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## ANALYSIS OF ENVIRONMENTAL ISSUES RELATED TO SMALL-SCALE HYDROELECTRIC DEVELOPMENT. VI. DISSOLVED OXYGEN CONCENTRATIONS BELOW OPERATING DAMS

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ENVIRONMENTAL SCIENCES DIVISION  
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ENVIRONMENTAL SCIENCES DIVISION  
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## ABSTRACT

CADA, G. F., K. D. KUMAR, J. A. SOLOMON, and S. G. HILDEBRAND.  
1981. Analysis of environmental issues related to small-scale hydroelectric development. VI. Dissolved oxygen concentrations below operating dams.

This report presents the results of an effort aimed at determining whether or not water quality degradation, as exemplified by dissolved oxygen concentrations, is a potentially significant issue affecting small-scale hydropower development in the United States. The approach was to pair operating hydroelectric sites of all sizes (listed in the U.S. Army Corps of Engineers National Hydropower Study data base) with dissolved oxygen measurements from nearby downstream U.S. Geological Survey water quality stations (acquired from the WATSTORE data base). The USGS data were used to calculate probabilities of non-compliance (PNCs), i.e., the probabilities that dissolved oxygen concentrations in the discharge waters of operating hydroelectric dams will drop below 5 mg/L.

PNCs were estimated for each site, season (summer vs remaining months), and capacity category ( $\leq 30$  MW vs  $> 30$  MW). Because of the low numbers of usable sites in many states, much of the subsequent analysis was conducted on a regional basis. During the "winter" months (November through June) all regions had low mean PNCs regardless of capacity. Most regions had higher mean PNCs in summer than in winter, and summer PNCs were greater for large-scale than for small-scale sites. Among regions, the highest mean summer PNCs were found in the Great Basin, the Southeast, and the Ohio Valley.

To obtain a more comprehensive picture of the effects of season and capacity on potential dissolved oxygen problems, cumulative probability distributions of PNC were developed for selected regions. Our analysis indicates that low dissolved oxygen concentrations in the tailwaters below operating hydroelectric projects are a problem largely confined to large-scale facilities.

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## 1. INTRODUCTION

In 1977 the U.S. Department of Energy (DOE) initiated a program to stimulate the redevelopment of existing dams for hydroelectric generation. The DOE Small-Scale Hydroelectric Development Program is directed toward dam and impoundment systems that have a potential capacity of 30 MW or less. Through both technical support and financial assistance, the DOE goal is to stimulate development by the public and private sector of 1000 MW of capacity by 1985. The DOE Small-Scale Hydroelectric Program includes an Environmental Subprogram for identifying and analyzing potential environmental issues related to small-scale hydroelectric (SSH) development. This report addresses potential concerns related to alteration in water quality below small-scale hydroelectric facilities.

Water quality problems in the discharges from hydroelectric reservoirs can occur as a result of seasonal warming and the consequent thermal stratification of impounded waters. 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). Although the phenomenon is common in temperate regions, not all lakes and reservoirs stratify. The occurrence and extent of thermal stratification is influenced by a number of factors, including size, depth, surface area, morphometry, fetch, basin orientation in relation to prevailing winds, depth volume relationships, protection by surrounding topography and vegetation, and flushing rate. Extensive discussions of thermal stratification and

modifying factors can be found in Hutchinson (1957) and Wetzel (1975). In general, reservoirs most likely to stratify are deep, have a low surface area/volume ratio and flushing rate, and are protected from mixing by their orientation to wind and the surrounding topography.

One of the potential consequences of thermal stratification is a progressively declining dissolved oxygen concentration in the hypolimnion. Plant and animal respiration, bacterial decomposition of organic matter, and chemical oxidation all remove dissolved oxygen from hypolimnetic waters. This decrease in dissolved oxygen is not generally offset by the renewal mechanisms of atmospheric diffusion, circulation, and photosynthesis that operate in the epilimnion (Wetzel 1975). In temperate regions, the decline in hypolimnetic dissolved oxygen concentrations begins at the onset of stratification (summer) and continues until either anaerobic conditions predominate or reoxygenation occurs during the fall overturn.

The chemically reducing conditions brought about by an absence of dissolved oxygen may have an effect on other water quality parameters. For example, decomposition of sulfur and nitrogen compounds in the absence of dissolved oxygen may result in the buildup of toxic hydrogen sulfide and ammonia, respectively (Smalley and Novak 1978). Reducing conditions will also increase the solubility of iron, manganese, and some heavy metals (U.S. EPA 1976), and these materials may consequently be leached from the reservoir sediments or suspended particulate matter.

Hypolimnetic discharges from hydroelectric facilities that have low dissolved oxygen concentrations and elevated levels of iron, manganese, heavy metals, ammonia, and sulfides may have adverse effects

on downstream biota and alternate water users. Adequate dissolved oxygen levels in the discharge are necessary not only for aesthetic qualities of the water (taste, odor) but also to support a balanced community of aquatic organisms, to maintain the waste assimilative capacity of tailwaters, and to increase the disinfection efficiency of chlorination (U.S. EPA 1976). Hydrogen sulfide creates odor problems and may cause downstream fishkills (Smalley and Novak 1978). High levels of dissolved iron and manganese increase the cost of domestic water treatment, since they impart objectionable tastes to beverages and can stain laundered clothes and plumbing fixtures (U.S. EPA 1976).

Downstream water quality problems resulting from the discharge of deoxygenated hypolimnetic water from a hydroelectric dam could constitute a serious obstacle to the development of hydropower resources. While mitigative techniques are available or under development to control water quality in reservoir discharges (Legg 1979, Schohl et al. 1979, Vigander and Ruane 1979, Brye et al. 1979), the cost of structural measures, if necessary, may be excessive for small, marginally economical hydroelectric facilities.

The purpose of this report is to assess the potential for water quality problems at small-scale hydroelectric projects ( $\leq 30$  MW). Our analysis focuses on a single, representative water quality parameter, dissolved oxygen, and relates its concentrations in the tailwaters of operating hydroelectric plants to various physical characteristics of dam/impoundment systems.

The report is the sixth in a series of reports analyzing environmental issues related to small-scale hydroelectric development.

Other reports in the series address the topics of dredging (Loar et al. 1980), upstream fish passage (Hildebrand 1980a), water level fluctuation (Hildebrand 1980b), turbine-related fish mortality (Turbak et al. 1981), instream flow (Loar and Sale, in press), and mitigation of downstream fish passage problems (Loar et al., in preparation). All of the above reports, prepared by Oak Ridge National Laboratory, are or will be available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

## 2. METHODS

### Selection of Water Quality Criteria

In its development of water quality criteria, the U.S. Environmental Protection Agency attempted to "specify concentrations of water quality constituents which, if not exceeded, are expected to result in an aquatic ecosystem suitable for the higher uses of water" (U.S. EPA 1976). The EPA stresses that water quality criteria are not standards (i.e., not legal entities) and thus do not have direct regulatory use; however, they do form the basis for judgment in several EPA and state programs that are involved with water quality considerations. The U.S. EPA (1976) further states that "to violate quality criteria for any substantial length of time or in any substantial portion of a waterway may result in an adverse effect on aquatic life and perhaps a hazard to man or other consumers of aquatic life."

The U.S. EPA (1976) determined that a dissolved oxygen concentration of no less than 5.0 mg/L was necessary for maintaining good aesthetic quality of the water, avoiding anaerobic conditions (and attendant problems with dissolved iron, manganese, hydrogen sulfide, and methane), and supporting a "well-rounded population" of fish. It was recognized that fish vary in their oxygen requirements and can survive temporarily at dissolved oxygen concentrations considerably below that considered suitable for a thriving population. However, it is also believed that even dissolved oxygen concentrations as high as 5 or 6 mg/L are low enough to cause partial mortality or retard

development of sensitive fish embryonic and larval stages (U.S. EPA 1976).

In view of these considerations, we utilized the EPA criterion of a minimum dissolved oxygen concentration of 5.0 mg/L as a basis for the following analysis of potential water quality problems at small-scale hydroelectric facilities.

#### Description of Data Bases

Dissolved oxygen data used in our analyses were acquired from the National Water Data Storage and Retrieval System (WATSTORE), maintained by the Chief Hydrologist, U.S. Geological Survey, National Center, MS 409, Reston, Virginia 22092. This data base contains historical water quality data at approximately 270,000 stations throughout the United States. Further information on the contents and use of WATSTORE is available from U.S. Geological Survey (1975a). WATSTORE data tapes were obtained from the USGS, and a Water Quality Data Base (WQDB) system was developed at ORNL which allowed rapid retrieval of data through a time-sharing system (Kumar, in preparation).

Information on operating hydroelectric dams in the United States was obtained from the U.S. Army Corps of Engineers National Hydropower Study (NHS) data base. The NHS data base contains descriptive data on approximately 15,300 existing dams and potential dam sites, including project name, name of river, latitude and longitude information, height of dam, and electrical capacity. A listing of the individual dams and information available for each can be found in U.S. Army Corps of Engineers (1979).

### Station - Dam Selection

Selection of operating hydroelectric dams that were used in the analysis was based on the existence of appropriate water quality data for that dam in the USGS data base. A water quality station was considered appropriate if it (1) was downstream from the dam, (2) was within 4.8 km (3 miles) of the dam, and (3) had more than two measurements of dissolved oxygen.

First, all USGS stations within a radius of 16.1 km (10 miles) were identified by a computer program which calculated (from latitude-longitude information) the linear distance between the dam and each station in nearby counties. From these potential stations, only those located on the same stream as the dam and having more than one dissolved oxygen measurement were considered.

Determination of the exact location of the station relative to the dam was done manually by first checking the brief description of the site in the USGS data base [e.g., Tennessee River at Ft. Loudon Dam, Tennessee]. If this was not sufficient, reference was made to the USGS Water-Data Reports (U.S. Geological Survey 1977-1979) for each state, where more complete descriptions of many of the sites were found (e.g., 2.4 km (1.5 miles) downstream from Thurlow Dam at Tallahassee at mile 48.1). If this, too, was inconclusive, various maps (U.S. Dept. of Energy 1981; Geological Survey 1972, 1975b) were used to establish the course of the river in the vicinity of the dam. Using latitude-longitude information, the location of the station relative to the dam could be determined (e.g., whether the station was northwest or

southeast of the dam). Comparison of this relationship with the course of the river then identified the station as being either upstream or downstream from the dam. If it was still impossible, with these sources, to determine whether the station was downstream from the dam, the station-dam combination was not used. The list of operating hydroelectric dams which satisfied these dam/water quality station pairing criteria (and therefore were used in the subsequent analyses) is provided in Appendix Tables A-1 and A-2.

### Probability Estimation

A probability of non-compliance (PNC) was chosen as the statistic of interest in this study because it directly addresses the question, "what are the chances that discharges below a hydroelectric dam will violate dissolved oxygen criteria"? PNC is defined as the probability that concentrations of dissolved oxygen will be less than some specified value, in this case 5 mg/L. Otherwise stated,

$$\text{PNC} = \text{Prob} \{ [\text{DO}] \leq C \} , \quad (1)$$

where  $[\text{DO}]$  = dissolved oxygen concentration (mg/L), and  $C$  = critical dissolved oxygen concentration value of 5 mg/L.

Assuming that one has  $n$  dissolved oxygen concentration measurements  $(x_1, x_2, x_3, \dots, x_n)$  from a given site and that  $x_i$  has a normal distribution with mean  $\mu$  and variance  $\sigma^2$ , then PNC can be obtained from the cumulative distribution function of the normal distribution. However, because the mean and variance are

estimated from the data, the estimator must be adjusted for the variability of the mean and variance. A minimum-variance, unbiased estimator of PNC can be calculated based on a technique in Johnson and Kotz (1970a):

$$\hat{\text{PNC}} = \begin{cases} B[\frac{1}{2}, \frac{1}{2}n-1]^{-1} \int_{-1}^{(C-\bar{x})/s\sqrt{n-1}} (1-v^2)^{\frac{1}{2}(n-4)} dv & \text{for } |C-\bar{x}| \leq s\sqrt{n-1} \\ 0 & \text{for } C < \bar{x} - s\sqrt{n-1} \\ 1 & \text{for } C > \bar{x} + s\sqrt{n-1} \end{cases}, \quad (2)$$

where

$\hat{\text{PNC}}$  = estimate of PNC,

$\bar{x}$  = sample mean =  $\frac{1}{n} \sum x_i$ ,

$s$  = sample standard deviation =  $\sqrt{\frac{1}{n-1} \sum (x_i - \bar{x})^2}$ ,

$n$  = number of samples, and

$B(p, q)$  = beta function with parameters  $p$  and  $q$ .

The integral can be readily computed using the incomplete beta function.

Owen (1968) discusses methods for estimating the confidence limits on one-sided percentiles like PNC. For example, the lower limit can be written as:

$$\text{Prob} \{ (\text{non-central } t \text{ with } \delta = K_p \sqrt{n}) \leq k \sqrt{n} \} = \gamma \quad , \quad (3)$$

where  $\delta$  = non-centrality parameter of the non-central Student's t distribution,

$$k = \frac{C - \bar{x}}{s} \quad ,$$

$\gamma$  = confidence level, and

$$P = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{kp} \exp\left(\frac{-x^2}{2}\right) dx \quad , \quad (3a)$$

i.e., at least proportion  $P$  of the population is less than  $C$ .

The value of  $K_p$  is obtained by solving equation (3). Since (3) is a monotonic function of  $K_p$ ,  $K_p$  can be obtained using root-finding techniques. The secant method (Conte and de Boor 1972) was used to solve for  $K_p$ . The value of  $P$  is obtained by substituting the estimated value of  $K_p$  in equation (3a). The upper confidence limit was obtained in an analogous manner. The non-central t-distribution was estimated using routines in the IMSL (1975) subroutine package. A special link between the Statistical Analysis System (SAS 1979) and the IMSL routine was developed to facilitate computations of the confidence limits. It should be observed that the confidence limits are independent of the estimate of PNC given by equation (2).

The Small Hydropower Development Program of the U.S. Department of Energy defined small-scale hydroelectric facilities as those facilities with maximum generation capacities of 30 MW. As a result, dams used in this analysis were characterized as either small-scale ( $\leq 30$  MW) or large-scale ( $> 30$  MW). Also, because thermal stratification and resultant oxygen depletion are seasonal phenomena (see Section 1), two probabilities were calculated for each site; one for the summer months (July, August, September, and October) and another for the remaining (winter) months.

### 3. RESULTS

The hydroelectric projects which were used in this analysis are listed in Appendix Tables A-1 and A-2, with descriptive information for each site. Although a large number of dams were included in the NHS data base, surprisingly few could be identified with USGS water quality stations sufficiently close or with enough dissolved oxygen measurements to be useful. A total of 65 small-scale hydroelectric sites were selected, of which four did not have both summer and winter dissolved oxygen data. In addition, 74 large-scale hydroelectric dams were paired with nearby water quality stations. However, three of these stations did not have both summer and winter dissolved oxygen measurements.

The state with the largest number of usable small-scale hydroelectric sites was South Carolina (9), whereas Tennessee and Washington had the largest numbers of large-scale sites, 17 and 13 respectively. Most states had less than 10 suitable sites and many had only one. Fifteen states (Alaska, Delaware, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Mississippi, Nevada, Ohio, Rhode Island, South Dakota, Virginia, West Virginia) had no operating dam/water quality station pairs that satisfied the three criteria employed in this study (Section 2).

Much of the subsequent analysis was based on a regional approach, rather than a state-by-state comparison, for two primary reasons: (1) the small number of usable sites per state in most cases preclude

the identification of meaningful patterns for individual states, and (2) geographic and climatic differences across the country result in different reservoir basin morphometries, seasonal inflows, and water temperatures, all of which can influence the extent and duration of thermal stratification. Consequently, the 48 conterminous states were combined into eight regions based on geographic and climatic similarities.

The states comprising each of these regions are listed in Table 1. The greatest number of suitable small-scale hydro/water quality station pairs were in the Southeast (18), Northeast (16), Rocky Mountains (9), and Pacific Coast (7). Large-scale hydro sites with nearby downstream USGS stations were most common in the Southeast (18), Ohio Valley (18), and Pacific Coast (19).

Appendix Tables B-1, B-2, B-3, and B-4 provide dissolved oxygen information for each of the hydroelectric sites used in our study, categorized by both capacity ( $\leq 30$  MW vs  $> 30$  MW) and season (summer vs winter). Most sites had more than ten dissolved oxygen measurements, although a small number of sites did have as few as three or four measurements. In addition to mean dissolved oxygen values, the tables list, for each site, the actual proportion of dissolved oxygen measurements in the data base which was below 5 mg/L (observed proportion of non-compliance), the probability of non-compliance (PNC) computed from the formula given in Section 2, and the upper and lower 95% confidence limits on the PNC.

Table 1. States comprising each of the eight regions used in the water quality analysis, excluding Alaska and Hawaii

---

Region	States
Southeast	Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina
Ohio Valley	Delaware, Illinois, Indiana, Kentucky, Maryland, Missouri, Ohio, Tennessee, Virginia, West Virginia
Northeast	Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont
Great Plains	Iowa, Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, Texas
Lake States	Michigan, Minnesota, Wisconsin
Great Basin	Arizona, Nevada, New Mexico, Utah
Rocky Mountains	Colorado, Idaho, Montana, Wyoming
Pacific Coast	California, Oregon, Washington

---

### State-by-State Comparisons

Figures 1 through 4 display the mean PNCs for each state, capacity category, and season. Although the scales are not identical among the four figures, i.e., the same PNC value will result in different sized peaks in different figures, these displays are useful for comparing PNCs among states within a given figure. For small-scale hydroelectric sites in the summer (Fig. 1), the highest peaks (highest mean PNCs) occur in a band along the Atlantic Coast, the Southeast, and the Southwest. Low mean PNCs ( $<0.1$ ) were found in states in the Great Plains (only one site), the Rocky Mountains, and along the Great Lakes and the Pacific Coast. Similar regional patterns are evident for large-scale sites in the summer (Fig. 2), although the mean PNCs are generally greater than those for small-scale sites in the same states. An exception to this trend occurs in the Great Basin states, in which the probability of dissolved oxygen levels in the discharge waters dropping below 5 mg/L appears to be greater for small-scale than for large-scale sites. The high mean PNC for small-scale facilities in this region is due to large individual PNCs at two sites. The NHS data base contains little information on one of the sites (Lower Beaver No. 2 in Utah), but Elephant Butte Reservoir in New Mexico, with a PNC of 0.565, has a relatively large dam height and storage capacity and a relatively low mean annual inflow for a small-scale hydro site (Appendix Tables A-1 and A-2). These are conditions that would lead to long reservoir turnover times and tend to favor thermal stratification and subsequent oxygen depletion.

ORNL-DWG 81-13852 ESD

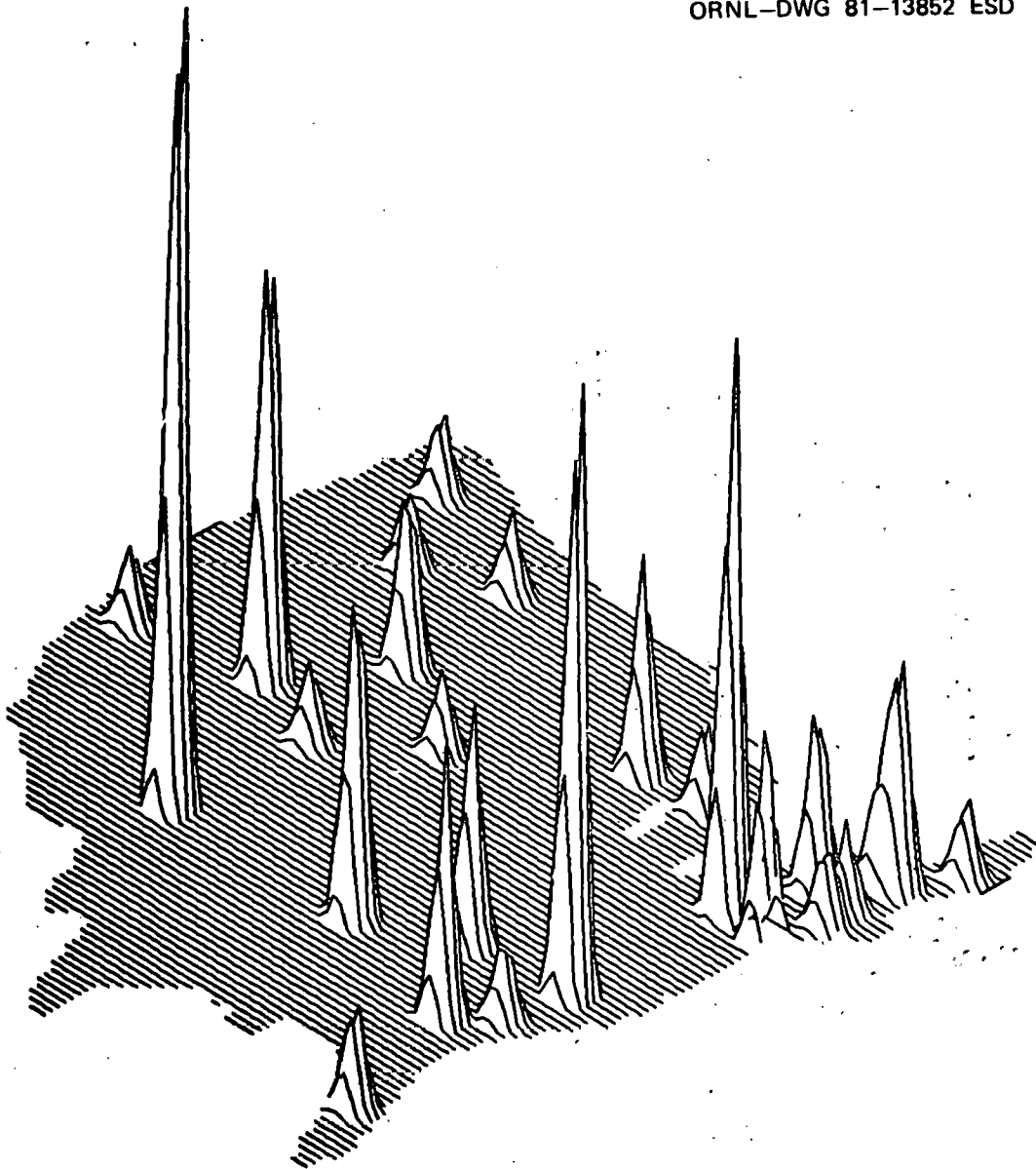


Fig. 1. Mean probabilities of non-compliance (PNCs) for small-scale ( $\leq 30$  MW) hydroelectric sites in selected states, summer months. Higher spikes represent higher mean PNCs (averaged by states).

ORNL-DWG 81-13850 ESD

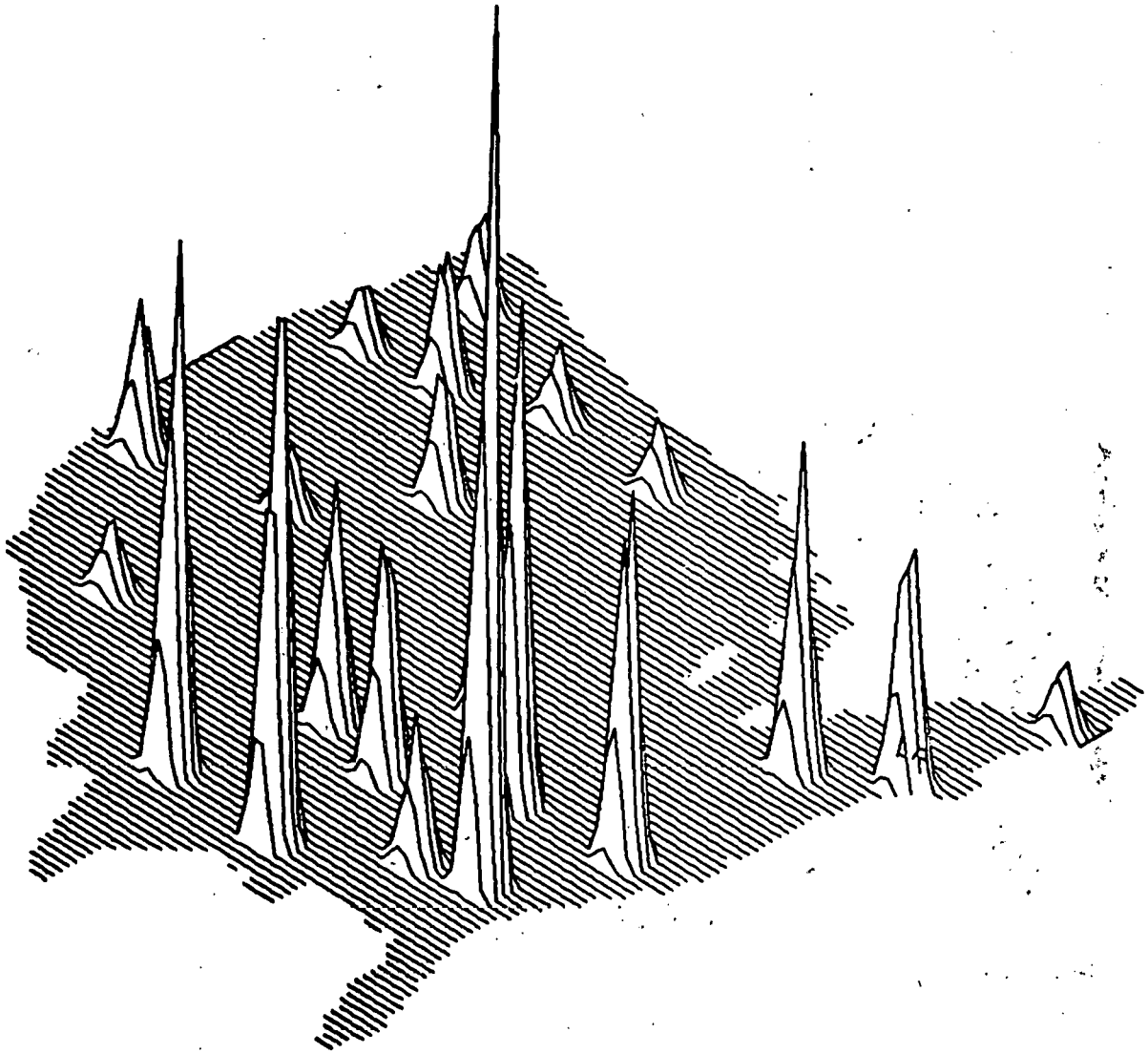


Fig. 2. Mean probabilities of non-compliance (PNCs) for large-scale (> 30 MW) hydroelectric sites in selected states, summer months. Higher spikes represent higher mean PNCs (averaged by states).

ORNL-DWG 81-13851 ESD

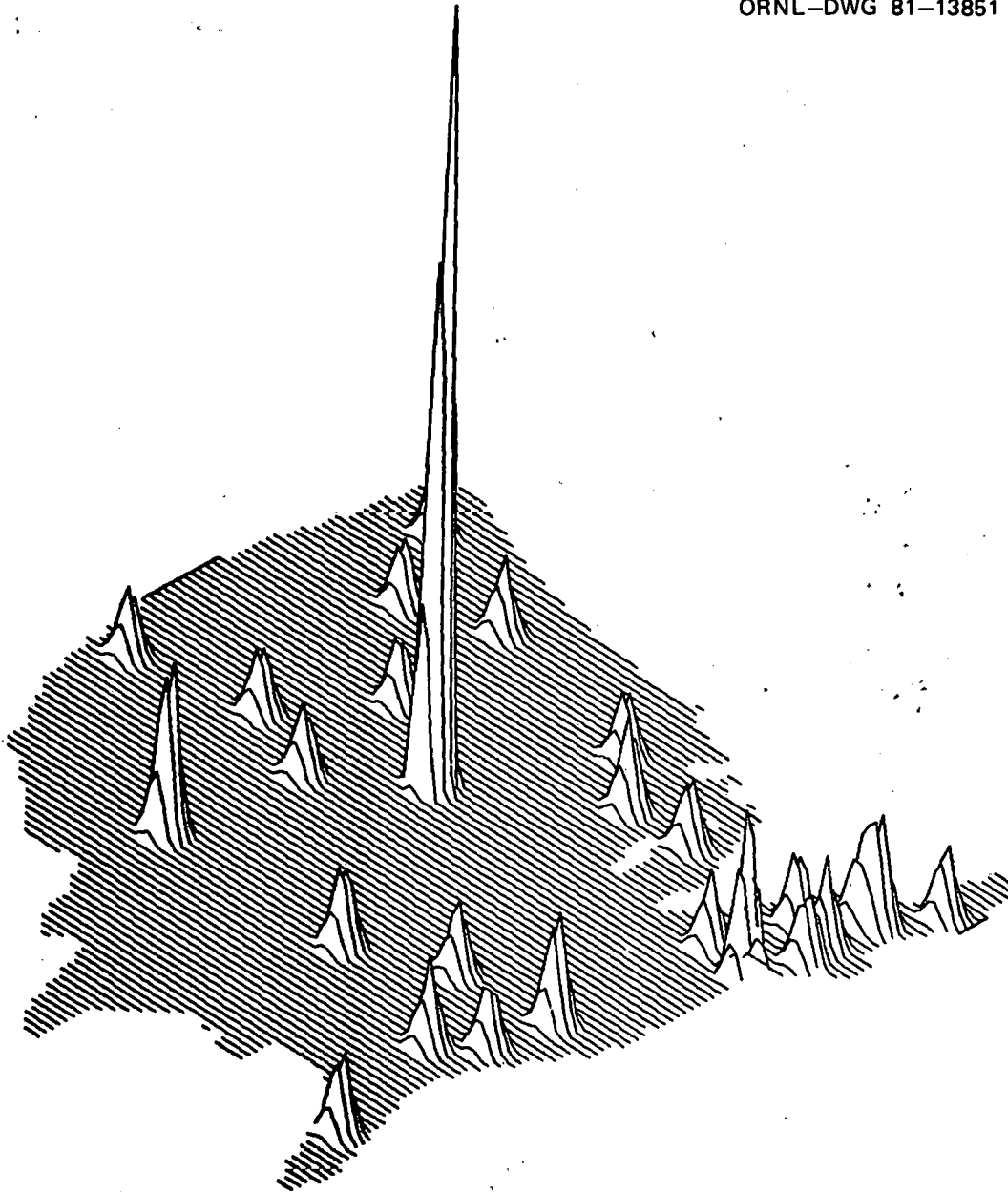


Fig. 3. Mean probabilities of non-compliance (PNCs) for small-scale ( $\leq 30$  MW) hydroelectric sites in selected states, winter months. Higher spikes represent higher mean PNCs (averaged by states).

ORNL-DWG 81-13853 ESD

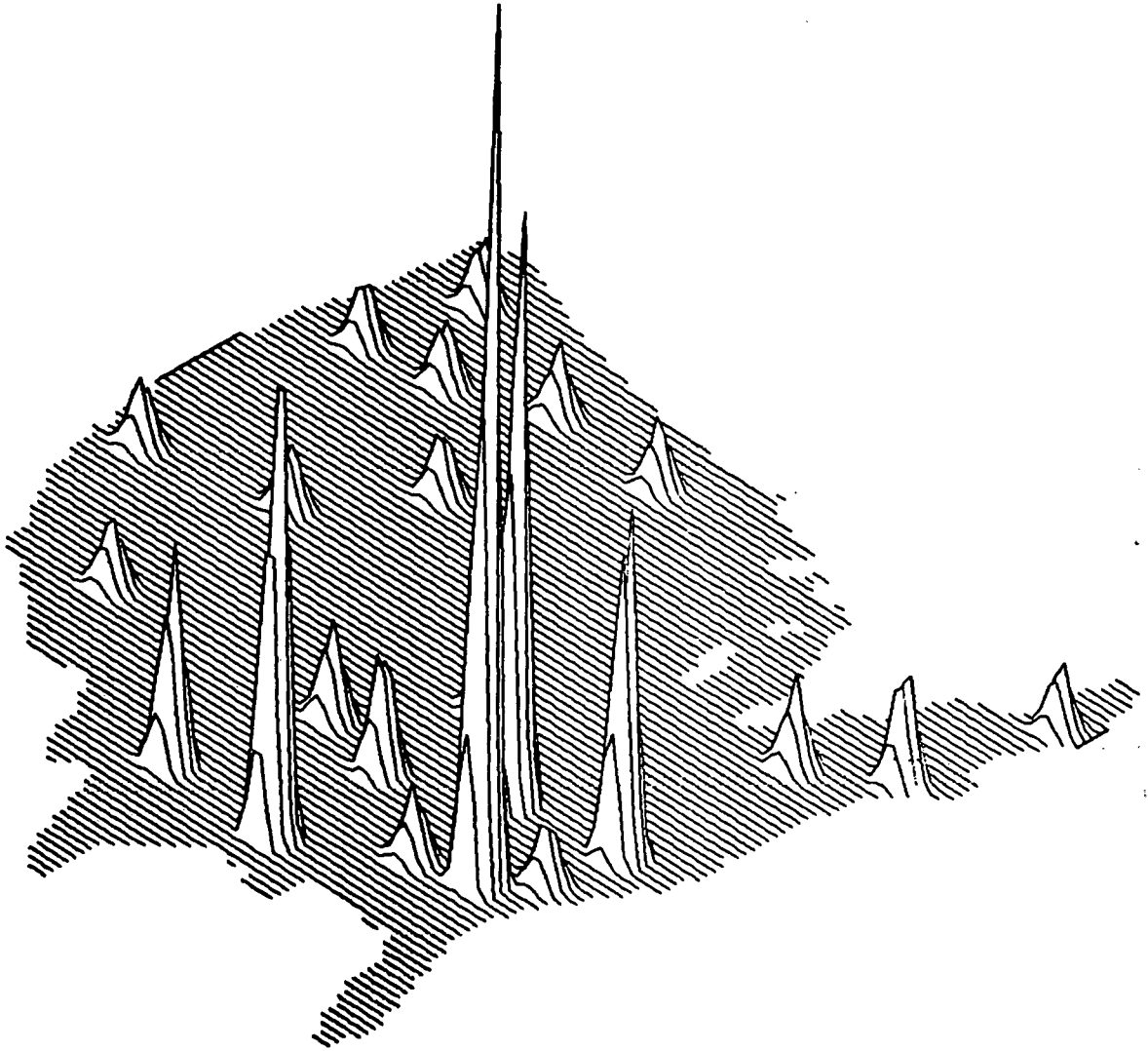


Fig. 4. Mean probabilities of non-compliance (PNCs) for large-scale (>30 MW) hydroelectric sites in selected states, winter months. Higher spikes represent higher mean PNCs (averaged by states).

### Regional Comparisons

The patterns shown in the mean PNCs for individual states also support the need for a regional approach to the summarization of tailwater dissolved oxygen data. Table 2 provides mean PNCs for each of the eight regions in the conterminous United States, as well as median, minimum, and maximum values. Figures 5 through 8 are graphical representations of the regional mean PNC values (as given in Table 2), for each season and capacity category.

During the winter months, all regions have low mean PNCs, i.e., generally less than 0.05, regardless of capacity (Figs. 7 and 8). Small-scale hydroelectric sites in the Great Plains (Fig. 7) appear to be an exception to this rule, although this observation may simply reflect the limited data available for the region. This mean value is based on only two sites, one of which had a PNC of zero (Appendix Table B-2). The other site had a PNC of 1.0 (all dissolved oxygen readings were below 5 mg/L) based on four measurements. In our opinion, it would not be meaningful to ascribe wintertime water quality problems to the entire Great Plains region based on such limited data.

With the exception of small-scale sites in the Great Plains, all regions had higher mean PNCs in the summer than in the winter (Table 2). Highest mean summer PNCs for small-scale sites were found in the Great Basin states, an observation which might be attributed to high water temperatures and low inflows (turnover times) in reservoirs in this region. The Southeast and Ohio Valley also have relatively higher mean summer PNCs (Fig. 5). It should be noted, however, that in both of these regions the median value is lower than the mean

Table 2. Regional mean probabilities of non-compliance (PNCs) estimated for each capacity category and season

Region	Number of dams used	Mean PNC	Standard deviation	Median PNC	Minimum PNC	Maximum PNC
Dams with capacity $\leq 30$ MW, summer season						
Great Basin	3	0.373	0.321	0.550	0.002	0.565
Great Plains	1	0.000	.	0.000	0.000	0.000
Hawaii	1	0.000	.	0.000	0.000	0.000
Lake States	5	0.043	0.081	0.000	0.000	0.187
Northeast	15	0.066	0.104	0.004	0.000	0.323
Ohio Valley	3	0.111	0.191	0.000	0.000	0.332
Pacific Coast	7	0.003	0.006	0.000	0.000	0.016
Rocky Mountain	9	0.027	0.077	0.000	0.000	0.233
Southeast	17	0.131	0.261	0.022	0.000	1.000
Dams with capacity $> 30$ MW, summer season						
Great Basin	3	0.004	0.003	0.005	0.000	0.006
Great Plains	6	0.182	0.178	0.168	0.000	0.435
Northeast	3	0.144	0.125	0.204	0.001	0.228
Ohio Valley	16	0.404	0.370	0.327	0.000	0.998
Pacific Coast	19	0.039	0.117	0.000	0.000	0.409
Rocky Mountain	6	0.052	0.096	0.000	0.000	0.238
Southeast	18	0.308	0.278	0.246	0.000	0.926

Table 2. (continued)

Region	Number of dams used	Mean PNC	Standard deviation	Median PNC	Minimum PNC	Maximum PNC
Dam with capacity $\leq 30$ MW, winter season						
Great Basin	3	0.027	0.047	0.000	0.000	0.082
Great Plains	2	0.500	0.707	0.500	0.000	1.000
Hawaii	1	0.000	.	0.000	0.000	0.000
Lake States	6	0.005	0.012	0.000	0.000	0.030
Northeast	16	0.010	0.019	0.001	0.000	0.071
Ohio Valley	3	0.001	0.001	0.000	0.000	0.002
Pacific Coast	6	0.000	0.000	0.000	0.000	0.000
Rocky Mountain	9	0.000	0.001	0.000	0.000	0.004
Southeast	18	0.010	0.018	0.003	0.000	0.066
Dams with capacity $> 30$ MW, winter season						
Great Basin	3	0.000	0.000	0.000	0.000	0.000
Great Plains	6	0.003	0.012	0.002	0.000	0.028
Northeast	3	0.005	0.006	0.003	0.000	0.011
Ohio Valley	18	0.095	0.127	0.029	0.000	0.344
Pacific Coast	19	0.000	0.000	0.000	0.000	0.001
Rocky Mountain	6	0.000	0.000	0.000	0.000	0.000
Southeast	18	0.039	0.065	0.011	0.000	0.209

ORNL-DWG 81-13773 ESD

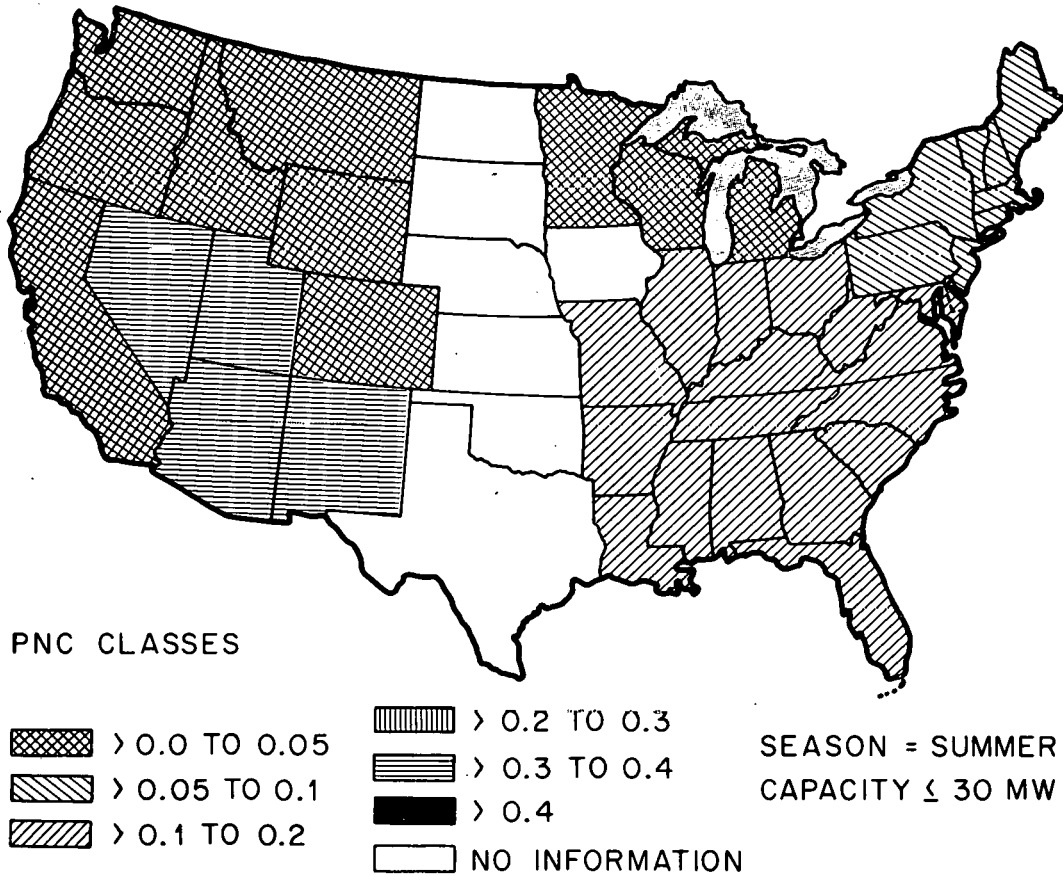


Fig. 5. Regional mean probabilities of non-compliance (PNCs) for small-scale hydroelectric sites, summer months.

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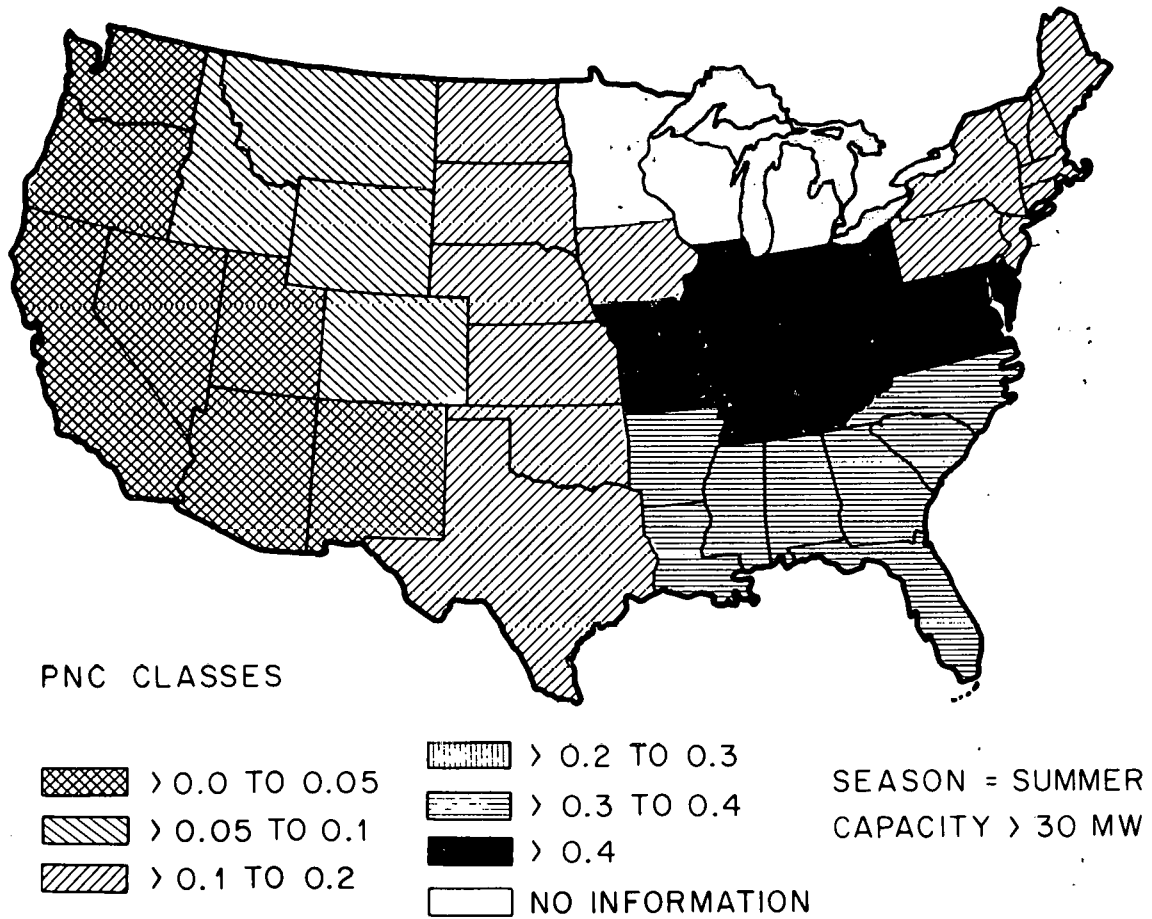
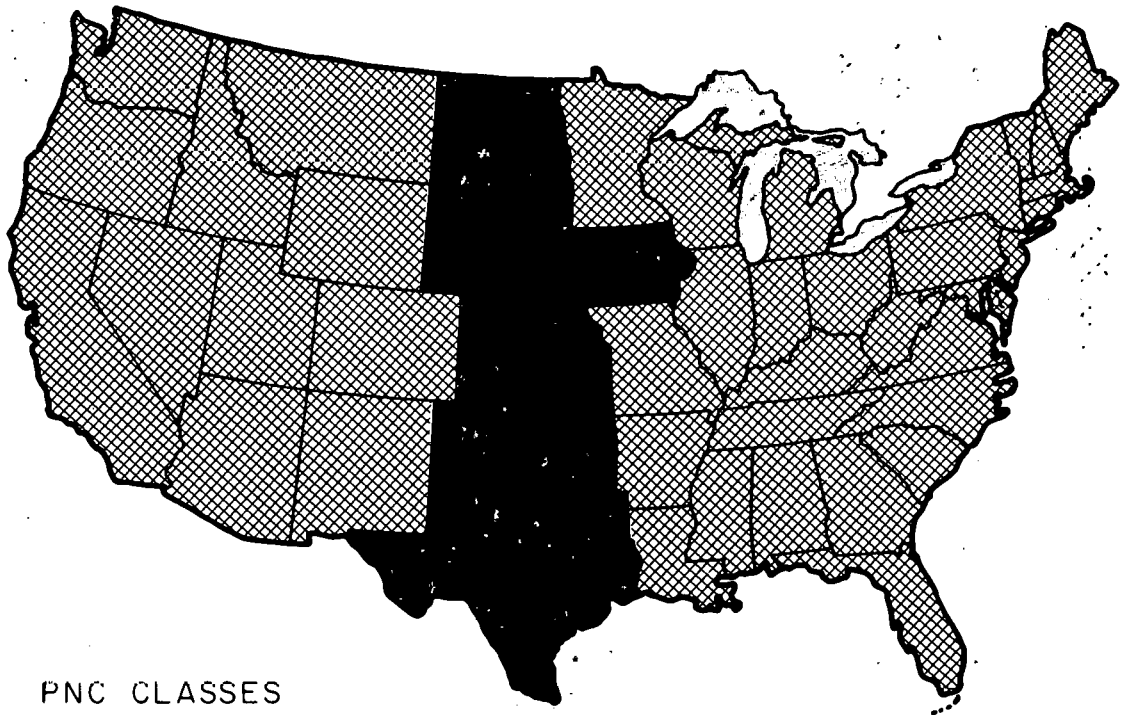


Fig. 6. Regional mean probabilities of non-compliance (PNCs) for large-scale hydroelectric sites, summer months.

ORNL-DWG 81-13775 ESD



PNC CLASSES

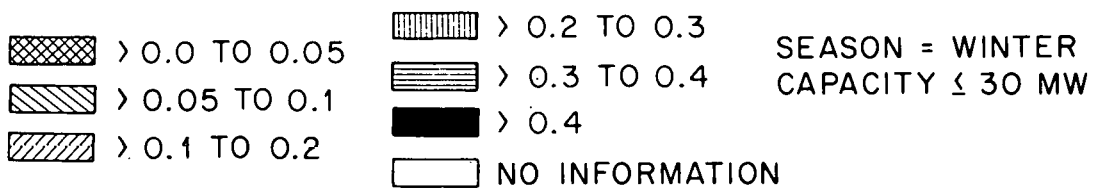


Fig. 7. Regional mean probabilities of non-compliance (PNCs) for small-scale hydroelectric sites, winter months.

ORNL - DWG 81 - 13776 ESD

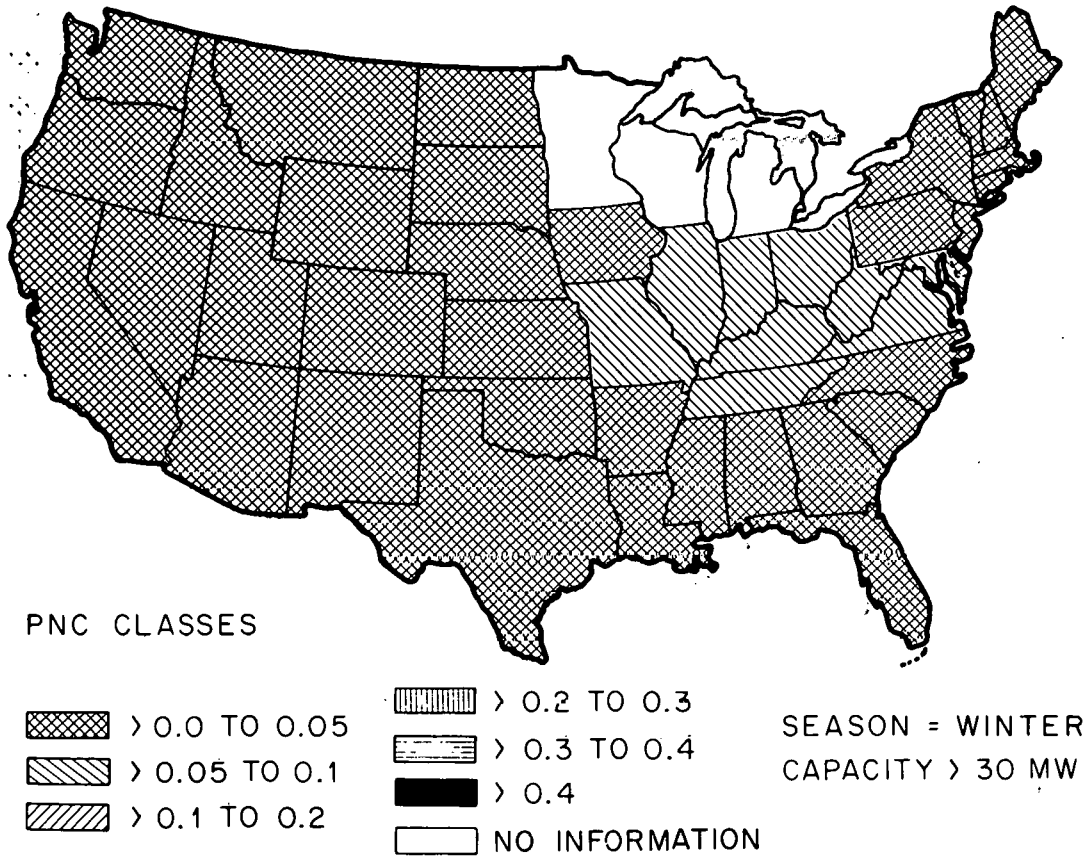


Fig. 8. Regional mean probabilities of non-compliance (PNCs) for large-scale hydroelectric sites, winter months.

(Table 2), indicating skewed data (i.e., a relatively small number of sites with large PNCs can unduly influence the regional mean PNC). Median PNC values for small-scale hydro sites outside of the Great Basin were always below 0.05 (Table 2).

Within most regions, mean summer PNCs were greater for large-scale than for small-scale sites. Also not surprisingly, large-scale sites had higher regional PNCs in the summer than in the winter. The highest summer PNCs for large-scale hydroelectric facilities were found in the Ohio Valley, Southeast, Great Plains, and Northeast regions (Table 2; Fig. 6).

#### Effects of Distance Below Dam on PNC

To judge the appropriateness of our 4.8-km (3-mile) criterion, regional mean PNCs were calculated from dissolved oxygen data collected within various maximum distances (3.2, 4.8, and 8.0 km) downstream of the dam. It was hypothesized that if reaeration of the tailwaters occurred rapidly, dissolved oxygen measurements taken as far as 4.8 km away from the dam might not be representative of conditions at the discharge. On the other hand, the number of USGS water quality stations decreased with decreasing distance from the dam, thereby further limiting the data base. With small-scale projects, for example, the number of usable sites decreased from 74 to 61 to 50 at maximum distances of 8.0, 4.8, and 3.2 km respectively. The results of these comparisons for summer data are shown in Table 3. From these results, it was apparent that in the summer the regional mean PNCs changed very little as the maximum distance for dissolved oxygen

Table 3. Regional mean probabilities of non-compliance (PNCs) estimated from summer dissolved oxygen data collected at various maximum distances below operating hydroelectric dams

Region	Maximum distance from dam (km)		
	3.2	4.8	8.0
$\leq 30$ MW			
Great Basin	0.284	0.373	0.373
Great Plains	0.000	0.000	0.000
Lake States	0.072	0.043	0.043
Northeast	0.044	0.066	0.074
Ohio Valley	0.111	0.111	0.120
Pacific Coast	0.004	0.003	0.002
Rocky Mountains	0.030	0.027	0.027
Southeast	0.149	0.131	0.137
$> 30$ MW			
Great Basin	0.004	0.004	0.004
Great Plains	0.178	0.182	0.182
Lake States	-	-	-
Northeast	0.144	0.144	0.157
Ohio Valley	0.404	0.404	0.404
Pacific Coast	0.047	0.039	0.036
Rocky Mountains	0.052	0.052	0.044
Southeast	0.348	0.308	0.270

measurements was increased from 3.2 to 8.0 km, suggesting that our 4.8-km criterion was representative of water quality conditions over a substantial range of distances below the dams.

#### Relationship Between PNC and Selected Dam/Reservoir Characteristics

Pearson product-moment correlation coefficients (SAS 1979) were calculated in order to examine the relationships between arcsine-transformed, individual site PNCs, and selected physical characteristics of the dam/reservoir systems (Table 4). Hydraulic dam height was the factor most frequently correlated with PNC, having a statistically significant ( $\alpha = 0.05$ ) positive correlation in the Northeast, Ohio Valley, Pacific Coast, and Southeast regions. Calculated power head is a parameter used to represent the net power head in calculating energy and capacity at a given site. It is the value of the normal net power head (if available) or it is a function of the height of the conservation pool or hydraulic height of the dam, and thus would be expected to have a relationship to PNC similar to that of the dam height. Calculated power head was positively correlated ( $\alpha = 0.05$ ) with PNC in the Northeast and the Ohio Valley. The only other reservoir characteristic we examined which showed a statistically significant correlation with PNC was maximum storage capacity in the Northeast (Table 4). None of the dam/reservoir characteristics were significantly correlated with PNC during the winter months.



Table 4. (continued)

Region	Number of sites	Dam/reservoir characteristics				
		Hydraulic dam height (m)	Existing capacity (MW)	Calculated power head (m)	Average annual inflow (m <sup>3</sup> /s)	Maximum storage (10 <sup>6</sup> m <sup>3</sup> )
		Winter				
Great Basin	6	0.140	-0.314	-0.056	-0.177	0.249
		0.791	0.544	0.916	0.737	0.634
Great Plains	8	-0.642	-0.297	-0.558	-0.339	-0.279
		0.086	0.474	0.151	0.411	0.544
Lake States	6	-0.512	-0.377	-0.507	0.613	-0.518
		0.299	0.462	0.304	0.196	0.293
Northeast	19	-0.123	-0.130	-0.096	-0.039	-0.254
		0.616	0.597	0.695	0.874	0.294
Ohio Valley	21	0.217	0.146	0.185	-0.029	0.165
		0.346	0.527	0.423	0.901	0.476
Pacific Coast	25	0.186	0.044	-0.066	-0.078	0.084
		0.374	0.834	0.754	0.710	0.691
Rocky Mountains	15	0.006	-0.153	-0.025	-0.205	0.112
		0.983	0.587	0.931	0.463	0.690
Southeast	36	0.035	0.003	0.087	-0.008	0.191
		0.839	0.987	0.614	0.963	0.263

<sup>a</sup>Value is the probability of estimating a larger correlation coefficient given that the true correlation coefficient equals zero.

### Cumulative Probability Functions of PNC

In the preceding discussion, the mean PNC was employed to discuss the differences and similarities between regions, capacity categories, and seasons. The regions are large and cover a wide range of environmental conditions. Additionally, site-specific parameters, such as height of the dam, depth of the water column in the reservoir, upstream water quality, and water-use patterns, play a role in determining the level of dissolved oxygen in the downstream water body. A more comprehensive picture emerges when the probability distribution function of PNC is considered.

The probability distribution function of PNC can be modeled by a two-parameter beta distribution function, which is defined as

$$f(x) = \frac{1}{B(p,q)} x^{p-1}(1-x)^{q-1} \text{ for } 0 < x < 1, \quad (4)$$

where  $B(p,q)$  = beta function with parameters  $p$  and  $q$ .

The parameters  $p$  and  $q$  characterize the shape of the density function, and can be estimated by equating the sample and population values of the first two moments of the distribution function and solving for  $p$  and  $q$ . The resulting equations (Johnson and Kotz 1970b) are:

$$p = \frac{(m_1)^2 (1-m_1)}{m_2} - m_1 \quad (5)$$

and

$$q = \frac{m_1 (1-m_1)}{m_2} - 1 - p, \quad (6)$$

where  $m_1$  = first moment about zero (mean), and  $m_2$  = second central moment.

Estimated distribution functions for small- and large-scale hydroelectric facilities in selected regions are shown in Figs. 9 through 11. These figures display the cumulative frequency distributions of PNC values, and can therefore be used to estimate the probability of observing a PNC greater than or equal to a particular value for a given season or capacity category. This is done by determining, from the plots, the cumulative probability value (ordinate) which is associated with the desired PNC (abscissa) and subtracting that value from unity. For example, the plots in Fig. 9 indicate that the probability of encountering a PNC  $\geq 0.1$  at large-scale dams in the summer is 0.68 ( $1.0 - 0.32$ ). On the other hand, the probability of observing that same PNC value at small-scale sites in the summer is much lower ( $1.0 - 0.74 = 0.26$ ). The probabilities of encountering PNCs  $\geq 0.1$  in the Southeast during the winter are even smaller. The same patterns are apparent for the Ohio Valley (Fig. 10) and the Northeast (Fig. 11); i.e., the probability of observing a given PNC value (or greater) is highest for large-scale sites in the summer and generally is much lower for small-scale hydropower facilities.

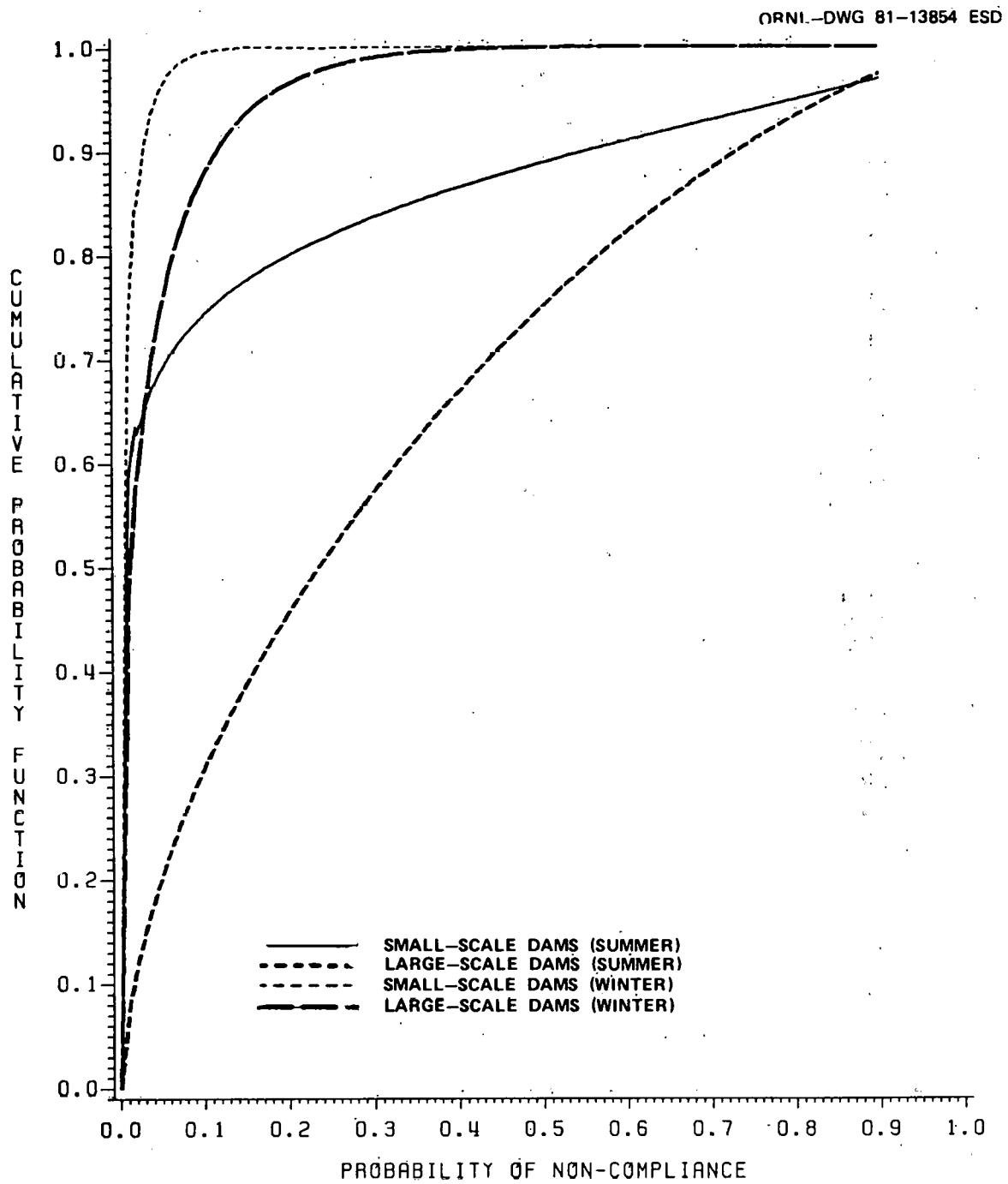


Fig. 9. Cumulative probability functions of the probabilities of non-compliance (PNCs) for hydroelectric sites in the Southeast region.

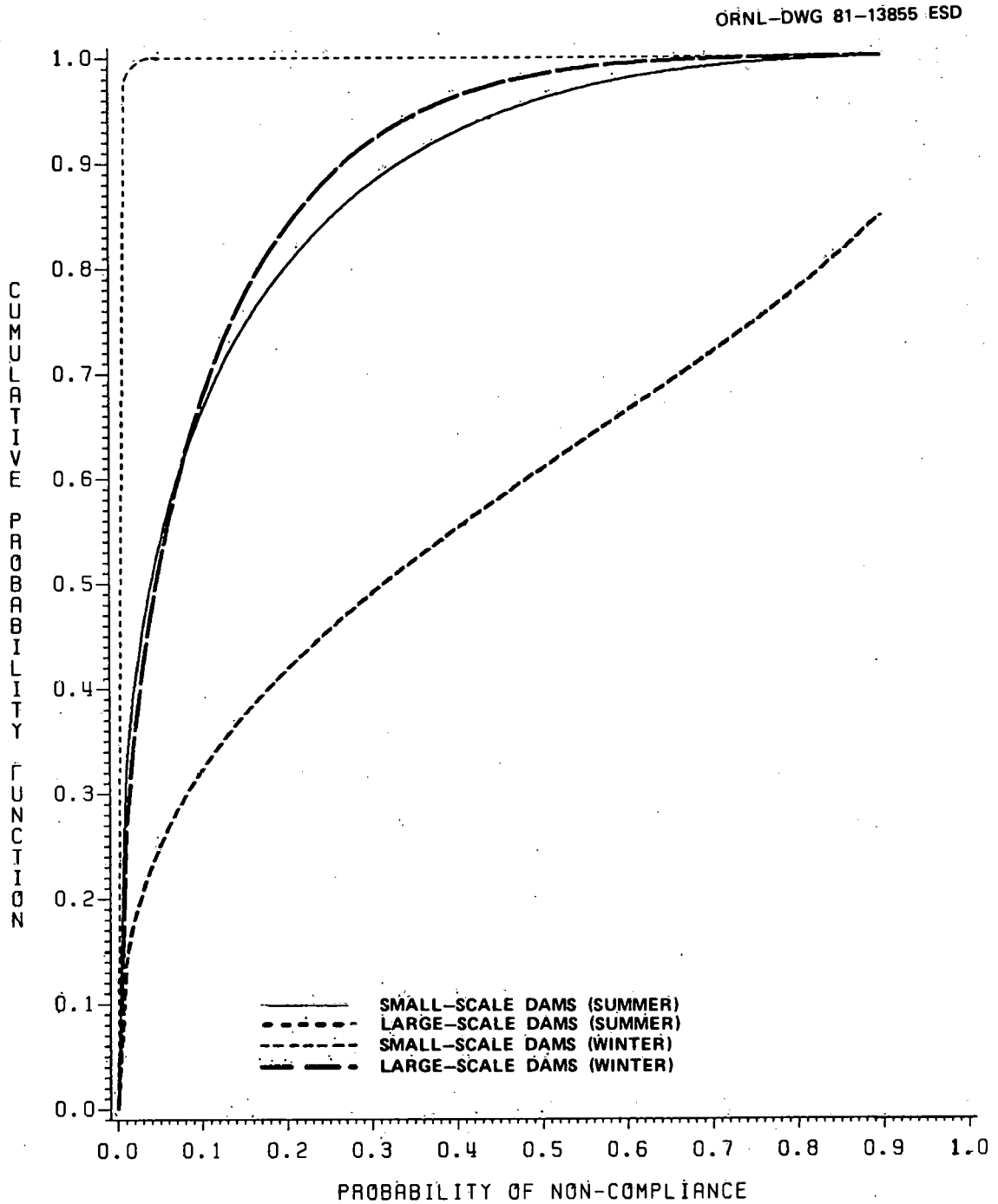


Fig. 10. Cumulative probability functions of the probabilities of non-compliance (PNCs) for hydroelectric sites in the Ohio Valley region.

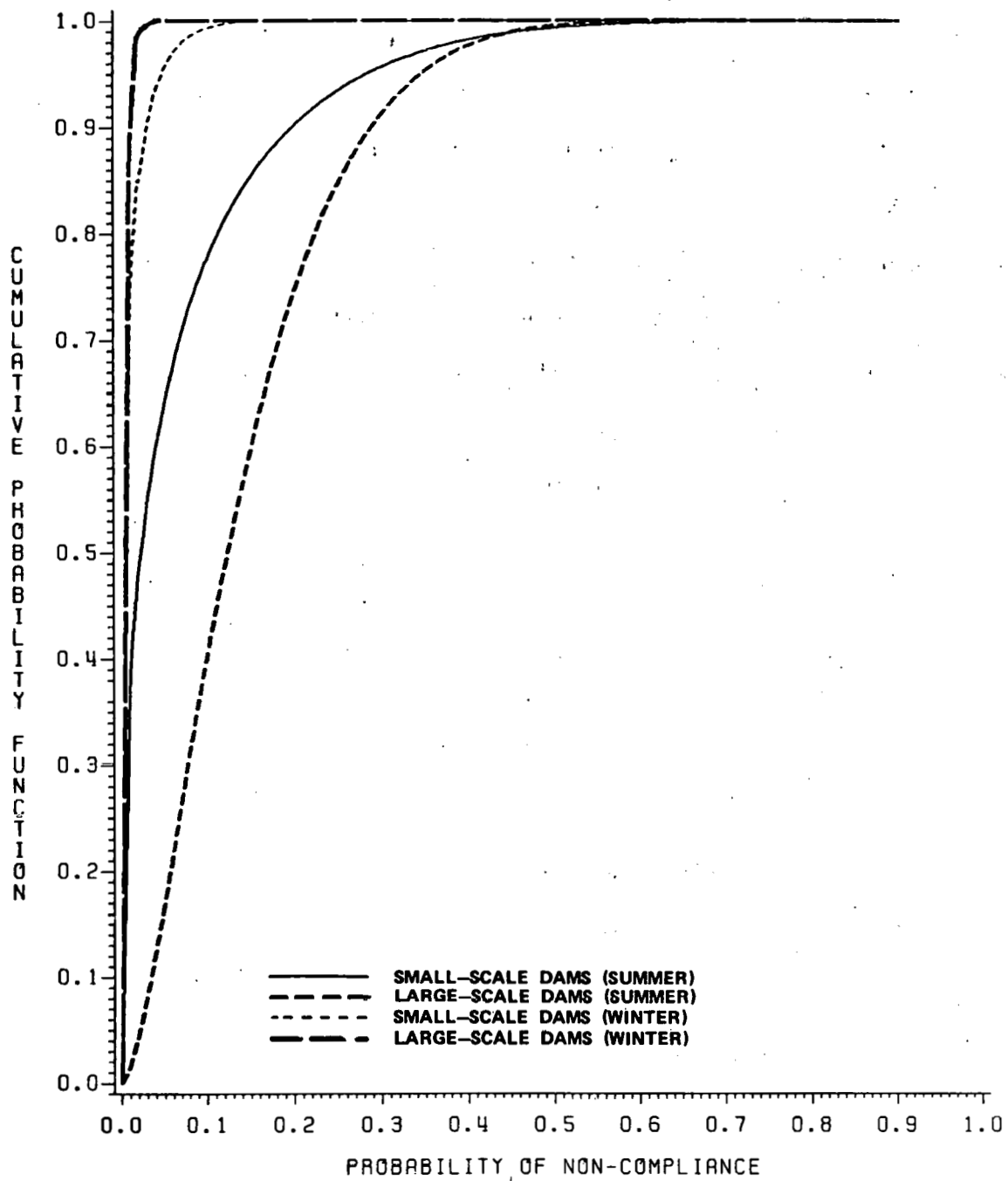


Fig. 11. Cumulative probability functions of the probabilities of non-compliance (PNCs) for hydroelectric sites in the Northeast region.

#### 4. DISCUSSION

Although numerous characteristics of reservoirs can influence thermal stratification and consequently hypolimnetic oxygen depletion (see Section 1), to a large extent the regional patterns which resulted from our examination of dissolved oxygen measurements in tailwaters of operating hydroelectric facilities can be explained on the basis of water temperatures. Because water temperatures are low during the winter, oxygen solubilities are relatively high. Reservoirs of all sizes are thoroughly mixed or at least unstratified, as demonstrated by the low mean winter PNCs for all regions, regardless of capacity.

In the summer months, on the other hand, regional differences in PNCs were observed for both small-scale and large-scale sites. The warmer climate of the southern continental states (Southeast and Great Basin) would cause reservoirs in these regions to stratify earlier and remain stratified longer than reservoirs in, for example, the Northeast or the Northwest. All else being equal, one would expect the probability of summer dissolved oxygen levels dropping below 5 mg/L to be greater in the discharge of warm reservoirs that stratify longer, and this hypothesis was supported by the data on regional mean PNCs. Therefore, it seems likely that climatic effects on summer water temperatures can be an important influence on tailwater dissolved oxygen levels in some areas of the United States.

There are undoubtedly many other factors which affect tailwater quality on a regional or site-specific basis. As mentioned in Section 1, reservoir depth has a direct effect on the occurrence and degree of stratification. It was not surprising, then, that depth (as represented by dam height) had a statistically significant positive correlation with the probability of non-compliance in many regions. Other characteristics, such as outlet depth, surface area, morphometry, topography, and flushing rate, as well as headwater quality, BOD inputs between the dam and the water quality station, hydroelectric operating schedules, and intake design and depth, could all influence the dissolved oxygen concentrations measured in discharged water. For example, if the water entering a reservoir had dissolved oxygen concentrations less than 5 mg/L, it would have the effect of increasing the PNC at that site for reasons unrelated to hydroelectric generation. Because these are factors for which we had little or no information, they could not be incorporated into the analysis.

The generality and predictive value of these results are constrained by three fundamental limitations of the data sets that were used: (1) absence of a complete set of descriptive data for many of the reservoirs (which restricted our ability to relate dissolved oxygen levels in the discharge to physical or morphometric aspects of the reservoir), (2) infrequent dissolved oxygen measurements, and (3) the general paucity of operating hydro sites with nearby USGS water quality stations. Many states had no suitable dam/water quality pairs, and, in one instance, information on the mean summer PNC for small-scale facilities in an entire region (Great Plains) was limited to a single site.

Concern about the small number of suitable dam/water quality pairs led us to select 4.8 km (3 miles) as the maximum distance downstream of the dam for which dissolved oxygen data would be considered. It is certainly possible that at some sites a substantial amount of reaeration of oxygen-depleted water can occur within a few kilometers of the discharge. At other sites, however, channel or flow conditions may be such that reoxygenation proceeds very slowly. The selection of a 4.8-km limit was seen as a compromise between the desire to utilize dissolved oxygen data representative of reservoir discharge conditions (which argue for decreasing the distance) and obtaining as much data as possible to increase the reliability of our analysis (which dictates an increase in the maximum distance downstream of the dam for which dissolved oxygen data may be used). While our analysis may not represent the exact dissolved oxygen levels at the reservoir discharges, they do mirror general tailwater quality within a few kilometers of the reservoirs.

To summarize, it appears from the data available that low concentrations of dissolved oxygen in the tailwaters below hydroelectric dams are primarily a problem of large-scale (>30 MW) facilities. It should be noted that PNCs are not a function of electrical capacity per se, but rather appear to be dependent upon factors which are related to capacity, such as reservoir depth. While discharges from some small-scale hydroelectric dams have violated the 5 mg/L dissolved oxygen criterion, the probability of violating this limit is relatively low at the majority of existing sites, particularly

in the northern and Pacific Coast regions. Although other water quality factors (e.g., heavy metals, toxic materials) may be important concerns at particular sites, our analysis indicates that potential dissolved oxygen problems (as defined by violations of the 5 mg/L criterion) are unlikely to hinder the development of small-scale hydropower in the United States.

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APPENDIX TABLE A  
DESCRIPTION OF OPERATING HYDROELECTRIC DAMS USED IN THE ANALYSIS

Table A-1. Description of operating hydroelectric dams used in the analysis (Dams with capacity  $\leq 30$  MW)

State	Project name	Project ID <sup>a</sup>	Existing capacity (MW)	Hydraulic dam height (m)	Calculated power head (m) <sup>b</sup>	Average annual inflow (m <sup>3</sup> /s)	Maximum storage (10 <sup>6</sup> m <sup>3</sup> )
AR	Lake Greeson	3AR00154	25.50	56.08	40.23	11.30	740.83
CA	Cascades	CA08001	2.00	.c	108.51	17.16	.
CA	Farad	CA08007	2.80	.	25.30	22.71	.
CA	Senator Wash	1CA10185	7.20	23.77	18.49	0.03	21.96
CO	Shoshone	C008005	14.40	.	51.82	.	.
CT	Cone Pond	CT60619	0.76	.	.	.	.
CT	Great Falls	CT60514	9.00	.	.	.	.
CT	Rainbow PD	CT60039	8.00	.	.	.	.
FL	Jim Woodruff Dam	FL00438	30.00	16.15	23.47	227658.82	501.04
GA	Lake Toccoa	9GAU0114	20.00	46.63	34.47	17.73	241.64
GA	Nottely Lake	8GAU0113	15.00	51.82	38.30	16.34	215.00
GA	Porterdale	0GA01903	1.20	14.63	14.33	14.10	1.11
HI	Waiiau	HI00129	1.10	.	98.15	.	.
ID	Minidoka Dam	3ID00275	13.40	14.63	12.22	181.08	132.28
ID	Post Falls	ID00220	11.25	17.98	17.07	187.03	277.53
MA	Pawtucket	MA65102	30.00	.	.	.	.
ME	Caribou Dam	ME62232	0.90	.	.	.	.
MI	Barton	0MI00560	1.55	8.84	7.92	12.29	5.92

Table A-1. (continued)

State	Project name	Project ID <sup>a</sup>	Existing capacity (MW)	Hydraulic dam height (m)	Calculated power head (m) <sup>b</sup>	Average annual inflow (m <sup>3</sup> /s)	Maximum storage (10 <sup>6</sup> m <sup>3</sup> )
MI	Superior	OMI00558	1.41	9.75	4.88	13.45	1.23
MI	Victoria	2MI00203	12.00	34.44	25.46	14.70	24.92
MN	Winton	OMN00607	4.00	12.50	6.40	27.07	14.88
MT	Lake Ennis	1MT00561	9.00	14.94	13.41	50.07	74.01
MT	Milltown	OMT00222	3.04	17.98	8.84	87.25	1.23
MT	Thompson Falls	OMT00224	30.00	.	18.29	600.36	30.59
NC	Chatuga Dam	1NCU0106	10.00	36.58	27.04	13.31	305.66
NC	Cliffside	ONC00134	1.52	9.14	8.53	8.35	0.09
NC	Rhodhiss	5NC00104	25.50	21.95	17.98	48.14	140.48
NC	Stice Shoals	ONC00412	0.60	7.62	6.10	11.89	0.17
NE	Barneston	ONE01317	0.75	5.79	4.28	21.58	3.08
NE	Wilber	NEU0002	0.26	15.54	15.54	10.20	.
NH	Merrimack #1	NH61946	1.60	.	.	.	.
NJ	Little Falls	NJ00600	2.40	10.97	10.97	32.54	.
NM	Elephant Butte	9NM00129	24.30	56.69	48.19	27.95	2707.49
NY	Gouverneur Vil	ONY00423	0.16	.	1.81	33.98	.
NY	High Dam	ONY0C401	7.60	.	5.18	68.79	.
NY	Raymondville	ONY0C746	2.00	.	4.15	30.02	.

Table A-1. (continued)

State	Project name	Project ID <sup>a</sup>	Existing capacity (MW)	Hydraulic dam height (m)	Calculated power head (m) <sup>b</sup>	Average annual inflow (m <sup>3</sup> /s)	Maximum storage (10 <sup>6</sup> m <sup>3</sup> )
NY	Shank, Auburn	NY00843	0.30	.	6.40	8.21	.
NY	Swinging Bridge	ONY00596	5.00	37.49	37.19	7.08	21.24
PA	Piney Dam	2PA00514	28.80	30.48	25.91	49.28	40.70
SC	Apalachee Mill	OSC00734	1.30	7.92	14.02	1.93	0.90
SC	Clifton #1	OSC01062	0.53	5.49	5.18	12.46	0.12
SC	Gaston Shoals	OSC01075	9.14	15.85	14.33	57.49	4.93
SC	Hartsville	SC00611	0.32	3.05	4.57	8.52	1.70
SC	Lake Marion	7SC00732	1.92	15.24	14.33	62.30	1726.87
SC	Lockhart	SC01059	12.30	16.15	15.85	103.08	1.73
SC	Parr Shoals	1SC00110	14.88	11.58	8.56	58.59	61.67
SC	Saluda	SC00024	2.40	14.33	12.50	16.99	9.27
SC	Ware Shoals	OSC01067	5.00	15.85	15.54	28.32	0.12
TN	Ocoee #1	OTNU0082	21.00	5.49	4.05	33.11	0.06
TN	Ocoee #3	OTNU0081	27.00	31.09	22.98	31.80	4.98
TN	Wilbur	OTNU0084	10.70	21.34	15.77	22.74	0.88
UT	Gateway	UT08056	4.27	.	45.11	15.63	.
UT	Lower Beaver #2	UT08081	0.27	.	42.67	1.42	.
VT	Cavendish	VT68751	1.44	.	.	.	.

Table A-1. (continued)

State	Project name	Project ID <sup>a</sup>	Existing capacity (MW)	Hydraulic dam height (m)	Calculated power head (m) <sup>b</sup>	Average annual inflow (m <sup>3</sup> /s)	Maximum storage (10 <sup>6</sup> m <sup>3</sup> )
VT	Newport #11	VT61013	1.60	.	.	.	.
VT	Wilder Dam	VT68259	16.20	.	.	.	.
WA	Elwha Dam	OWA00242	12.00	33.53	31.70	49.53	9.25
WA	Meyers Falls	OWA00020	1.20	.	38.10	9.12	0.07
WA	Mud Mountain	4WA00300	9.88	.	97.54	42.28	.
WA	Nine Mile	OWA00068	12.00	28.96	19.81	234.40	7.15
WI	Rapide Croche	OWI00853	2.40	4.27	3.15	116.65	4.07
WI	St Croix Falls	OWI00023	23.20	18.29	17.98	100.45	15.73
WY	Boysen	1WY01299	15.00	43.89	42.37	49.84	1816.92
WY	Fontenelle	WY01389	10.00	36.88	31.39	48.14	499.76
WY	Glendo	8WY01291	24.00	51.82	50.29	46.95	1386.43

<sup>a</sup>Unique identifier for each project in the National Hydropower Study data base (U.S. Army Corps of Engineers 1979).

<sup>b</sup>Value used as net power head in calculating capacity and energy at this site.

<sup>c</sup>Data item missing from the NHS data base.

Table A-2. Description of operating hydroelectric dams used in the analysis (Dams with capacity >30 MW)

State	Project name	Project ID <sup>a</sup>	Existing capacity (MW)	Hydraulic dam height (m)	Calculated power head (m) <sup>b</sup>	Average annual inflow (m <sup>3</sup> /s)	Maximum storage (10 <sup>6</sup> m <sup>3</sup> )
AL	Jordan Lk	1AL01423	100.00	33.53	28.50	459.58	283.70
AL	Wilson Lk	1ALU027	629.80	35.36	26.13	1473.21	790.66
AR	Beaver Dam	9AR00174	112.00	66.45	57.91	42.54	2407.75
AR	Bull Shoals	1AR00160	340.00	74.07	60.35	170.77	6670.66
AR	Dardanelle	1AR00162	124.00	20.12	14.94	1031.33	599.72
AR	Degray	5AR00151	58.00	72.54	53.34	20.90	1698.50
AR	Greers Ferry	7AR00173	96.00	38.40	56.08	63.30	3508.02
AR	Lake Hamilton	1AR00534	58.00	33.53	28.65	63.04	23.44
AR	Lk Ouachita	9AR00150	75.00	69.80	51.21	37.30	4639.74
AR	Norfork	0AR00159	70.00	62.79	53.04	61.14	2445.99
AZ	Davis Dam	AZ10309	234.00	40.84	34.72	.	2242.47
AZ	Parker Dam	4AZ10312	120.00	24.38	20.73	448.70	764.14
CA	Kern R #3 PH	CA08010	32.00	.	250.24	24.38	.
CA	Keswick	CA10160	75.00	36.88	23.77	247.72	30.96
CA	New Exchequer	CA00240	80.10	133.20	141.43	36.82	1259.38
CA	Poe Forebay	CA00328	124.20	3.66	148.74	85.33	1.42
CT	Stevenson	CT60023	30.50	.	.	.	.
GA	Lk Sidney Lanier	GA00824	86.00	58.83	45.28	.	3150.31

Table A-2. (continued)

State	Project name	Project ID <sup>a</sup>	Existing capacity (MW)	Hydraulic dam height (m)	Calculated power head (m) <sup>b</sup>	Average annual inflow (m <sup>3</sup> /s)	Maximum storage (10 <sup>6</sup> m <sup>3</sup> )
GA	Lloyd Shcals	4GA00487	144.00	31.09	30.48	48.14	131.98
GA	West Point	GA00820	73.40	32.31	25.91	.	877.00
ID	Albeni Falls	9ID00319	42.60	19.51	8.53	35.40	.
ID	American Fls	ID00274	92.40	32.61	32.61	204.64	2067.31
ID	Brownlee	ID00056	360.40	82.91	70.47	.	1759.81
LA	Toledo Bend	5LA00030	81.00	31.09	21.95	165.67	6293.21
ME	Wyman Camp	ME60408	72.00	.	.	.	.
MO	Table Rock	8MO30202	200.00	68.58	62.18	113.73	4270.31
MT	Bighorn	0MT00576	250.00	150.57	149.05	102.55	1761.41
MT	Libby Dam	4MT00652	40.00	104.85	103.94	305.60	7165.29
NC	Apalachia Lk	2NCU004	78.90	43.28	31.99	68.90	85.55
NC	Cheoah Lk	1NCU0094	110.00	67.67	50.01	106.00	51.81
NC	High Rock	4NC00388	33.00	19.81	17.98	131.01	476.34
NC	Roanoke Rapids	2NC00827	100.08	28.04	20.73	237.89	266.91
ND	Sakakawea	8ND00145	430.00	59.13	57.61	629.92	.
OK	Ft Gibson	2OK10314	45.00	33.53	17.68	223.59	1584.28
OK	Markham Ferry	2OK00134	100.00	28.65	15.85	222.74	548.28
OK	Pensacola	4OK00135	90.00	43.59	36.88	198.89	2709.96

Table A-2. (continued)

State	Project name	Project ID <sup>a</sup>	Existing capacity (MW)	Hydraulic dam height (m)	Calculated power head (m) <sup>b</sup>	Average annual inflow (m <sup>3</sup> /s)	Maximum storage (10 <sup>6</sup> m <sup>3</sup> )
OK	Tenkiller Ferry	70K10311	34.00	57.00	40.54	43.07	1518.17
OR	McNary L & D	OR00613	980.00	22.56	16.67	.	228.19
OR	The Dalles	00R00002	1806.80	34.75	25.30	4678.46	407.05
PA	Holtwood	PA00854	107.20	18.29	15.54	1062.00	23.44
SC	Jeffries	6SC01076	132.61	23.47	20.73	396.48	1369.16
TN	Boone	4TNU0062	75.00	46.63	34.47	86.35	238.56
TN	Center Hill	9TNU0044	135.00	65.53	48.44	121.97	2580.44
TN	Cherokee	8TNU0061	120.00	51.21	37.85	145.65	1900.79
TN	Chickamauga	1TNU0075	108.00	31.39	23.20	1033.03	911.54
TN	Chilhowee	1TNU0059	50.00	19.81	14.64	130.33	49.34
TN	Cordell Hull	1TNU0042	100.00	25.30	18.70	379.18	383.49
TN	Douglas	3TNU0067	115.00	59.44	43.93	190.11	1819.38
TN	Ft Loudon	2TNU0060	135.60	35.05	25.91	399.82	484.76
TN	Ft Pat Henry	1TNU0098	36.00	26.82	19.82	89.29	33.18
TN	Melton Hill	1TNU0057	72.00	29.57	21.85	142.00	155.42
TN	Nickajack	0TNU0071	97.20	20.42	15.09	1086.70	311.33
TN	Norris	5TNU0058	100.80	72.54	53.62	123.67	3147.84
TN	Pickwick Ldg	1TNU0068	220.00	27.74	20.50	1859.83	1363.00

Table A-2. (continued)

State	Project name	Project ID <sup>a</sup>	Existing capacity (MW)	Hydraulic dam height (m)	Calculated power head (m) <sup>b</sup>	Average annual inflow (m <sup>3</sup> /s)	Maximum storage (10 <sup>6</sup> m <sup>3</sup> )
TN	South Holston	8TNU0054	35.00	79.86	59.02	33.96	942.38
TN	Tims Ford	6TNU0069	45.00	48.77	36.05	28.12	749.96
TN	Watauga	8TNU0063	50.00	89.92	66.46	29.62	835.07
TN	Watts Bar	2TNU0066	153.30	32.00	23.66	860.14	1449.34
TX	Sam Rayburn	6TX00011	52.00	31.09	21.95	76.86	6919.82
UT	Flaming Gorge	8UT10121	108.00	138.07	132.59	58.68	4937.62
WA	Alder Dam	7WA00257	50.00	.	82.60	40.47	.
WA	Box Canyon	0WA00013	60.00	30.48	14.02	762.88	61.67
WA	Gorge Lake	0WA00168	137.70	.	115.82	126.05	11.35
WA	Grand Coulee	WA00262	6180.00	115.82	103.94	.	11794.54
WA	Ice Harbor	WA00347	603.00	30.48	25.39	849.60	463.79
WA	La Grande	0WA00253	64.00	.	127.71	47.04	3.79
WA	Lake Chelan	4WA00004	48.00	.	119.48	61.06	1469.99
WA	Lake Merwin	3WA00149	136.00	66.45	55.17	138.68	518.06
WA	Lake Shannon	4WA00172	64.00	84.73	78.94	58.34	.

Table A-2. (continued)

State	Project name	Project ID <sup>a</sup>	Existing capacity (MW)	Hydraulic dam height (m)	Calculated power head (m) <sup>b</sup>	Average annual inflow (m <sup>3</sup> /s)	Maximum storage (10 <sup>6</sup> m <sup>3</sup> )
WA	Long Lake	2WAO0021	70.00	63.40	52.12	271.56	282.47
WA	Lower Granite	WAO0349	405.00	32.00	26.27	849.60	596.76
WA	Mayfield	2WAO0152	121.50	69.80	54.56	180.17	205.50
WA	Priest Rapids	OWAO0088	788.50	29.57	23.47	3425.64	308.62
WY	Kortes	OWYO1294	36.00	68.28	66.75	28.09	5.88

<sup>a</sup>Unique identifier for each project in the National Hydropower Study data base (U.S. Army Corps of Engineers 1979).

<sup>b</sup>Value used as net power head in calculating capacity and energy at this site.

<sup>c</sup>Data item missing from the NHS data base.

APPENDIX B  
MEAN DISSOLVED OXYGEN CONCENTRATIONS AND PROBABILITIES OF  
NON-COMPLIANCE (PNCS) CALCULATED FROM DATA COLLECTED BELOW  
SELECTED HYDROELECTRIC DAMS

Table B-1. Mean dissolved oxygen concentrations and probabilities of non-compliance (PNCs) calculated from data collected below selected hydroelectric dams (Dams used having capacities  $\leq 30$  MW, summer)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
AR	Lake Greeson	24	7.04	2.38	0.167	0.202	0.107	0.325
CA	Cascades	50	8.38	0.94	0.000	0.000	0.000	0.002
CA	Farad	20	8.74	0.60	0.000	0.000	0.000	0.000
CA	Senator Wash	20	7.75	0.73	0.000	0.000	0.000	0.004
CO	Shoshone	25	8.32	0.89	0.000	0.000	0.000	0.003
CT	Cone Pond	23	9.02	1.07	0.000	0.000	0.000	0.003
CT	Great Falls	12	8.68	1.55	0.000	0.004	0.001	0.082
CT	Rainbow Pd	12	8.37	1.48	0.000	0.007	0.001	0.092
FL	Jim Woodruff Dam	18	6.82	0.93	0.000	0.023	0.004	0.102
GA	Lake Toccoa	8	6.75	1.57	0.250	0.150	0.033	0.371
GA	Nottely Lake	18	6.80	1.87	0.111	0.176	0.078	0.316
GA	Porterdale	30	7.13	1.06	0.000	0.021	0.006	0.071
HI	Waiau	13	9.05	0.35	0.000	0.000	0.000	0.000
ID	Minicoka Dam	5	8.72	0.91	0.000	0.000	0.000	0.055
ID	Post Falls	22	8.79	0.78	0.000	0.000	0.000	0.000
MA	Pawtucket	7	6.41	0.38	0.000	0.000	0.000	0.036
ME	Caribou Dam	20	9.52	1.66	0.000	0.002	0.000	0.029
MI	Barton	5	9.44	1.53	0.000	0.000	0.000	0.148
MI	Superior	13	7.48	1.32	0.077	0.028	0.004	0.141

Table B-1. (continued)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
MI	Victoria	13	9.65	1.01	0.000	0.000	0.000	0.001
MT	Lake Ennis	12	8.50	0.60	0.000	0.000	0.000	0.000
MT	Milltown	8	9.60	1.65	0.000	0.000	0.000	0.079
MT	Thompson Falls	18	9.32	1.04	0.000	0.000	0.000	0.002
NC	Chatuga Dam	6	1.23	0.51	1.000	1.000	1.000	1.000
NC	Cliffside	75	7.93	0.92	0.000	0.001	0.000	0.003
NC	Rhodhiss	36	4.94	1.16	0.333	0.520	0.411	0.627
NC	Stice Shoals	24	7.55	2.00	0.125	0.104	0.043	0.209
NE	Wilber	4	7.97	1.37	0.000	0.000	0.000	0.314
NH	Merrimack #137	37	7.37	1.90	0.135	0.109	0.055	0.190
NJ	Little Falls	20	6.96	1.49	0.100	0.099	0.036	0.214
NM	Elephant Butte	9	4.63	2.02	0.444	0.565	0.353	0.767
NY	Gouvernor Vil	9	8.09	1.15	0.000	0.000	0.000	0.076
NY	High Dam	19	8.70	1.12	0.000	0.000	0.000	0.010
NY	Raymondville	9	8.68	0.94	0.000	0.000	0.000	0.014
NY	Shank, Auburn	7	7.60	2.44	0.143	0.165	0.034	0.406
NY	Swinging Bridge	8	6.71	2.27	0.250	0.247	0.081	0.474
PA	Piney Dam	7	6.36	2.60	0.143	0.323	0.121	0.565
SC	Apalachee Mill	4	8.15	0.70	0.000	0.000	0.000	0.081
SC	Clifton #1	4	8.32	0.48	0.000	0.000	0.000	0.011
SC	Gaston Shoals	3	8.80	0.66	0.000	0.000	0.000	0.117

Table B-1. (continued)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
SC	Hartsville	5	8.20	1.04	0.000	0.000	0.000	0.131
SC	Lake Marion	35	7.01	1.04	0.000	0.026	0.008	0.075
SC	Lockhart	6	8.20	1.29	0.000	0.000	0.000	0.158
SC	Saluda	5	8.38	0.73	0.000	0.000	0.000	0.033
SC	Ware Shoals	17	7.81	0.84	0.000	0.000	0.000	0.012
TN	Ocoee #1	6	7.90	0.46	0.000	0.000	0.000	0.002
TN	Ocoee #3	7	7.01	0.46	0.000	0.000	0.000	0.014
TN	Wilbur	4	6.47	2.53	0.500	0.332	0.074	0.641
UT	Gateway	28	9.64	1.73	0.000	0.002	0.000	0.023
UT	Lower Beaver #2	4	4.85	0.87	0.500	0.550	0.251	0.839
VT	Newport #11	9	10.12	2.11	0.000	0.002	0.000	0.104
VT	Wilder Dam	26	6.78	0.96	0.000	0.032	0.009	0.097
WA	Elwha Dam	6	11.10	0.47	0.000	0.000	0.000	0.000
WA	Meyers Falls	38	9.09	1.43	0.000	0.002	0.000	0.013
WA	Mud Mountain	7	12.17	3.19	0.000	0.002	0.000	0.162
WA	Nine Mile	14	7.97	1.44	0.000	0.016	0.002	0.106
WI	Rapide Croche	4	8.47	3.20	0.000	0.187	0.018	0.520
WI	St Croix Falls	5	8.38	0.62	0.000	0.000	0.000	0.014
WY	Boysen	16	7.71	1.07	0.000	0.003	0.000	0.050
WY	Fontenelle	18	9.48	1.93	0.000	0.007	0.001	0.061
WY	Glendo	15	7.27	2.98	0.133	0.233	0.108	0.395

<sup>a</sup>The proportion of actual dissolved oxygen measurements which yielded values less than 5 mg/L.

<sup>b</sup>95% lower confidence limit.

<sup>c</sup>95% upper confidence limit.

Table B-2. Mean dissolved oxygen concentrations and probabilities of non-compliance (PNCs) calculated from data collected below selected hydroelectric dams (Dams used having capacities  $\leq 30$  MW, winter)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
AR	Lake Greeson	52	8.99	1.83	0.019	0.014	0.005	0.040
CA	Farad	42	10.61	0.79	0.000	0.000	0.000	0.000
CA	Senator Wash	43	9.03	0.86	0.000	0.000	0.000	0.000
CO	Shoshone	53	10.24	1.24	0.000	0.000	0.000	0.000
CT	Conè Pond	40	12.04	1.91	0.000	0.000	0.000	0.002
CT	Great Falls	24	8.60	1.58	0.000	0.010	0.002	0.053
CT	Rainbow Pd	21	9.75	1.70	0.000	0.001	0.000	0.024
FL	Jim Woodruff Dam	42	9.15	1.82	0.000	0.010	0.003	0.036
GA	Lake Toccoa	19	9.44	1.85	0.000	0.006	0.001	0.052
GA	Nottely Lake	40	9.43	1.74	0.000	0.005	0.001	0.023
GA	Porterdale	40	9.47	1.68	0.000	0.003	0.001	0.018
HI	Waiau	22	9.09	0.42	0.000	0.000	0.000	0.000
ID	Minidoka Dam	7	12.64	1.59	0.000	0.000	0.000	0.008
ID	Post Falls	48	12.40	1.24	0.000	0.000	0.000	0.000
MA	Pawtucket	7	10.57	2.64	0.000	0.006	0.001	0.183
ME	Caribou Dam	34	10.25	1.95	0.000	0.003	0.000	0.019
MI	Barton	7	13.46	2.11	0.000	0.000	0.000	0.024
MI	Superior	24	11.95	2.60	0.000	0.002	0.000	0.027
MI	Victoria	23	12.12	2.12	0.000	0.000	0.000	0.007
MN	Winton	5	10.46	1.66	0.000	0.000	0.000	0.111

Table B-2. (continued)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
MT	Lake Ennis	16	10.71	1.29	0.000	0.000	0.000	0.001
MT	Milltown	16	11.66	0.90	0.000	0.000	0.000	0.000
MT	Thompson Falls	32	12.01	1.10	0.000	0.000	0.000	0.000
NC	Chatuga Dam	16	8.11	2.04	0.000	0.066	0.017	0.186
NC	Cliffside	138	10.05	2.32	0.000	0.015	0.008	0.028
NC	Rhodhiss	120	8.28	1.18	0.025	0.003	0.001	0.007
NC	Stice Shoals	45	8.69	2.17	0.067	0.045	0.019	0.096
NE	Barneston	4	3.25	0.60	1.000	1.000	0.789	1.000
NE	Wilber	6	9.60	1.38	0.000	0.000	0.000	0.073
NH	Merrimack #1	56	9.87	2.55	0.018	0.028	0.011	0.062
NJ	Little Falls	19	9.60	3.11	0.000	0.071	0.022	0.180
NM	Elephant Butte	15	10.52	3.90	0.067	0.082	0.022	0.215
NY	Gouvernor Vil	25	10.86	1.93	0.000	0.000	0.000	0.013
NY	High Dam	30	11.45	1.95	0.000	0.000	0.000	0.006
NY	Raymondville	15	10.85	1.91	0.000	0.000	0.000	0.023
NY	Shank, Auburn	18	11.05	3.30	0.056	0.032	0.007	0.120
NY	Swinging Bridge	14	11.11	1.84	0.000	0.000	0.000	0.016
PA	Piney Dam	9	9.78	1.72	0.000	0.000	0.000	0.068
SC	Apalachee Mill	12	9.93	1.66	0.000	0.000	0.000	0.036
SC	Clifton #1	12	10.37	1.35	0.000	0.000	0.000	0.007

Table B-2. (continued)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
SC	Gaston Shoals	8	9.49	1.69	0.000	0.000	0.000	0.093
SC	Hartsville	12	10.02	1.33	0.000	0.000	0.000	0.010
SC	Lake Marion	62	9.83	1.76	0.000	0.003	0.001	0.011
SC	Lockhart	12	10.18	1.54	0.000	0.000	0.000	0.019
SC	Parr Shoals	4	10.57	1.53	0.000	0.000	0.000	0.140
SC	Saluda	8	9.56	1.95	0.000	0.002	0.000	0.128
SC	Ware Shoals	19	9.65	1.88	0.000	0.004	0.001	0.046
TN	Ocoee #1	16	9.79	1.27	0.000	0.000	0.000	0.006
TN	Ocoee #3	16	9.27	1.40	0.000	0.000	0.000	0.021
TN	Wilbur	9	9.53	1.90	0.000	0.002	0.000	0.108
UT	Gateway	46	10.99	1.57	0.000	0.000	0.000	0.001
UT	Lower Beaver #2	4	8.65	1.21	0.000	0.000	0.000	0.202
VT	Cavendish	4	9.75	1.21	0.000	0.000	0.000	0.117
VT	Newport #11	12	12.16	2.39	0.000	0.000	0.000	0.034
VT	Wilder Dam	60	10.74	2.14	0.000	0.003	0.001	0.013
WA	Elwha Dam	12	12.82	0.57	0.000	0.000	0.000	0.000
WA	Meyers Falls	68	10.84	1.55	0.000	0.000	0.000	0.001
WA	Mud Mountain	16	13.01	2.33	0.000	0.000	0.000	0.010
WA	Nine Mile	27	11.41	1.18	0.000	0.000	0.000	0.000
WI	Rapide Croche	7	11.10	3.38	0.000	0.030	0.003	0.236

Table B-2. (continued)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
WI	St Croix Falls	6	9.75	1.50	0.000	0.000	0.000	0.087
WY	Boysen	30	10.53	2.15	0.000	0.004	0.001	0.027
WY	Fontenelle	32	10.65	0.99	0.000	0.000	0.000	0.000
WY	Glendo	31	10.20	1.69	0.000	0.001	0.000	0.010

<sup>a</sup>The proportion of actual dissolved oxygen measurements which yielded values less than 5 mg/l.

<sup>b</sup>95% lower confidence limit.

<sup>c</sup>95% upper confidence limit.

Table B-3. Mean dissolved oxygen concentrations and probabilities of non-compliance (PNCs) calculated from data collected below selected hydroelectric dams (Dams used having capacities > 30 MW, summer)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
AL	Jordan Lk	13	7.18	1.55	0.077	0.083	0.020	0.230
AL	Wilson Lk	12	7.02	1.29	0.000	0.060	0.012	0.205
AR	Beaver Dam	44	7.42	2.28	0.136	0.147	0.086	0.228
AR	Bull Shoals	62	6.35	2.29	0.323	0.280	0.208	0.360
AR	Dardanelle	56	7.41	1.45	0.071	0.048	0.023	0.094
AR	Degray	30	7.59	0.91	0.000	0.001	0.000	0.015
AR	Greers Ferry	32	7.30	2.89	0.188	0.218	0.130	0.324
AR	Lake Hamilton	14	4.53	1.68	0.643	0.604	0.431	0.765
AR	Lk Ouachita	36	7.34	1.82	0.083	0.101	0.049	0.182
AR	Norfolk	20	7.34	2.47	0.200	0.179	0.084	0.312
AZ	Davis Dam	5	7.10	0.51	0.000	0.000	0.000	0.054
AZ	Parker Dam	23	7.31	0.96	0.000	0.006	0.001	0.043
CA	Kern R #3 Ph	10	9.22	0.54	0.000	0.000	0.000	0.000
CA	Keswick	78	9.96	0.99	0.000	0.000	0.000	0.000
CA	New Exchequer	104	11.40	14.54	0.038	0.331	0.272	0.394
CA	Poe Forebay	12	9.25	0.98	0.000	0.000	0.000	0.003
CT	Stevenson	70	6.85	2.22	0.243	0.204	0.145	0.273
GA	Lk Sidney Lanier	18	3.50	1.03	0.944	0.926	0.812	0.978
GA	Lloyd Shoals	30	3.41	1.60	0.800	0.835	0.731	0.912
GA	West Point	28	6.27	2.20	0.214	0.287	0.182	0.407

Table B-3. (continued)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
ID	Albeni Falls	8	10.27	0.73	0.000	0.000	0.000	0.000
ID	American Fls	16	9.61	1.54	0.000	0.000	0.000	0.023
ID	Brownlee	4	6.32	1.46	0.250	0.238	0.031	0.561
LA	Toledo Bend	18	4.94	2.33	0.556	0.509	0.358	0.660
ME	Wyman Camp	33	8.05	1.02	0.000	0.001	0.000	0.011
MO	Table Rock	15	6.88	2.08	0.200	0.192	0.081	0.350
MT	Bighorn	8	10.25	0.51	0.000	0.000	0.000	0.000
MT	Libby Dam	75	11.95	1.86	0.000	0.000	0.000	0.001
NC	Apalachia Lk	10	8.60	0.58	0.000	0.000	0.000	0.000
NC	Cheoah Lk	8	5.48	1.67	0.250	0.400	0.192	0.625
NC	High Rock	27	4.93	0.64	0.667	0.540	0.415	0.663
NC	Roanoke Rapids	24	6.10	2.31	0.125	0.322	0.204	0.453
ND	Sakakawea	15	8.67	0.91	0.000	0.000	0.000	0.003
OK	Ft Gibson	22	7.19	1.66	0.136	0.098	0.037	0.206
OK	Markham Ferry	7	7.30	1.07	0.000	0.005	0.001	0.176
OK	Pensacola	7	6.01	1.27	0.286	0.238	0.067	0.481
OK	Tenkiller Ferry	9	5.84	1.64	0.333	0.319	0.138	0.534
OR	McNary L & D	8	10.20	1.11	0.000	0.000	0.000	0.006
OR	The Dalles	9	10.08	2.17	0.000	0.003	0.000	0.114
PA	Holtwood	18	6.64	2.13	0.333	0.228	0.114	0.375

Table B-3. (continued)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
TN	Boone	12	5.16	0.79	0.250	0.426	0.250	0.612
TN	Cherokee	9	2.32	1.91	0.889	0.912	0.720	0.985
TN	Chickamauga	12	7.46	0.99	0.000	0.003	0.000	0.071
TN	Chilhowee	5	7.56	0.56	0.000	0.000	0.000	0.036
TN	Douglas	9	2.89	1.75	0.778	0.874	0.672	0.972
TN	Ft Loudon	12	5.19	1.41	0.500	0.450	0.271	0.635
TN	Ft Pat Henry	9	4.71	0.66	0.556	0.655	0.441	0.842
TN	Melton Hill	13	7.68	1.40	0.000	0.025	0.004	0.134
TN	Nickajack	9	6.68	0.72	0.000	0.003	0.000	0.113
TN	Norris	12	2.86	2.05	0.833	0.841	0.667	0.948
TN	Pickwick Ldg	13	7.23	0.90	0.000	0.003	0.000	0.066
TN	Scuth Holston	7	4.14	1.87	0.571	0.656	0.414	0.864
TN	Tims Ford	10	1.45	1.47	0.900	0.998	0.908	1.000
TN	Watauga	6	6.47	1.57	0.167	0.205	0.043	0.469
TN	Watts Bar	18	6.14	1.47	0.222	0.228	0.114	0.375
TX	Sam Rayburn	38	5.37	2.22	0.526	0.435	0.332	0.541
UT	Flaming Gorge	58	8.51	1.40	0.000	0.005	0.002	0.020
WA	Alder Dam	5	9.20	0.71	0.000	0.000	0.000	0.008
WA	Box Canyon	10	9.14	1.24	0.000	0.000	0.000	0.027
WA	Gorge Lake	16	11.92	0.29	0.000	0.000	0.000	0.000

Table B-3. (continued)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
WA	Grand Coulee	18	9.94	1.57	0.000	0.000	0.000	0.015
WA	Ice Harbor	15	8.41	1.45	0.000	0.006	0.001	0.069
WA	La Grande	13	10.87	1.03	0.000	0.000	0.000	0.000
WA	Lake Chelan	21	9.37	0.55	0.000	0.000	0.000	0.000
WA	Lake Merwin	8	9.70	1.06	0.000	0.000	0.000	0.009
WA	Lake Shannon	12	10.50	0.66	0.000	0.000	0.000	0.000
WA	Long Lake	96	5.43	1.87	0.542	0.409	0.344	0.475
WA	Lower Granite	11	8.45	0.91	0.000	0.000	0.000	0.011
WA	Mayfield	5	10.96	0.42	0.000	0.000	0.000	0.000
WA	Priest Rapids	9	10.77	0.79	0.000	0.000	0.000	0.000
WY	Kortes	33	7.19	1.50	0.031	0.073	0.031	0.149

<sup>a</sup>The proportion of actual dissolved oxygen measurements which yielded values less than 5 mg/L.

<sup>b</sup>95% lower confidence limit.

<sup>c</sup>95% upper confidence limit.

Table B-4. Mean dissolved oxygen concentrations and probabilities of non-compliance (PNCs) calculated from data collected below selected hydroelectric dams (Dams used having capacities >30 MW, winter)

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
AL	Jordan Lk	26	10.42	1.78	0.000	0.000	0.000	0.012
AL	Wilson Lk	34	9.92	1.57	0.000	0.000	0.000	0.007
AR	Beaver Dam	88	10.27	2.34	0.000	0.012	0.005	0.028
AR	Bull Shoals	106	10.43	2.48	0.019	0.014	0.007	0.030
AR	Dardanelle	90	10.69	1.98	0.000	0.002	0.001	0.007
AR	Degray	70	10.48	1.70	0.000	0.000	0.000	0.003
AF	Greers Ferry	80	9.56	2.73	0.050	0.047	0.025	0.083
AF	Lake Hamilton	24	9.65	2.26	0.000	0.018	0.004	0.074
AR	Lk Ouachita	73	9.39	1.88	0.000	0.009	0.003	0.025
AR	Norfolk	38	11.46	2.26	0.000	0.001	0.000	0.013
AZ	Davis Dam	16	9.96	1.05	0.000	0.000	0.000	0.001
AZ	Parker Dam	46	9.27	1.06	0.000	0.000	0.000	0.001
CA	Kern R #3 Ph	16	11.26	1.20	0.000	0.000	0.000	0.000
CA	Keswick	160	11.13	1.37	0.000	0.000	0.000	0.000
CA	New Exchequer	190	10.40	0.99	0.000	0.000	0.000	0.000
CA	Poe Forebay	8	10.47	1.02	0.000	0.000	0.000	0.002
CT	Stevenson	128	10.12	2.25	0.008	0.011	0.005	0.023
GA	Lloyd Shoals	46	7.46	2.81	0.217	0.194	0.124	0.280
GA	West Point	44	8.47	2.47	0.045	0.082	0.040	0.148
ID	Albeni Falls	16	10.70	1.82	0.000	0.000	0.000	0.018

Table B-4. (continued).

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
ID	American Fls	28	11.82	1.67	0.000	0.000	0.000	0.001
ID	Brownlee	8	11.50	2.32	0.000	0.000	0.000	0.079
LA	Toledo Bend	35	8.15	2.29	0.114	0.086	0.039	0.164
ME	Wyman Camp	69	11.48	1.56	0.000	0.000	0.000	0.000
MO	Table Rock	26	10.88	2.33	0.038	0.004	0.001	0.033
MT	Bighorn	16	12.15	0.80	0.000	0.000	0.000	0.000
MT	Libby Dam	150	14.06	2.08	0.000	0.000	0.000	0.000
NC	Apalachia Lk	28	10.57	1.88	0.000	0.001	0.000	0.013
NC	Cheoah Lk	26	10.33	1.90	0.000	0.001	0.000	0.019
NC	High Rock	63	7.39	2.93	0.333	0.209	0.146	0.283
NC	Roanoke Rapids	48	9.63	2.42	0.000	0.027	0.011	0.066
ND	Sakakawea	28	11.54	1.30	0.000	0.000	0.000	0.000
OK	Ft Gibson	55	10.81	2.12	0.000	0.003	0.001	0.012
OK	Markham Ferry	14	9.76	2.30	0.000	0.016	0.002	0.105
OK	Pensacola	14	9.66	1.54	0.000	0.000	0.000	0.026
OK	Tenkiller Ferry	22	11.01	2.18	0.000	0.001	0.000	0.025
OR	McNary L & D	15	11.88	1.49	0.000	0.000	0.000	0.001
OR	The Dalles	15	12.09	1.31	0.000	0.000	0.000	0.000
PA	Holtwood	39	11.51	2.44	0.026	0.003	0.001	0.018
SC	Jeffries	4	10.05	1.35	0.000	0.000	0.000	0.131

Table B-4. (continued).

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
TN	Boone	21	7.96	2.28	0.095	0.101	0.038	0.213
TN	Center Hill	3	9.37	1.99	0.000	0.000	0.000	0.426
TN	Cherokee	23	6.66	3.91	0.391	0.341	0.218	0.476
TN	Chickamauga	31	9.05	1.63	0.000	0.005	0.001	0.031
TN	Chilhowee	11	9.98	2.01	0.000	0.002	0.000	0.078
TN	Cordell Hull	3	10.53	0.31	0.000	0.000	0.000	0.000
TN	Douglas	29	6.23	2.90	0.379	0.340	0.230	0.460
TN	Ft Loudon	28	8.32	2.28	0.071	0.074	0.029	0.159
TN	Ft Pat Henry	16	9.00	4.07	0.063	0.172	0.070	0.321
TN	Melton Hill	30	9.55	1.37	0.000	0.000	0.000	0.006
TN	Nickajack	28	9.06	1.98	0.000	0.019	0.005	0.068
TN	Norris	23	8.55	2.28	0.043	0.061	0.020	0.152
TN	Pickwick Ldg	30	9.51	1.98	0.000	0.010	0.002	0.046
TN	South Holston	16	8.27	1.75	0.063	0.029	0.005	0.123
TN	Tims Ford	16	7.02	2.28	0.313	0.198	0.087	0.351
TN	Watauga	19	9.21	2.23	0.105	0.028	0.006	0.109
TN	Watts Bar	58	10.86	14.45	0.017	0.344	0.265	0.429
TX	Sam Rayburn	79	9.00	2.10	0.051	0.028	0.014	0.056
UT	Flaming Gorge	86	9.15	1.09	0.000	0.000	0.000	0.001
WA	Alder Dam	15	12.09	0.79	0.000	0.000	0.000	0.000

Table B-4. (continued).

State	Project name	Number of samples	Mean dissolved oxygen conc. (mg/L)	Standard deviation	Observed proportion of non-compliance <sup>a</sup>	Probability of non-compliance (PNC)	Lower limit PNC <sup>b</sup>	Upper limit PNC <sup>c</sup>
WA	Box Canyon	24	12.07	0.99	0.000	0.000	0.000	0.000
WA	Gorge Lake	31	12.96	0.97	0.000	0.000	0.000	0.000
WA	Granc Coulee	32	13.17	2.22	0.000	0.000	0.000	0.002
WA	Ice Harbor	30	12.06	1.55	0.000	0.000	0.000	0.000
WA	La Grande	31	12.46	0.72	0.000	0.000	0.000	0.000
WA	Lake Chelan	42	11.24	0.87	0.000	0.000	0.000	0.000
WA	Lake Merwin	16	11.27	0.90	0.000	0.000	0.000	0.000
WA	Lake Shannon	28	11.70	0.92	0.000	0.000	0.000	0.000
WA	Long Lake	152	10.95	1.93	0.000	0.001	0.000	0.003
WA	Lower Granite	15	12.03	1.04	0.000	0.000	0.000	0.000
WA	Mayfield	17	12.44	1.16	0.000	0.000	0.000	0.000
WA	Priest Rapids	15	13.05	1.57	0.000	0.000	0.000	0.000
WY	Kortes	60	9.95	1.13	0.000	0.000	0.000	0.000

<sup>a</sup>The proportion of actual dissolved oxygen measurements which yielded values less than 5 mg/L.

<sup>b</sup>95% lower confidence limit.

<sup>c</sup>95% upper confidence limit.

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- Region V, 230 South Dearborn Street, Chicago, IL 60604
467. Regional Administrator, U.S. Environmental Protection Agency  
- Region VI, First International Building, 1201 Elm Street,  
Dallas, TX 75270
468. Regional Administrator, U.S. Environmental Protection Agency  
- Region VII, 1735 Baltimore Street, Kansas City, MO 64108
469. Regional Administrator, U.S. Environmental Protection Agency  
- Region VIII, 1860 Lincoln Street, Denver, CO 80203
470. Regional Administrator, U.S. Environmental Protection Agency  
- Region IX, 215 Fremont Street, San Francisco, CA 94105
471. Regional Administrator, U.S. Environmental Protection Agency  
- Region X, 1200 6th Street, Seattle, WA 98101
472. Regional Director, Bureau of Reclamation, Lower Colorado  
Region, P.O. Box 427, Boulder City, NV 89005
473. Regional Director, Bureau of Reclamation, Lower Missouri  
Region, Bldg. 20, Denver Federal Center, Denver, CO 80225
474. Regional Director, Bureau of Reclamation, Mid-Pacific Region,  
2800 Cottage Way, Sacramento, CA 95825
475. Regional Director, Bureau of Reclamation, Pacific Northwest  
Region, P.O. Box 043, U.S. Court House, 550 W. Fort St.,  
Boise, ID 83724
476. Regional Director, Bureau of Reclamation, Southwest Region,  
Herring Plaza, Box H-4377, Amarillo, TX 79101
477. Regional Director, Bureau of Reclamation, Upper Colorado  
Region, P.O. Box 11568, Salt Lake City, UT 84111
478. Regional Director, Bureau of Reclamation, Upper Missouri  
Region, P.O. Box 2553, Billings, MT 59103
479. Regional Director, North Central Region, U.S. Fish & Wildlife  
Service, Federal Bldg., Fort Snelling, Twin Cities, MN 55111
480. Regional Director, Northeast Region, U.S. Fish & Wildlife  
Service, 1 Gateway Center, Newton, MN 02158
481. Regional Director, Pacific Region, U.S. Fish & Wildlife  
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482. Regional Director, Southeast Region, U.S. Fish & Wildlife  
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483. Regional Director, Southwest Region, U.S. FISH & WILDLIFE,  
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488. John Reynolds, Consumers Power Company, 1945 Parnell Road,  
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489. Graham A. Richard, President, Midwest Hydro Corporation, P.O. Box 5343, Fort Wayne, IN 46895
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508. Dean Shumway, Federal Energy Regulatory Commission, 825 N. Capitol Street, Washington, DC 20426
509. Carl Shuster, Office of Regulatory Analyses, Federal Energy Regulatory Commission, 825 N. Capital St., NE, Washington, DC 20426
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518. State Energy Office, State Capitol, Denver, CO 80203
519. State Energy Office, State House, Boise, ID 83720
520. State Energy Office, 108 Collins Building, Tallahassee, FL 32304
521. State Office of Energy Management, Capitol Place Office, 1533 North 12th Street, Bismarck, ND 58501
522. State Planning Coordinator, 2320 Capitol Avenue, Cheyenne, WY 82002
523. State of Kansas Energy Office, 503 Kansas Avenue, Topeka, KS 66603
524. Q. J. Stober, Fisheries Research Institute, College of Fisheries, University of Washington, Seattle, WA 98195
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527. Thomas Tatham, Charles T. Main Inc., c/o Power Authority, State of New York, 10 Columbus Circle, (17th Floor), New York, NY 10019
528. Maurice H. Taylor, U.S. Fish & Wildlife Service (OBS), Lloyd 500 Bldg., Portland, OR 97232
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556. William B. Wren, Tennessee Valley Authority, Athens, AL 35611
557. R. A. Wright, Manager, Hydraulic Plant Equipment, Ontario Hydro, 700 University Avenue, Toronto M5G 1X6, Canada

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- 560-769. Given distribution as shown in DOE/TIC-4500 under category  
UC-97e, Hydroelectric Power Generation