONSTRAINTS TO HYDROELECTRIC DEVELOPMENT

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INTRODUCTION

The U.S. Department of Energy (DOE) initiated a hydropower development program in 1977 to promote small-scale (≤30 MW) hydroelectric projects across the country. Consistent with DOE's support of research on environmental aspects of energy production, it was recognized that analysis of potential environmental constraints should be an integral part of the DOE program. The Environmental Sciences Division at Oak Ridge National Laboratory implemented studies on the environmental effects of hydropower development in 1978 in support of the DOE effort (Hildebrand and Grimes, 1979). This paper summarizes our analyses of two issues that relate to the general theme of this conference: problems associated with the concentration of dissolved oxygen in tailwaters below dams and instream flow requirements for fisheries. In addition, the need for and technical challenges related to assessment of the environmental effects of multiple-project development in river basins are discussed. Although the focus of the DOE program is on small-scale hydroelectric development, the issues discussed here are applicable to large-scale facilities as well.

DISSOLVED-OXYGEN CONCENTRATIONS IN TAILWATERS OF HYDROELECTRIC DAMS

Water quality problems with the discharges of hydroelectric reservoirs can result from the seasonal warming and consequent thermal stratification of impounded waters. Hypolimnetic discharges from hydroelectric generating facilities that have low concentrations of dissolved oxygen and elevated levels of iron, manganese, heavy metals, ammonia, and sulfides may adversely affect downstream biota and water users.

The U.S. Environmental Protection Agency (1976) determined that a dissolved oxygen concentration of not less than 5.0 mg/L was necessary to maintain the aesthetic quality of the water, avoid anaerobic conditions (and attendant problems with dissolved iron, manganese, hydrogen sulfide, and methane), and support a well-rounded population of fish. We used the 5.0 mg/L criterion for dissolved oxygen to assess the potential for water quality problems at small-scale hydroelectric projects (≤30 MW) versus larger-scale projects (>30 MW) in the United States by examining the WATSTORE data base and the National Hydropower Study data base developed by the U.S. Army Corps of Engineers (see Cada et al. 1983 for a detailed presentation of this work).

Using existing data, we calculated the probabilities of noncompliance (PNC's), defined as the probabilities that dissolved oxygen concentrations in discharges of currently operating hydroelectric dams will drop below 5 mg/L. The continental United States was divided into eight regions, based on geographic and climatic similarities. Most of the regions had higher mean PNC's in summer than in winter, and summer PNC's were greater for large-scale than for small-scale hydropower facilities. Cumulative probability distributions of PNC also indicated that low dissolved oxygen concentrations in the tailwaters of operating hydroelectric dams are phenomena largely confined to sites with large-scale facilities. The PNC's are not a function of electrical capacity per se, but rather appear to depend on factors related to capacity, such as reservoir depth.

Although discharges from some small-scale hydroelectric dams have violated the 5-mg/L dissolved oxygen concentration criterion, the PNC is relatively low at most existing sites, particularly in the northern and Pacific Coast regions. In certain situations, however, small hydropower development still has the potential to adversely affect dissolved gases in rivers. For example, some low-head, retrofitted applications may involve the introduction of new turbines into existing dams that are not currently generating electricity. If the river in question carries a high waste load, and reaeration during spillage over an existing dam contributes significantly to the oxygen budget of the river, then loss of this aeration when the flow passes through turbines can depress the concentration of dissolved oxygen downstream.

Water quality problems could also arise at high-head applications of small hydropower facilities where air can be entrained at the penstock entrance. Although this may serve to reoxygenate tailwaters, nitrogen supersaturation and downstream fishkills could also occur (Berg et al. 1984).

INSTREAM FLOW AND HYDROPOWER DEVELOPMENT

Instream flow needs refer to the amount of water (stream flow) that is required within a natural stream channel to maintain instream resource values at acceptable levels (Bayha, 1978). The issue is primarily one of water quantity, as opposed to water quality, and focuses on the conflicts between out-of-stream and instream water uses. One of the most controversial uses of water within the natural stream channel has been for the protection of fishery resources, although attention is turning to the maintenance of instream flows to preserve riparian vegetation, recreation, and aesthetic values. Flow requirements that include the needs of fish as well as the integrity of the aquatic ecosystem as a whole have been difficult to measure and are often assigned a low priority when they are perceived as nonbeneficial uses of water resources. Management for instream flow needs below dams usually takes the form of minimum release requirements, which are incorporated into operation schedules.

The development of analytical techiques for determining instream flow needs has taken place gradually over the last two decades (Stalnaker and Arnette, 1976; Orsborn and Allman, 1976a, b). Although most of this research has occurred in the western United States, where competition for scarce water resources has prompted many conflicts between instream and out-of-stream uses, the need for an objective means for quantifying minimum instream flows is a national problem.

Three general approaches for determining minimum flow requirements have been identified: (1) discharge methods, which rely solely on the use of historical flow records for making recommendations; (2) hydraulic rating methods, which construct tradeoff relationships between stream flow and hydraulic parameters, such as maximum depth or wetted perimeter (submerged bottom area); and (3) habitat rating methods, which analyze in detail both the quality and quantity of habitat available to target fish species under different flow regimes. Loar and Sale (1981) reviewed available methods and made detailed comparisons of the strengths and weaknesses of each.

A misconception that often complicates the instream flow issue is that a single method can serve the assessment needs of all types of water projects. The use of high-resolution habitat rating methods at small hydropower projects that have little or no potential for altering stream flows is as inappropriate as the use of low resolution methods at large projects that have major effects on stream flows. Both extremes fail to promote the protection and management of instream resources. The selection of appropriate methods for determining minimum flow requirements should be directed toward achieving a reasonable match between potential project impacts and resource requirements.

One final note deserves emphasis. There is a significant lack of validation of existing methods for instream flow assessments. We recently completed a study (Loar, 1985) evaluating the validity of using physical habitat indices to predict the response of trout populations to changes in stream flow. Based on our results, the assumption that the abundance of fish varies in direct response to some expression of their physical habitat could not be rejected. Habitat-based assessment methods can be valuable tools for determining minimum flows in southern Appalachian streams if proper attention is paid to identifying the critical life stages of a target species and to quantifying the minimum habitat values over annual cycles under the new flow regime. Much more emphasis needs to be placed on such evaluation studies and on testing and refining current assessment methods.

MULTIPLE-PROJECT ASSESSMENT AT THE BASIN LEVEL

One of the most significant challenges to those interested in the environmental effects of hydropower development is how to assess the cumulative impacts of multiple hydropower project development on river basins. The issue of cumulative environmental impacts is critical to small hydropower development, especially in California and the Pacific Northwest. Public pressure and litigation is such that the Federal Energy Regulatory Commission (FERC) is not likely to license projects within 22 river basins until the cumulative impact issue is resolved. In these basins, more than 150 small hydropower projects have pending license applications and many more have license exemptions and preliminary permits.

Furthermore, the cumulative impact issue is likely to be raised in other river basins in the near future (e.g., the upper Mississippi River basin and the Northeast). The FERC has proposed a cluster impact assessment procedure to evaluate the impacts of multiple hydropower projects on a river basin level (U.S. Fed. Energy Reg. Comm. 1985). This procedure is intended to provide the Commission with sufficient information for deciding which projects within a basin can be licensed with minimal risks of significant cumulative impacts.

The cluster impact assessment procedure consists of a four-stage process: (1) geographic scoping, (2) resource scoping, (3) multiple project assessment, and (4) National Environmental Policy Act (NEPA) documentation. The first two steps are intended to define the resource system to be studied (hydropower projects plus nonpower resources that would be affected by hydropower development). The final step would be to issue some type of NEPA document, such as an environmental impact statement or an environmental assessment, to report the findings. All four stages are designed to solicit and incorporate input from the public and resource management agencies.

The cluster proposal is a first step toward the comprehensive river basin planning that the Federal Power Act requires of FERC. Cumulative impacts have rarely been addressed by Federal agencies (Reed et al. 1984), especially at a programmatic level, as FERC proposes.

As the scientific community rises to the challenge of assessing the cumulative impacts of multiple hydroelectric projects, the following appear to be the needed areas of development:

- Procedures for identifying projects that may contribute to significant cumulative impacts and projects that are independent of other hydropower development (in terms of environmental impacts);
- Guidelines and/or acquisition of data bases for multiple-project assessments;
- Procedures for quantifying the cumulative impacts of multiple projects;
- Procedures for using multiple project, multiple resource impact data in decisionmaking; and
- Technology transfer of all these to all agencies and the public involved in multiple project assessments.

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PERSPECTIVES ON SEPTIC TANKS AS NONPOINT SOURCE POLLUTION

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A septic tank and soil adsorption system, when properly designed and installed, can effectively remove contaminants from human wastes to produce better quality water than a municipal waste treatment plant providing secondary and tertiary treatment.

Although hundreds of thousands of conventional septic systems have been installed in rural and suburban locations during the past century, the systems have seldom been designed according to quantitative theory. The success or failure of the system reflects various empirically derived criteria with designs produced by observations of systems "working" in a satisfactory number of cases. When inexperienced, unknowing, or uncaring persons design septic systems, the criteria may be relaxed or altered.

The normal definition of a failed septic system is when the sewage effluent collects on the ground surface or when toilets and drains no longer evacuate the wastewater. The pollutional aspects of the subsurface hydrologic environment are often ignored while the surface pollutional problems may be exaggerated since there is little or no background data to define "natural" conditions.

CONDITIONS AFFECTING SEPTIC SYSTEM EFFECTIVENESS

Many of the problems associated with septic systems can be minimized or eliminated through common sense and some knowledge. For example, common sense warns that a soil adsorption trench placed in a zone saturated with perched water will perform poorly when water tables are high. Some knowledge is required to predict how high and for how long the perched water table will occur. When known, a simple design modification (such as shallow placement of the soil trench and site landscaping) might be sufficient to overcome problems.

In reviewing literature on the treatment capabilities of properly functioning septic tank/soil adsorption systems, Hansel and Machmeier (1980) indicated little or no pollution of surface or subsurface waters. The study indicated reductions in biochemical oxygen demand (BOD) from 270–400 mg/L in raw waste to less than 1 mg/L at a point 30 cm (1 foot) below the drainfield trench. Total suspended soilds (TSS) were reduced from 300–400 mg/L in raw wastes to zero below the trench bottom. Fecal coliform bacteria were reduced from 10^6 to 10^8/100 ml in raw wastes to less than 1/100 ml at depths of 91 cm (3 feet) below the drainfield. Ammonium nitrogen, organic nitrogen and phosphorus were all reduced to background levels within the same distance. Nitrate nitrogen reduction was more variable—as high as 40 mg/L below some systems while others showed no increase below the trench.

The data do not necessarily indicate that conventional systems are working if effluent does not surface. Treatment of the wastes may be seriously impaired if unsaturated and aerobic conditions are not maintained around the drainfield trenches (Reneau, 1978). Oxygen is essential for maximizing biological degradation of wastes by soil organisms and deactivating anaerobic organisms from the septic tank effluent, which may include disease-causing pathogens. Problems occur when there is insufficient distance between the trench bottom and groundwater, when there is a restrictive horizon over which water can perch, or when the trench is located immediately over fractured rock where little or no treatment occurs.

Studies in high water table areas of North Carolina (Carlile et al. 1981) and in Virginia (Stewart and Reneau, 1981) show that the separation distance between the trench bottom and the seasonal high water table is the most significant factor affecting septic system performance and local groundwater quality. Hydraulic overloading of the trenches reduces the thickness of the unsaturated zone, possibly making a marginal problem into a serious one. In conventional septic systems where effluent is not uniformly distributed, 61 cm (2 foot) separations from the trench bottom to the water table provided excellent treatment of all waste components except viruses in sandy soils. Separation distances of up to 1.2 m (4 feet) may be needed in sandy soils to prevent virus mitigation to the water table. In most systems, viruses were not present in the groundwater at a 7.6 m (25 foot) horizontal distance from the trench.

Nonuniform distribution of septic tank effluent in soil adsorption trenches is a major cause of poor treatment of wastewater in conventional trench systems (Stewart and Reneau, 1981; Cogger and Carlile, 1984). A concentrated plume of pollutants moves from the drainfield toward a drainage facility in sites with high water tables. The beginning of this plume is generally where the effluent enters the soil adsorption trench.

MODIFIED AND ALTERNATIVE SYSTEMS

Any septic system that combines dosing, uniform distribution and shallow placement of effluent increases the effectiveness of the soil filtration process. Such a system maximizes the unsaturated zone, improves the environment for aerobic soil organisms and reduces the survival of enteric bacteria.

The conventional septic system can be modified in many ways. Most modifications are designed to serve one or two functions: (1) reduce the clogging potential and maintain maximum permeability of the soil trench; and (2) enhance the treatment capabilities of the soil system before the wastes enter ground or surface waters. The V-ditch system and the large-pipe, gravelless system enhance effluent distribution in the trench and thus decrease the progressive clogging phenomena common to conventional systems (Carlile and Messick, 1982; Anderson et al. 1983). These improvements reduce the chances that the trench will "relieve" itself into the nearest road ditch, degrading surface water quality.

Pressure dosing and distribution systems use pumps or siphons to enhance wastewater treatment and maintain soil permeability. They are used in soils with high water tables, impermeable layers, shallow depths, or generally slow permeability. The Low Pressure Pipe (LPP) system makes optimal use of the entire area of the drainfield, eliminating local overloading and progressive failure. It provides dosing and resting cycles to maintain aerobic soil conditions in and around the trenches (Ubler, 1980).

Numerous studies with LPP systems as an alternative to conventional gravity flow systems have shown their potential to adequately limit bacteria and phosphorus movement and optimize nitrogen losses by denitrification on site (Carlile et al. 1981; Cogger and Carlile, 1984; Stewart and Reneau, 1981; Otis, 1977). Movement of pollutant indicators is limited in contrast to that of gravity-flow systems when steeper hydraulic gradient was present (Reneau, 1978; Carlile et al. 1981). LPP systems provide enhanced treatment whether the water table is deep or shallow.

All of these conditions are conducive to good treatment of wastewater and minimum impact on surface and ground water.

Current technology in home waste systems can minimize or eliminate nonpoint pollution from many sites now considered marginal or unsuited for septic systems. For the homeowner and the public to profit from this technology, alternative home waste systems must be permitted and encouraged by State and local regulatory agencies.

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HYDROLOGIC MODIFICATION: COMPOUNDING THE IMPACT OF NONPOINT SOURCE POLLUTION

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The potential impact of impoundment upon the quality of resultant tailwaters is well documented. While reservoir-specific characteristics and behavior must be considered, thermal fluctuations, dissolved oxygen depletion, alternate substrate inundation and dewatering, and sluicing of sediments are among the stress factors to which tailwater stream segments are subjected.

Tailwater stream segments or stream segments directly impacted by tailwaters from large impoundments present complex water quality management challenges, often of immediate concern. Power generation, flood control, agricultural development, water contact recreation, and economic development receive consideration during formulation of impoundment strategies. Consideration of water quality issues has only recently begun to result in reservoir management plans integrating waste allocation and hydrological modeling with specific water quality criteria to achieve a defined level of protection.

A dilemma facing regulatory agencies, power-generating utilities, and industries and municipalities that use tailwater stream segments as points of discharge for treated wastewater includes the following:

- Consideration of designated stream use classifications
- Identification of applicable water quality criteria
- Characterization of background water quality resulting from impoundment, including seasonal dissolved oxygen and temperature behavior
- Coordination of NPDES permit limitations, standards, and criteria with minimum guaranteed daily average discharges
- Evaluation of worst-case conditions resulting from maximum daily discharge of pollutants potentially toxic to fish and aquatic life during periods of no discharge from impoundment structures.

The complexity of defining water quality management strategies for tailwater stream segments is sufficiently challenging without considering acute and cumulative impact of nonpoint source pollution from both urban and rural sources. Milligan et al. (1984) report that a metropolitan area with a population of 350,000, with mixed commercial, industrial, and residential development, may generate pollution loading in the form of urban runoff equivalent to the annual mass loading of pollutants discharged from the attendant municipal wastewater treatment facility. While National Pollution Discharge Elimination System (NPDES) permits for industrial and municipal dischargers to tailwater stream segments are based on daily average minimum flows, slugs of pollutants from urban nonpoint source runoff may, under worst-case conditions, occur during periods of no discharge from the upstream impoundment and daily maximum discharge from NPDES sources.

With few exceptions, water quality management strategies for tailwater segments fail to consider the effect of the injection of significant urban runoff. Indeed, sufficient site-specific data to quantify pollutants from urban runoff is seldom available. In water-quality-limited stream segments requiring best available technology for NPDES discharges, the suddent influx of nonpoint source pollution may instantaneously violate water quality criteria for bacteria, metals, and temperature. Where applicable, water quality regulatory agencies responsible for the NPDES permit system must consider the influence of urban nonpoint source pollution as a major factor in management strategies for stream segments influenced by tailwater releases.

While the acute impact of agriculturally related nonpoint source pollutants upon unimpounded stream segments is somewhat ameliorated by attendant increase in flow and resultant distribution contaminants, tailwater stream segments, particularly those subjected to extended periods of no or little release, are unable to benefit from the assimilative capacity mechanisms available to free-flowing streams. A worst-case condition of extended no release from a major impoundment combined with short-duration, high-intensity storm events followed by a period of clear, warm weather may result in spectacular algae activity with attendant pH and dissolved oxygen alterations detrimental to fish and aquatic life. Optimum conditions for using the nonpoint source nutrients, such as occur in tailwater stream segments, may influence the establishment and success of rooted macrophyte communities and associated epiphytic algae. The potential for significant taste and odor problems for downstream domestic water supply intakes should be considered by water quality management agencies.

As understanding of the behavior and impact of nonpoint source pollution develops, agencies responsible for reservoir management programs and those responsible for water quality management, particularly the NPDES program, must integrate management strategies to account for this significant source of pollutants. Stream segments influenced by tailwater releases should receive priority during evaluation of regional nonpoint source pollution.

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