TENNESSEE VALLEY AUTHORITY

TVA/WR/WQ--90/17

Resource Development
River Basin Operations
Water Resources

DE91 005494

EVALUATION OF THE WATER QUALITY
II. THE RELEASES FROM THIRTY DAMS
IN THE TENNESSEE RIVER VALLEY

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September 1990

MASTER

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ACKNOWLEDGMENTS

The author is grateful to several people for their contributions to this report. David J. Bruggink performed the data retrieval and reduction. Mary B. Collins prepared many of the figures in the appendix. N. Fern Dillon prepared the final manuscript. Neil E. Carriker provided direction throughout the data analysis and preparation of the report.

EXECUTIVE SUMMARY

TVA has been routinely monitoring the dissolved oxygen and temperature from the tailwater releases of its dams for nearly 30 years. The purposes for use of this monitoring data has changed over this period without any reevaluation of the monitoring strategy and sampling design. Monitoring objectives must be clearly defined in order to provide the best information to decision makers without the waste of important resources. The historical data collected from these tailwaters was subjected to a number statistical tests to evaluate various monitoring objectives. The database is sufficient to confidently describe seasonal patterns and frequency distributions. The discharge quantity was found to explain some of the variance in the release DO and temperature patterns. Both positive and negative trends were detected in the release DO concentrations. No regional trends were detected in release temperatures. It is recommended that a design document be developed to identify monitoring objectives and sampling designs for the releases from TVA dams.

EVALUATION OF THE WATER QUALITY
IN THE RELEASES FROM THIRTY DAMS
IN THE TENNESSEE RIVER VALLEY

INTRODUCTION

The Tennessee Valley Authority (TVA) has routinely monitored dissolved oxygen (DO) and temperature from the tailwater releases of its dams since the 1950s. The original objective of this monitoring was to collect baseline information to support reaeration research and determine the relative impact of impoundments on the assimilative capacity of the river system. This monitoring has continued even though the original objective was satisfied. New purposes for this monitoring data have arisen in support of several programs, without new consideration of the monitoring strategy and sampling design.

Monitoring goals and objectives should be tied to decisions made by resource managers. Clearly stating the goals and objectives of a monitoring program is the most important aspect of its success, but is often poorly addressed (Messer, 1989). The most common problem in setting monitoring goals is lack of specificity. Broad scale monitoring goals tend to result in wide ranging objectives that provide little guidance on how the collected information is to be used. Programs that are well-designed to meet one set of goals and objectives are of less utility when applied to new goals or objectives. Monitoring objectives must be clearly defined in order to provide the best information to decision makers without the waste of important resources.

There are five different goals often defined for monitoring programs: (1) obtain baseline information to identify trends: (2) assess

cause/effect relationships for observed patterns: (3) assess the environmental impact of an action, such as experimental testing of an engineering application; (4) determine compliance with a standard as a regulatory requirement; and (5) estimate mass transport (Whitfield, 1988). The monitoring strategy for each of these goals can be quite different depending on how explicitly the objectives are defined. For example, fewer samples are needed to determine an average DO concentration over a season in contrast to the objective of determining what time of year a specific DO concentration is likely to occur. The primary purpose of this report is to compare the historical release data for 30 dams in the Tennessee Valley based on four different objectives: (1) comparison of seasonal patterns, (2) comparison of baseline conditions using descriptive statistics, (3) evaluation of monotonic trends, and (4) discussion of monitoring strategies that might be required to determine compliance with existing and proposed criteria. A secondary purpose of the report is to compile the existing database into tables and figures that would be useful for other investigators.

BACKGROUND

Before the construction of the dams in the Tennessee River Valley began in 1933 there was little concern over the consequences of the disposal of wastes into the river system. No state or federal legislation existed for pollution control and the public was preoccupied by the dismal economic and social conditions of the time. In May 1935, representatives of the U.S. Public Health Service, U.S. Geological Survey, and six Valley states requested that TVA undertake a survey to define the extent of pollution in the river system. The results of these studies were published in two reports (Scott, 1941; Scott and Jones, 1945). Although these studies were primarily concerned with sanitary sources and impacts, they concluded that DO was one of the most reliable measures of pollution in the river.

Research progressed to determining the theoretical reaeration rates for DO in turbulent streams (Kittrell and Kochtitzky, 1947). After evaluation of data collected in streams, empirical methods were developed to account for the numerous complexities encountered in the theoretical research on reaeration (Kittrell, 1949). Researchers began to realize the impoundments were contributing to the depressed DO levels in the river--DO depletion was not entirely caused by waste discharges (TVA, 1952; Davidson and Churchill, 1954). The release of water with low DO from the dams was having a detrimental effect on the assimilative capacity of the river for waste discharges downstream. Research was directed to collecting information on DO reaeration below the dams (Churchill and Buckingham, 1956; Churchill, 1957). During this period

routine monitoring of DO in the tailwaters of several dams was initiated. Combined with studies in reservoir pools, researchers were able to demonstrate the relationship of releases from upstream dams to low DO levels in several reservoirs (Churchill and Nicholas, 1966).

During the 1960s, the monitoring of release DO and temperature in the tailwaters was expanded to include most dams operated by TVA, and several operated by The Aluminum Company of America in the eastern valley. This monitoring continued through the 1970s, where the research emphasis shifted to investigating engineering solutions to improving the DO in the releases (TVA, 1972; Ruane et al., 1975; Fain, 1978; TVA, 1978). In 1982, TVA held a workshop to consolidate the numerous research findings and identify priorities and strategies for improving DO in its dam releases (Brown et al., 1984). This research effort continues to this day and has resulted in improved release DO from several projects (TVA, 1987).

The tailwater DO monitoring data has been used for a number of purposes other than reaeration research. The monitoring data is commonly used to calibrate mathematical models of TVA reservoirs and stream reaches. Meinert (1980) fit the data to harmonic functions and observed a significant decreasing trend in release DO for all main river projects, except Chickamauga, during the time period from 1975 to 1979. Further investigation showed the decline to be a step-trend occurring in 1977 (Williams and McDaniel, in prep.). In 1977, the sampling protocol for DO measurement was changed, affecting the accuracy of the measurement. The measurements were systematically lower due to absorption of iodine

into the plastic containers used for sampling. The measurement error was detected in 1983 and the sampling protocol used prior to 1977 was reestablished. Evaluation of the data collected during this period showed the systematic error was too variable to confidently be corrected (Fehring, in prep.). Thus, the declining trend detected by Meinert (1980) was not real, but caused by the change in procedure. No further efforts have been made to evaluate the monitoring data collected from all the dam tailwaters, other than annual reports of data plots.

DATABASE OF RELEASE WATER QUALITY

All data used for this report was retrieved from the U.S. Environmental Protection Agency (EPA) water quality database (STORET). Release DO concentration and temperature data from 30 dams in the Tennessee Valley were chosen for analysis. Tables 1 and 2 show the number of measurements made from each dam tailwater since 1960. Most of the available data begins in 1961 and measurements were generally made at weekly intervals, although close inspection of these tables shows a lot of deviation from the 52 measurements expected from weekly sampling. No preimpoundment data was used in this study. Although measurements were made prior to 1961 on several dam releases, this data has not been entered into the STORET database and exists only in archived paper files. It was beyond the scope of this study to find these older data and transfer them to a computer database. Also, the DO measurements collected from 1977 to 1984 were not used for the analysis due to the faulty sampling protocol previously described.

Table 1. Annual Number of Release Dissolved Oxygen Measurements.

Main River Projects	Year (1900+)																													
	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75	'76	'77 ^a	'78 ^a	'79 ^a	'80 ^a	'81 ^a	'82 ^a	'83 ^a	'84 ^a	'85	'86	'87	'88	'89
Kentucky	-	11	51	46	48	39	43	35	34	46	47	48	48	53	51	51	54	53	53	57	55	49	51	29	47	28	29	28	34	18
Pickwick	-	13	52	53	53	51	57	52	50	48	48	36	51	52	47	48	50	49	49	47	46	49	49	51	40	27	30	28	33	19
Wilson	-	12	47	50	53	50	53	51	49	53	54	52	50	54	54	54	54	46	52	57	60	51	53	51	44	26	30	29	33	17
Wheeler	40	41	41	36	41	37	39	45	51	47	49	41	48	54	58	59	55	58	57	60	60	53	52	49	46	29	29	28	33	18
Guntersville	47	50	51	50	54	53	47	50	44	53	37	49	49	53	50	48	52	54	50	56	52	52	49	46	34	30	32	28	42	18
Nickajack	-	-	-	-	-	-	-	-	48	53	52	54	51	58	42	49	51	48	48	40	41	29	53	47	27	24	27	29	34	31
Chickamauga	-	10	32	27	51	52	52	52	54	54	52	53	53	62	56	57	57	59	58	59	59	52	61	43	31	23	27	29	34	31
Watts Bar	7	19	51	51	52	50	50	48	46	38	51	53	53	61	62	60	63	62	57	52	48	47	69	49	42	34	43	49	39	42
Fort Loudoun	-	19	55	50	51	50	52	50	45	49	50	61	50	52	50	47	54	56	49	48	54	45	39	41	34	26	27	32	33	29
<u>Tributary Projects</u>																														
Apalachia	-	13	45	44	40	47	28	30	42	37	29	46	29	30	47	51	48	51	53	49	56	49	53	51	30	19	31	18	17	19
Blue Ridge	-	13	51	50	36	32	26	27	22	20	19	15	16	18	34	42	43	46	36	48	38	15	28	41	27	27	38	24	24	27
Boone	-	12	46	45	55	51	50	52	43	45	58	60	52	47	51	55	49	52	50	55	49	48	49	119	47	42	43	21	14	28
Chatuge	-	5	21	21	26	23	17	9	18	19	11	17	12	19	29	42	43	41	32	53	46	23	27	36	30	27	35	29	28	26
Cherokee	-	11	45	41	41	43	39	50	46	42	48	33	34	35	46	49	51	47	54	56	66	31	56	31	27	30	24	30	12	31
Chilhowee	-	13	48	50	47	47	56	41	29	28	41	34	39	43	52	53	53	53	53	54	52	52	49	46	-	12	6	6	7	
Douglas	-	12	53	50	51	49	51	50	39	68	64	50	48	55	60	50	64	51	48	59	54	37	42	33	27	30	25	31	10	31
Fontana	-	13	49	49	48	49	52	46	39	37	37	44	50	51	57	53	54	54	46	46	44	25	40	28	12	18	18	14	17	
Fort Patrick Henry	-	11	50	51	52	51	52	59	44	47	56	50	54	51	47	51	54	53	51	57	62	44	40	118	54	42	44	22	37	28
Hiwassee	-	11	49	44	46	39	40	43	26	19	12	25	24	16	29	41	33	38	33	26	32	28	8	28	18	19	33	18	18	20
Melton Hill	-	-	-	-	7	43	48	57	49	31	43	50	48	42	49	56	48	51	47	43	45	25	37	65	30	27	26	27	10	28
Normandy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	10	9	1	24	-	-	10	-	12	-	2	11	
Norris	-	13	51	50	47	49	43	50	41	45	49	46	46	46	47	51	50	49	46	52	48	28	37	41	44	29	32	27	13	29
Nottely	-	1	22	20	27	25	18	16	15	14	10	15	14	17	24	44	47	35	28	43	36	17	30	39	22	25	34	25	29	27
Ocoee No. 1	-	13	46	50	50	50	46	50	39	48	37	43	55	56	55	56	55	50	51	60	53	48	47	45	30	16	30	16	4	18
Ocoee No. 3	-	12	44	49	49	48	48	51	41	47	36	45	59	59	56	49	56	53	54	53	48	47	49	43	16	17	15	16	4	17
Santeeetlah	-	-	-	-	-	-	-	-	26	16	16	25	36	19	22	38	47	9	-	-	-	-	-	-	6	17	14	17	4	17
South Holston	-	13	51	51	47	44	39	44	39	35	39	41	43	37	34	46	41	49	39	48	50	34	54	32	49	40	38	25	13	24
Tims Ford	-	-	-	-	-	-	-	-	-	-	-	-	31	53	64	62	38	46	43	54	41	44	45	49	31	13	16	20	11	17
Watauga	-	11	48	47	48	47	45	46	34	31	31	28	33	29	43	42	44	44	46	51	54	34	40	43	27	26	33	16	13	16
Wilbur	-	11	44	45	46	44	40	42	36	27	26	23	33	32	40	44	45	3	-	-	-	-	-	-	22	26	31	16	5	15

a. Data collected from 1977 to 1984 not used in subsequent analyses due to faulty sampling protocol.

Table 2. Annual Number of Release Temperature Measurements.

Main River Projects	Year (1900+)																													
	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89
Kentucky	-	11	51	45	48	41	43	35	34	46	49	48	50	54	56	53	54	53	53	57	55	49	51	47	47	28	29	28	34	18
Pickwick	-	13	52	53	53	51	57	51	50	48	47	36	52	53	51	50	50	50	49	46	47	49	48	51	39	26	29	28	32	19
Wilson	-	12	48	50	53	52	53	51	49	53	54	51	50	54	56	56	56	47	52	57	59	51	51	52	43	25	29	29	32	17
Wheeler	40	42	41	36	41	37	40	45	49	47	49	41	48	55	59	59	57	58	57	60	61	53	51	49	47	29	29	28	33	18
Guntersville	47	53	51	50	54	53	48	50	45	53	39	49	49	53	52	49	54	54	50	56	52	52	49	46	34	30	32	28	42	18
Nickajack	-	-	-	-	-	-	-	-	48	52	52	53	51	58	46	50	53	48	48	40	41	29	53	47	27	24	28	29	34	31
Chickamauga	-	10	32	24	51	52	52	52	54	54	52	53	53	62	140	57	59	60	58	60	59	52	61	44	30	21	28	29	34	31
Watts Bar	6	19	51	51	52	50	51	49	46	40	52	52	53	60	66	60	64	63	57	51	48	46	67	49	42	31	43	50	38	42
Fort Loudoun	-	19	63	50	52	50	52	51	47	52	52	61	49	49	151	50	58	57	48	48	54	45	38	41	34	24	26	30	33	26
Tributary Projects																														
Apalachia	-	13	44	46	41	49	31	31	43	39	33	45	29	31	53	50	50	51	53	49	56	48	52	51	30	19	31	18	17	19
Blue Ridge	-	13	51	51	36	32	26	27	22	20	19	15	13	18	39	43	45	45	36	48	38	16	28	40	31	27	38	22	24	27
Boone	-	13	46	46	54	48	50	49	42	44	55	60	52	49	56	55	52	56	50	55	49	48	49	118	47	42	43	21	14	28
Chatuge	-	5	21	21	26	23	17	10	19	23	11	17	11	18	36	43	45	41	33	53	46	22	25	36	32	27	34	29	28	26
Cherokee	-	11	46	42	43	44	40	50	45	43	48	33	34	37	50	49	52	47	56	57	66	31	55	31	26	30	24	30	12	31
Chilhowee	-	13	49	51	48	48	55	42	30	28	42	36	39	43	55	56	56	53	53	55	52	52	49	46	-	12	6	6	7	
Douglas	-	12	53	50	51	49	51	50	40	69	64	50	49	56	60	51	65	51	48	59	54	37	42	33	27	30	25	31	10	31
Fontana	-	13	49	49	48	49	52	46	39	37	37	44	50	51	57	53	54	54	47	46	44	25	40	28	12	18	18	14	17	
Fort Patrick Henry	-	11	50	50	53	51	52	58	45	45	57	49	53	51	48	51	54	56	52	56	62	44	40	118	52	42	44	22	37	28
Hiwassee	-	11	49	46	46	39	41	43	26	20	12	27	25	16	31	43	33	38	33	26	32	28	8	28	21	19	33	18	18	20
Melton Hill	-	-	-	-	7	41	48	57	49	31	45	50	48	41	58	62	53	54	49	42	45	25	37	68	30	26	24	26	10	26
Normandy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	10	9	1	23	-	-	10	-	-	12	-	2	11
Norris	-	13	51	50	47	50	44	50	41	46	51	47	46	48	51	55	53	49	47	52	48	28	37	41	43	29	32	25	12	29
Nottely	-	1	23	20	27	25	18	17	15	14	10	15	13	17	31	46	50	36	29	43	36	17	30	38	25	25	34	25	29	27
Ocoee No. 1	-	13	46	50	50	50	49	51	39	52	38	44	55	56	56	56	55	51	51	61	53	48	47	45	30	16	30	16	4	18
Ocoee No. 3	-	12	45	50	51	48	48	53	41	46	35	46	59	59	59	49	57	53	56	53	50	47	49	44	17	17	15	16	4	17
Santeeetlah	-	-	-	-	-	-	-	-	-	26	16	16	25	36	19	24	39	49	9	-	-	-	-	-	6	16	14	18	4	17
South Holston	-	13	51	52	48	46	38	46	39	35	38	41	43	36	39	48	42	48	39	48	50	35	52	32	49	40	37	25	13	24
Tims Ford	-	-	-	-	-	-	-	-	-	-	-	-	-	41	53	65	64	39	46	45	53	42	44	45	49	31	13	16	20	11
Watauga	-	11	48	47	48	48	46	46	35	31	30	29	34	29	52	45	46	44	47	51	53	34	40	42	27	26	33	16	13	16
Wilbur	-	11	45	43	46	44	39	42	36	27	25	23	34	32	47	45	49	3	-	-	-	-	-	-	22	26	31	16	5	15

ANNUAL PATTERNS IN RELEASE WATER QUALITY

The DO concentration and temperature in the dam releases exhibit a periodic annual cycle. This seasonality varies among the different dams as a result of differences in numerous factors. The seasonal patterns also vary between years for any particular dam. This variation can be due to changes in meteorological and hydrological conditions, reservoir operations, or pollutant loadings. Variation is also introduced depending on the time the measurements are made. For example, the DO concentration in the release from a particular dam in a single day would be different depending on how long the dam had been discharging and which individual units were in use (EPRI, 1990). Collecting data over a period of years improves the ability to predict a mean value for a particular time in the annual cycle.

The seasonal pattern in the mean release water quality and the associated variance can be used to evaluate cause/effect relationships. These patterns can be used to characterize each particular dam for cross-sectional comparisons. Descriptive statistics of weekly mean release DO and temperature for the 30 subject dams are presented graphically in the appendix. These figures show the seasonal patterns and variance of those patterns for the historical measurements, excluding the years 1977 to 1984. Two observations can be made from these figures. The median and mean are generally similar which implies the set of measurements for each week follows a normal distribution. Also, the 95 percent confidence interval of the mean is generally quite small due to the large number of measurements made over the period of record. Thus, the seasonal patterns

Table 3. Onset and Duration of Specific Weekly Mean Dissolved Oxygen Concentrations

Main river projects	Mean Dissolved Oxygen Concentration					
	<5 mg/l		<3 mg/l		<1 mg/l	
	Starts on week number	Number of weeks duration	Starts on week number	Number of weeks duration	Starts on week number	Number of weeks duration
Kentucky	-	0	-	0	-	0
Pickwick	-	0	-	0	-	0
Wilson	-	0	-	0	-	0
Wheeler	-	0	-	0	-	0
Guntersville	-	0	-	0	-	0
Nickajack	-	0	-	0	-	0
Chickamauga	-	0	-	0	-	0
Watts Bar	26	9	-	0	-	0
Fort Loudoun	24	14	-	0	-	0
<u>Tributary Projects</u>						
Apalachia	-	0	-	0	-	0
Blue Ridge	33	7	-	0	-	0
Boone	38	7	-	0	-	0
Chatuge	27	16	31	8	-	0
Cherokee	21	21	24	13	27	7
Chilhowee	-	0	-	0	-	0
Douglas	23	19	26	11	31	2
Fontana	36	11	41	1	-	0
Fort Patrick Henry	25	19	-	0	-	0
Hiwassee	38	4	-	0	-	0
Melton Hill	-	0	-	0	-	0
Normandy	-	0	-	0	-	0
Norris	31	13	37	5	-	0
Nottely	28	15	31	8	-	0
Ocoee No. 1	-	0	-	0	-	0
Ocoee No. 3	-	0	-	0	-	0
Santeetlah	38	4	-	0	-	0
South Holston	34	13	40	4	-	0
Tims Ford	21	28	29	16	38	3
Watauga	42	4	-	0	-	0
Wilbur	-	0	-	0	-	0

of release DO concentration and temperature are well-defined for each dam, with the exception of Normandy.

The seasonal pattern of release DO can be compared among the various dams to identify periods when concentrations typically drop to levels of concern. Table 3 summarizes the extent and duration of weekly mean DO concentration from the releases of the subject dams. Three DO concentrations were used to define levels of concern: 5 mg/l is the standard used by most of the Valley states for the protection of aquatic life in warm water, 3 mg/l is the minimum level most rough fish species can survive for an extended period, and below 1 mg/l is the level where chemically reducing conditions can generate toxic hydrogen sulfide and solubilize metals like iron and manganese. These patterns show that over half of the dams have periods when the release DO is below the water quality standard, about a quarter have periods when rough fish may not survive, and three dams release essentially anoxic water for several weeks. These occurrences of periods of low DO are almost exclusively limited to the dams on Tennessee River tributaries. Only Fort Loudoun and Watts Bar Dams on the main stem Tennessee River show patterns of DO seasonally dropping to below 5 mg/l. This is most likely caused by extremely low DO concentrations in the two upstream releases from Cherokee and Douglas. The release DO concentrations improve in downstream dams due to reaeration.

DISTRIBUTION OF HISTORICAL MEASUREMENTS

An objective of many monitoring programs is to characterize the ambient concentration of a water quality variable. The usual purpose of the monitoring is to provide a spatial or temporal summary of average or extreme conditions. Descriptive statistics are often used for this purpose. The sampling strategy for the monitoring program is designed to provide an estimate of the target population at some predefined level of accuracy and precision. The parametric statistics that are commonly used for this purpose have specific requirements regarding the distribution of the population and independence of the measurements. These assumptions are frequently violated, which can result in summary information that is invalid and misleading. Nonparametric statistics can be used if a particular data set violates the required assumption of a normal distribution. Careful consideration of the monitoring objective and collected are necessary to ensure the appropriate statistics are applied.

The most common descriptive statistics used to summarize average conditions and relative dispersion are the arithmetic mean and variance. The variance can be described as a percentage of the mean as a coefficient of variation (CV). These parametric statistics assume the data are normally distributed and independent. The equivalent nonparametric statistics are the median and quantiles. Quartiles and percentages are terms used to describe specific quantile ranges. The upper and lower quartiles define the range where the middle 50 percent of the values

exist in a data set. The lower and upper quartiles are also called the 25th and 75th percentiles, respectively (Gaugush, 1986).

Parametric statistics are commonly misapplied to data sets that violate the assumptions of the tests. The two assumptions most frequently violated are the normality of the distribution and the mutual independence of the data values. Often water quality data is transformed into a normal distribution by taking the logarithm of each value (log-normal distribution). Usually, the extent of analysis performed to determine the validity of the normality assumption is by inspection of a histogram for a "Bell shape" or a probability plot for linearity. Figures of the cumulative frequency distribution of the historical DO measurements and the annual minimum DO are shown in the appendix.

Frequency distributions can be characterized as normal (Gaussian) by description of their symmetry and shape. A symmetrical distribution is one in which the mean and median are the same. The skewness parameter describes the relative relationship between the mean and median. Log-normal distributions are positively skewed with median value less than the mean. Kurtosis is a parameter measuring the shape of the distribution relative to a normal distribution. Distributions with positive kurtosis appear peaked with a large number of data points near the mean and long flat tails. Distributions with negative kurtosis appear as a flattened peak near the mean with short tails. The nonparametric Kolmogorov-Smirnov test is one method commonly used to test distributions for the assurance of normality (Zar, 1984).

Descriptive statistics of all historical measurements of release DO concentration and annual minimum release DO, excluding the years 1977 to 1984, are shown for the subject dams in tables 4 and 5. The main river projects have less variability relative to most of the tributary projects. The averages also indicate increasing release DO in the main river projects as one moves downstream. The low DO in the Cherokee and Douglas releases and wastewater discharges from the Knoxville metropolitan area has the effect of lowering the DO in the releases of Fort Loudoun and Watts Bar Dams. As the Tennessee River flows downstream, the river absorbs oxygen from the atmosphere by aeration, increasing the release DO in subsequent downstream dams. The frequency distribution of the historical measurements is normal for most of these dams but not the distribution of the annual minimum release DO. Therefore, non-parametric descriptive and inferential statistical tests should be used on the data set of annual minimum DO concentrations.

Percentiles can be used to compare the extent of low release DO among these dams. Table 6 presents the frequency of occurrence of historical and annual minimum DO for three DO concentration levels of concern. Generally, the main river projects have a less frequent occurrence of low DO than the tributary projects, with the exception of Fort Loudoun and Watts Bar Dams. Nearly half of the tributary projects always have an annual minimum DO less than the 5 mg/l standard for the protection of aquatic life. Nearly one-third of the tributary projects always have an annual minimum DO less than the 3 mg/l criteria for the survival of coarse fish species. Release DO from Cherokee and Douglas Dams consistently reach reducing conditions below 1 mg/l. Information

Table 4. Descriptive Statistics of Historical Dissolved Oxygen Measurements

Main River Projects	N	Mean (mg/l)	Median (mg/l)	CV (%)	Lower Upper		Skewness	Kurtosis	Kolmogorov-Smirnov		Probability	Normal Distribution
					Quartile (mg/l)	Quartile (mg/l)			D	D		
Kentucky	841	8.8	8.6	26	7.0	10.8	0.166	-0.725	0.0715	0.0004	0.0004	Yes
Pickwick	898	8.8	8.5	24	7.2	10.2	0.850	2.751	0.0635	0.0014	0.0014	Yes
Wilson	925	8.4	8.2	27	6.6	10.1	0.497	0.597	0.0729	0.0001	0.0001	Yes
Wheeler	919	8.3	8.1	25	6.6	10.1	0.109	-0.919	0.0755	<0.0001	<0.0001	Yes
Guntersville	987	8.4	8.0	23	6.8	10.0	0.365	-0.785	0.0953	<0.0001	<0.0001	Yes
Nickajack	603	7.7	7.2	27	6.0	9.5	0.487	-0.909	0.1168	<0.0001	<0.0001	Yes
Chickamauga	918	8.0	7.8	26	5.2	9.9	0.102	-0.977	0.0820	<0.0001	<0.0001	Yes
Watts Bar	1,022	7.5	7.4	35	5.4	9.7	0.019	-0.684	0.0607	0.0011	0.0011	Yes
Fort Loudoun	932	6.8	6.8	38	4.6	9.1	0.019	-1.044	0.0680	0.0004	0.0004	Yes
Tributary Projects												
Apalachia	710	8.1	8.2	25	6.4	9.9	0.006	-0.773	0.0528	0.0074	0.0074	Yes
Blue Ridge	604	7.1	7.2	36	5.3	9.1	-0.244	-0.581	0.0438	0.1977	0.1977	No
Boone	919	6.7	6.8	37	4.9	8.8	-0.246	-0.689	0.0524	0.0127	0.0127	Yes
Chatuge	477	5.1	4.7	66	2.1	7.5	0.581	-0.039	0.0914	0.0006	0.0006	Yes
Cherokee	781	5.6	5.7	69	1.8	9.3	-0.008	-1.403	0.1009	<0.0001	<0.0001	Yes
Chilhowee	706	8.8	9.0	17	7.5	10.0	-0.237	-0.865	0.0712	0.0015	0.0015	Yes
Douglas	941	5.8	6.1	58	2.9	8.8	-0.082	-1.215	0.0891	<0.0001	<0.0001	Yes
Fontana	986	6.8	7.2	37	4.9	8.8	-0.365	-0.681	0.0762	<0.0001	<0.0001	Yes
Fort Patrick Henry	953	6.3	6.2	43	4.2	8.6	0.177	-0.091	0.0565	0.0045	0.0045	Yes
Hiwassee	605	7.9	8.1	29	6.0	9.9	-0.211	-0.525	0.0947	0.0004	0.0004	Yes
Melton Hill	689	8.7	8.6	22	7.3	10.3	0.019	-0.299	0.0554	0.0292	0.0292	Yes
Normandy	37	9.5	9.3	11	9.0	9.8	1.808	1.016	0.1631	0.2788	0.2788	No
Norris	855	6.7	7.2	47	4.2	9.3	-0.210	0.139	0.0754	0.0001	0.0001	Yes
Nottely	469	5.2	5.1	59	2.2	7.6	0.179	-1.122	0.0856	0.0021	0.0021	Yes
Ocoee No. 1	833	8.7	8.6	16	7.6	9.9	-0.091	0.323	0.0801	<0.0001	<0.0001	Yes
Ocoee No. 3	818	8.2	8.1	17	7.1	9.3	0.049	-0.634	0.0542	0.0163	0.0163	Yes
Santee/Inah	314	8.4	8.9	26	6.8	10.2	-0.465	-0.683	0.1074	0.0014	0.0014	Yes
South Holston	784	6.8	7.4	40	4.7	9.0	-0.482	-0.856	0.0987	<0.0001	<0.0001	Yes
Tims Ford	326	5.0	4.9	69	1.6	8.3	0.123	-1.377	0.1223	0.0001	0.0001	Yes
Watauga	711	8.3	8.9	29	6.6	10.4	-0.606	-0.573	0.1046	<0.0001	<0.0001	Yes
Wilbur	671	8.9	9.3	23	7.5	10.6	-0.775	0.261	0.0919	<0.0001	<0.0001	Yes

Table 5. Descriptive Statistics of Annual Minimum Dissolved Oxygen Measurements

Main River Projects	N	Mean (mg/l)	Median (mg/l)	CV (%)	Lower Upper		Skewness	Kurtosis	Kolmogorov-Smirnov		Probability Distribution
					Quantile (mg/l)	Quantile (mg/l)			D	D	
Kentucky	20	4.9	5.1	19	4.6	5.4	-2.121	4.252	0.2631	0.1255	No
Pickwick	20	5.3	5.7	22	4.8	6.1	-1.166	1.166	0.1564	0.7121	No
Wilson	20	4.5	4.6	27	4.1	5.2	-1.209	2.302	0.1777	0.5525	No
Wheeler	22	4.9	5.3	16	4.4	5.5	-0.869	-0.289	0.1834	0.4496	No
Guntersville	22	5.3	5.2	14	5.0	6.0	-0.268	-0.704	0.1053	0.9677	No
Nickajack	14	4.8	4.9	11	4.5	5.1	-1.235	1.654	0.1634	0.8489	No
Chickamauga	20	4.6	4.8	19	4.2	5.2	-1.141	0.565	0.2239	0.2684	No
Watts Bar	21	3.4	3.2	37	2.3	3.9	0.811	0.313	0.1184	0.9301	No
Fort Loudoun	20	2.5	2.4	41	1.8	3.3	0.338	0.027	0.1512	0.7503	No
Tributary Projects											
Apalachia	21	4.7	4.9	18	4.0	5.3	-0.622	-0.668	0.1763	0.5312	No
Blue Ridge	21	2.6	3.1	45	1.9	3.5	-0.679	-0.666	0.2067	0.3309	No
Boone	21	2.0	1.9	50	1.5	2.6	0.229	-0.458	0.1487	0.7420	No
Chatuge	20	0.6	0.6	62	0.4	1.0	0.765	0.119	0.1731	0.5871	No
Cherokee	20	0.1	0.1	52	0.1	0.1	1.136	3.132	0.2804	0.0862	No
Chilhowee	20	6.3	6.0	19	5.6	6.9	1.219	0.969	0.2479	0.1712	No
Douglas	20	0.3	0.3	80	0.1	0.5	0.575	-0.802	0.1364	0.8505	No
Fontana	21	2.6	2.2	59	1.6	4.1	0.432	-1.021	0.1538	0.7033	No
Fort Patrick Henry	20	1.9	1.7	67	1.0	3.0	0.688	-0.188	0.1640	0.6554	No
Hiwassee	20	3.4	3.5	31	3.0	4.2	-0.796	0.469	0.1399	0.8288	No
Melton Hill	17	4.9	5.3	24	4.5	5.6	-0.815	-0.029	0.1693	0.7147	No
Normandy	3	8.3	8.1	6	7.9	8.8	1.389	0.000	0.3045	0.9437	No
Norris	21	0.7	0.6	62	0.4	1.0	0.567	-0.121	0.1244	0.9015	No
Nottely	20	0.9	0.9	52	0.5	1.3	-0.284	-0.751	0.1380	0.8409	No
Ocoee No. 1	19	6.0	6.3	25	5.9	7.0	-2.206	4.757	0.2945	0.0741	No
Ocoee No. 3	19	5.7	5.8	16	5.2	6.1	-0.018	0.006	0.1307	0.9017	No
Santee/la	13	4.4	4.3	21	3.7	4.9	1.288	2.065	0.1744	0.8242	No
South Holston	21	1.6	1.5	50	1.1	2.3	0.521	-0.386	0.1457	0.7643	No
Tims Ford	9	0.5	0.5	81	0.1	0.6	0.669	-0.705	0.2009	0.8608	No
Watauga	21	3.7	3.7	32	2.6	4.6	0.270	-0.693	0.1130	0.9514	No
Wilbur	19	4.3	4.3	44	3.9	5.7	-0.559	0.145	0.1994	0.4366	No

Table 6. Distribution of Historical and Annual Minimum Dissolved Oxygen Measurements

Main River Projects	Percent All Historical DO Measurements			Percent Annual Minimum DO		
	<5 mg/l	<3 mg/l	<1 mg/l	<5 mg/l	<3 mg/l	<1 mg/l
Kentucky	2	0.4	0	30	10	0
Pickwick	2	0.1	0	30	5	0
Wilson	4	0.2	0	70	10	0
Wheeler	4	0	0	36	0	0
Guntersville	1	0	0	27	0	0
Nickajack	3	0	0	50	0	0
Chickamauga	4	0.1	0	60	5	0
Watts Bar	20	4	0	86	43	0
Fort Loudoun	29	6	0.1	100	60	5
<u>Tributary Projects</u>						
Apalachia	4	0	0	52	0	0
Blue Ridge	21	5	1	100	48	14
Boone	26	9	1	100	81	19
Chatuge	53	34	7	100	100	75
Cherokee	45	33	18	100	100	100
Chilhowee	0	0	0	5	0	0
Douglas	43	25	9	100	100	100
Fontana	25	9	0.4	90	62	14
Fort Patrick Henry	34	11	0	100	75	25
Hiwassee	11	0.8	0	95	25	0
Melton Hill	2	0.1	0	35	6	0
Normandy	0	0	0	0	0	0
Norris	30	17	5	100	100	76
Nottely	49	31	6	100	100	55
Ocoee No. 1	0	0	0	10	10	0
Ocoee No. 3	0	0	0	10	0	0
Santeetlah	9	0	0	77	0	0
South Holston	26	14	0.6	100	90	19
Tims Ford	51	37	16	100	100	89
Watauga	13	2	0	86	33	0
Wilbur	4	0.5	0.3	68	16	12

on the frequency of occurrence of low release DO can be helpful in prioritizing projects for future assessments or corrective action.

Another assumption commonly violated when applying statistics is using dependent data. The assumption of independence is required for both parametric and nonparametric statistical tests. Water quality monitoring programs frequently use a systematic sampling design; samples are collected at equally spaced intervals over time (e.g. weekly). Systematic sampling design is usually selected because the monitoring goals are often defined to answer several objectives: mean concentrations, seasonal patterns, and detection of trends. If the data collected with a systematic sampling design follows a seasonality, misleading and biased descriptive statistics can result from data that are not mutually independent. Therefore, even the estimation of a mean can be invalid if the data are correlated by seasonality.

If observations from a data set following a seasonal pattern are collected close enough together in time, the data series can exhibit serial or autocorrelation. In a correlated data series, each data point contributes less new information because some of the information is already contained in the existing data points: some degree of redundancy occurs in successive observations. A sample mean estimated from correlated observations will contain less information than one computed from independent observations. Also, a sample mean estimated from correlated data will have a larger confidence interval associated with it. The dependence of a data series can be quantified by an autocorrelation function. Water quality time series data can often be described by

a first-order autoregressive (Markov type) dependence structure (Lettenmaier, 1976).

A first order autocorrelation coefficient, often called lag-one coefficient, is a measure of the correlation between adjacent values in a data series. Higher order autocorrelation coefficients describe the correlation between the data series and the same series shifted or lagged by more time intervals. The level of significance of the autocorrelations in higher order lags will determine the sampling frequency where observations would be independent. Effective sample size (N_e) can be estimated from several lags of the autocorrelation coefficient (Yevjevich, 1972). However, the most effective sample size will be slightly larger due to the unreliability of higher order coefficients. It is suggested that only the significant coefficient values be used when computing the effective sample size to minimize the effect of the uncertain higher lags (Reckhow and Chapra, 1983). If no autocorrelation is present and the data series is normally distributed, then the optimum sample size can be easily determined with estimates of the mean and variance (Gaugush, 1987).

The monitoring strategy for the measurement of DO and temperature in the releases of the subject dams uses a stratified sampling design; measurements are planned to be made weekly at a time of day when the hydro units are operating. However, examination of the collected data show the resulting sampling design is a combination of simple random, stratified random, and systematic sampling. Even though measurements were made weekly, the specific day of sampling varied. Thus the time interval between measurements varied from 3 days to 11 days. Also,

there are many weeks when sampling did not occur and other weeks where two or more measurements were made. Inspection of tables 1 and 2 show that measurements were not made consistently among years. Only rarely were 52 measurements made in single year indicating the systematic sampling design was not precisely followed over the years.

Since the release data were not sampled at equal time intervals, it is not possible to test the entire data series for autocorrelation. However, the dependence of the weekly pattern can be tested using the mean values for each week of the entire data set. This analysis would give a conservative estimate of the autocorrelation caused by seasonality and suggest an effective sampling size to estimate means. The estimated effective sampling size computed from the weekly means would actually be larger since the between week variance would not be included.

The autocorrelation coefficients and effective sampling size (N_e) for the reservoir release DO data are presented for annual and 20-week summer periods in tables 7 and 8. For the annual period, the data are significantly correlated over a 4 to 5 week lag period, with an effective sampling frequency every 7 weeks to estimate the annual mean. For the 20 week summer period, the data are significantly correlated over a 1 to 2 week lag period with an effective sampling frequency every 4 weeks to estimate the seasonal mean. These results suggest that systematic sampling should be conducted monthly in the spring and summer and bi-monthly in the fall and winter to compute seasonal and annual descriptive statistics. Monthly sampling is generally suggested to avoid problems with autocorrelation when estimating descriptive statistics (Sanders et al., 1983; Gilbert, 1987).

Table 7. Autocorrelation Coefficients and Effective Sample Size for 52-Week Period. Underlined values are significant at a 95 percent confidence level.

Main River Projects	Mean DO (mg/l)	CV (%)	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	N _e
Kentucky	9.0	24	<u>0.958</u>	<u>0.910</u>	<u>0.850</u>	<u>0.777</u>	0.696	0.607	7
Pickwick	8.9	20	<u>0.906</u>	<u>0.858</u>	<u>0.790</u>	<u>0.731</u>	0.633	0.564	8
Wilson	8.6	23	<u>0.954</u>	<u>0.901</u>	<u>0.833</u>	<u>0.760</u>	0.680	0.594	7
Wheeler	8.5	23	<u>0.953</u>	<u>0.901</u>	<u>0.838</u>	<u>0.763</u>	0.683	0.596	7
Guntersville	8.5	20	<u>0.957</u>	<u>0.912</u>	<u>0.847</u>	<u>0.772</u>	0.696	0.607	7
Nickajack	8.0	25	<u>0.956</u>	<u>0.900</u>	<u>0.837</u>	<u>0.770</u>	<u>0.697</u>	0.614	7
Chickamauga	8.2	24	<u>0.955</u>	<u>0.906</u>	<u>0.847</u>	<u>0.779</u>	0.708	0.627	7
Watts Bar	7.8	30	<u>0.962</u>	<u>0.924</u>	<u>0.871</u>	<u>0.801</u>	0.726	0.638	7
Fort Loudoun	7.0	34	<u>0.962</u>	<u>0.918</u>	<u>0.863</u>	<u>0.795</u>	0.716	0.637	7
<u>Tributary Projects</u>									
Apalachia	8.3	23	<u>0.978</u>	<u>0.948</u>	<u>0.907</u>	<u>0.852</u>	<u>0.786</u>	0.711	7
Blue Ridge	8.0	30	<u>0.960</u>	<u>0.917</u>	<u>0.855</u>	<u>0.797</u>	0.719	0.631	7
Boone	6.9	29	<u>0.951</u>	<u>0.905</u>	<u>0.844</u>	<u>0.771</u>	0.686	0.601	7
Chatuge	6.9	46	<u>0.905</u>	<u>0.856</u>	<u>0.799</u>	<u>0.770</u>	0.683	0.596	8
Cherokee	6.1	61	<u>0.975</u>	<u>0.936</u>	<u>0.883</u>	<u>0.815</u>	0.737	0.650	7
Chilhowee	8.9	15	<u>0.982</u>	<u>0.953</u>	<u>0.914</u>	<u>0.864</u>	<u>0.806</u>	0.737	7
Douglas	6.2	52	<u>0.968</u>	<u>0.925</u>	<u>0.872</u>	<u>0.805</u>	<u>0.725</u>	0.640	7
Fontana	7.1	30	<u>0.981</u>	<u>0.949</u>	<u>0.900</u>	<u>0.836</u>	<u>0.760</u>	0.675	7
Fort Patrick Henry	6.6	35	<u>0.965</u>	<u>0.934</u>	<u>0.884</u>	<u>0.826</u>	<u>0.753</u>	0.678	7
Hiwassee	8.0	26	<u>0.969</u>	<u>0.935</u>	<u>0.887</u>	<u>0.830</u>	<u>0.765</u>	0.691	7
Melton Hill	8.9	18	<u>0.938</u>	<u>0.895</u>	<u>0.859</u>	<u>0.790</u>	0.707	0.652	7
Norris	7.1	40	<u>0.968</u>	<u>0.932</u>	<u>0.878</u>	<u>0.809</u>	0.732	0.646	7
Nottely	6.7	45	<u>0.945</u>	<u>0.904</u>	<u>0.838</u>	<u>0.774</u>	0.694	0.610	7
Ocoee No. 1	8.7	14	<u>0.963</u>	<u>0.923</u>	<u>0.871</u>	<u>0.805</u>	0.734	0.655	7
Ocoee No. 3	8.2	14	<u>0.938</u>	<u>0.883</u>	<u>0.816</u>	<u>0.751</u>	0.666	0.585	8
Santeetlah	8.2	25	<u>0.960</u>	<u>0.939</u>	<u>0.888</u>	<u>0.848</u>	<u>0.778</u>	0.714	7
South Holston	7.1	35	<u>0.984</u>	<u>0.956</u>	<u>0.912</u>	<u>0.853</u>	<u>0.784</u>	0.706	7
Tims Ford	5.4	59	<u>0.945</u>	<u>0.904</u>	<u>0.853</u>	<u>0.797</u>	<u>0.736</u>	0.654	7
Watauga	8.5	26	<u>0.979</u>	<u>0.950</u>	<u>0.904</u>	<u>0.848</u>	<u>0.783</u>	0.712	7
Wilbur	9.0	19	<u>0.950</u>	<u>0.929</u>	<u>0.886</u>	<u>0.837</u>	<u>0.770</u>	0.699	7

Table 8. Autocorrelation Coefficients and Effective Sample Size for 20-Week Period (May-September). Underlined values are significant at a 95 percent confidence level.

Main River Projects	Mean DO (mg/l)	CV (%)	Lag 1	Lag 2	Lag 3	Lag 4	N _e
Kentucky	6.7	10	<u>0.721</u>	0.510	0.389	0.154	6
Pickwick	7.3	7	0.324	0.408	0.105	-0.032	8
Wilson	6.6	9	<u>0.680</u>	0.450	0.260	0.096	6
Wheeler	6.5	6	<u>0.559</u>	0.378	0.314	0.028	7
Guntersville	6.7	5	<u>0.594</u>	0.337	0.176	-0.008	7
Nickajack	6.1	9	<u>0.728</u>	0.599	0.415	0.248	5
Chickamauga	6.2	9	<u>0.655</u>	0.517	0.355	0.088	6
Watts Bar	5.3	16	<u>0.679</u>	0.531	0.272	0.058	6
Fort Loudoun	4.6	17	<u>0.787</u>	0.556	0.373	0.163	5
<u>Tributary Projects</u>							
Apalachia	7.1	20	<u>0.861</u>	<u>0.707</u>	0.569	0.440	5
Blue Ridge	6.0	31	<u>0.875</u>	<u>0.735</u>	0.569	0.425	5
Boone	5.5	14	<u>0.503</u>	0.286	0.156	-0.009	8
Chatuge	4.1	56	<u>0.872</u>	<u>0.737</u>	0.575	0.415	5
Cherokee	2.2	82	<u>0.721</u>	0.550	0.294	0.079	6
Chilhowee	8.3	11	<u>0.848</u>	<u>0.714</u>	0.583	0.441	5
Douglas	2.9	64	<u>0.818</u>	0.618	0.422	0.209	5
Fontana	6.8	23	<u>0.842</u>	0.664	0.517	0.361	5
Fort Patrick Henry	4.6	22	<u>0.717</u>	0.511	0.384	0.256	6
Hiwassee	6.8	23	<u>0.828</u>	0.672	0.551	0.414	5
Melton Hill	7.7	12	<u>0.645</u>	0.469	0.501	0.407	6
Norris	5.6	42	<u>0.883</u>	<u>0.740</u>	0.588	0.458	5
Nottely	4.2	57	<u>0.891</u>	<u>0.744</u>	0.592	0.431	5
Ocoee No. 1	7.6	6	<u>0.699</u>	0.533	0.438	0.217	6
Ocoee No. 3	7.1	5	<u>0.748</u>	0.583	0.338	0.208	5
Santeetlah	7.2	20	<u>0.823</u>	0.631	0.510	0.430	5
South Holston	6.7	29	<u>0.851</u>	<u>0.715</u>	0.580	0.419	5
Tims Ford	3.0	55	<u>0.750</u>	0.602	0.543	0.443	5
Watauga	8.2	19	<u>0.848</u>	<u>0.728</u>	0.567	0.419	5
Wilbur	8.7	15	<u>0.862</u>	0.691	0.561	0.401	5

TREND ANALYSIS

One of the primary goals of long-term monitoring is the detection of changes or trends over time. The detection and estimation of a trend in water quality is complicated by a number of factors including changes in procedures, seasonality, autocorrelation, and correlations with stream flow. A change in sampling protocol or an analytical procedure is likely in any long-term monitoring program. Unfortunately, if comparative studies are not conducted with such a change, the data may show an apparent trend. This was shown to be the case with the trend in release DO detected by Meinert (1980). The seasonal cycles common in water quality data make trend detection more difficult due to the added variation. Most trend tests require the data to be serially independent, so data must be carefully evaluated in order to select an appropriate trend test. Also, many water quality variables are correlated to stream flow. Data of this type must be adjusted so that trends are not detected that are caused by changes in hydrologic conditions.

Many different methods have been used for trend analysis. Graphical methods are often used as a first step in identifying trends. Usually a plot of the data or residual against time is visually inspected. If a trend is apparent, a linear regression of the variable against time is fit to the data and a t-test is used to evaluate whether the resulting slope is significantly different than zero. However, the data must be normally distributed, serially independent, and not have seasonal cycles (Montgomery and Loftis, 1987). If any one of these assumptions are violated, the t-test may indicate a significant slope when the true slope

is actually zero (Hirsch et al., 1982). Fehring (in prep.) used this method to demonstrate that a step-trend occurred as a result of the change in sampling protocol for the measurement of release DO.

Intervention analysis is another widely used technique for evaluating trends. The approach is a generalization of the autoregressive integrated moving-average (ARIMA) time series models (Box and Tiao, 1975; Box and Jenkins, 1976). These modeling techniques are powerful methods for the analysis of time series data and are included in several packaged statistical programs. The analysis separates the data series into four components: base level, trend, cycle, and random fluctuations. These components are combined into a mathematical model that predicts future values of the series. However, the technique has two primary disadvantages over other methods: (1) a long record of evenly spaced observations with no missing values is required, and (2) it is technically difficult to apply. Meinert (1980) used a similar method for the trend analysis of release DO from Tennessee River projects.

Nonparametric methods for trend detection are particularly useful for most water quality data series. These tests have a number of advantages for use with water quality data: missing values are allowed, no particular frequency distribution is required, and data reported as less than the detection limit can be used. Although a number of nonparametric trend tests are available (Berryman et al., 1988), the Mann-Kendall test is the most commonly used (Mann, 1945; Kendall, 1975). A modification of the Mann-Kendall trend test is used if seasonal cycles are present. The modified method, called the seasonal Kendall test, removes the seasonal

cycles before the test for trend is evaluated (Hirsch et al., 1982). Several investigators have recommended the seasonal Kendall trend test to numerous other trend tests after rigorous statistical comparisons (Berryman et al., 1988; Lettenmaier, 1988; Loftis and Taylor, 1989). The seasonal Kendall trend test requires mutually independent data, but it is robust to mild violations of this assumption and the results can be corrected for slightly significant autocorrelation (Hirsch and Slack, 1984). Also, the test detects only monotonic trends; trends in different directions will cancel.

Hydrologic conditions can have an effect on the measured release DO of the subject dams. Fehring (in prep.) showed that for the main river projects, mean summer release DO correlated strongly with mean summer discharge, with an average explained variance of about 80 percent. Thus, a decrease in discharge may lower the concentration of release DO. A similar effect may also occur with release temperature. It is important to account for flow relationships when testing for trends. The Tennessee Valley experienced a drought during the years 1984 through 1988. If trend tests were conducted on the release data without accounting for the lower flows, trends could be detected that were the result of the drought. Removing the effect of flow the release water quality allows the detection of trends not associated with hydrologic conditions.

The approach to removing the flow effect on release data is to develop a time series of flow-adjusted measurements, which are residuals from significant regression equations. The time series of residuals are then tested for trends. The residual is the actual measurement minus the

estimate derived from the regression. If there is no trend in the time series, the residuals would fluctuate randomly about zero over the period of record. A trend would be detected if the residuals changed significantly from zero over time. Smith et al. (1982) proposes that several regression models be tested for flow relationships. It is suggested that the model that explains the greatest variance be used to compute the residual, but only if the regression is significant. If no significant regressions can be found between the measurements and flow, then residuals should not be computed and the actual measurements used for trend testing.

Since the seasonal Kendall trend test requires data that is serially independent, the reservoir release data must be reduced to eliminate any autocorrelation before testing for trends. In the previous section it was shown that a 4 to 5 week lag was required to eliminate significant autocorrelation in the annual patterns of release DO. Thus, monthly means were used to test for trends in release DO and temperature from the subject dams. The monthly mean release data was regressed against monthly mean flows using 6 regression models: linear, logarithmic, inverse, multiplicative, exponential, and reciprocal (hyperbolic). The regression model which explained the most variance was chosen to compute residuals. If the probability of the regression was greater than 0.05, residuals were not computed and the monthly mean was retained for the time series. The residuals or monthly mean measurements were then tested for trend with the seasonal Kendall test.

The regressions of monthly mean DO on monthly mean discharge that were selected to compute flow-adjusted concentrations are shown in table 9. Figures of the regressions and monthly discharge for each dam are presented in the appendix. Normandy was the only project that a significant regression was not found with the models tested. The explained variance was quite low for most of the regressions. The main river projects show a better relationship to discharge than the tributary projects. Also, the discharge relationship is generally higher with downstream projects. Although many of these regressions only explain a small percentage of the variance, the residuals from significant regressions were still used to eliminate any discharge effect on the trend analysis.

The results of the trend tests for monthly mean DO are shown in table 10. The results are ranked according to their relative probability, with significant positive trends listed at the top and significant negative trends at the bottom. One should note not only the significance of the detected trend, but the magnitude as well. For example, although release DO data from Ocoee No. 3 show a highly significant positive trend, the magnitude is less than 0.1 mg/l. The significant positive trends in release DO for the other projects can probably be explained by reductions in wastewater loadings. Significant negative trends were detected in the releases of 6 projects, 3 of which are in the Hiwassee River watershed. Negative trends in this watershed may be related to the rapid development of second homes and retirement homes (Cox, 1989).

Table 9. Selected Regression Equations of Monthly Mean Dissolved Oxygen on Monthly Mean Discharge

Main River Projects	Degrees of freedom	Selected model	Model coefficients		Percent explained variance	Probability
			a	b		
Kentucky	241	DO = aQ^b	5.19E-05	0.2399	32.96	<0.00001
Pickwick	240	DO = $a+b(\ln Q)$	-11.47	1.8919	35.79	<0.00001
Wilson	242	DO = aQ^b	0.0037	0.2210	24.88	<0.00001
Wheeler	263	DO = $a+b(\ln Q)$	-13.6847	2.0852	32.40	<0.00001
Guntersville	262	DO = $a+bQ$	6.9827	3.90E-05	20.79	<0.00001
Nickajack	163	DO = $a+bQ$	6.3665	4.90E-05	18.63	<0.00001
Chickamauga	237	DO = $\exp(a+bQ)$	1.8735	6.00E-06	14.90	<0.00001
Watts Bar	249	DO = $\exp(a+bQ)$	1.7234	9.79E-06	12.61	<0.00001
Fort Loudoun	240	DO = $a+bQ$	5.2326	1.22E-04	9.89	<0.00001
<u>Tributary Projects</u>						
Apalachia	238	DO = $a+b(1/Q)$	7.6977	858.54	4.48	0.00099
Blue Ridge	189	DO = $a+b(\ln Q)$	13.9136	-1.0132	9.24	0.00002
Boone	241	DO = $\exp(a+bQ)$	1.6124	1.09E-0	8.78	<0.00001
Chatuge	164	DO = $a+b(\ln Q)$	10.8852	-0.8481	3.29	0.01979
Cherokee	235	DO = $a+b(\ln Q)$	15.3240	-1.1303	5.36	0.00034
Chilhowee	203	DO = $a+b(1/Q)$	8.1318	3244.18	5.37	0.00086
Douglas	237	DO = $a+bQ$	5.1450	1.48E-04	2.09	0.02582
Fontana	240	DO = $a+b(\ln Q)$	20.5231	-1.6255	12.58	<0.00001
Fort Patrick Henry	242	DO = $1/(a+bQ)$	0.2399	-2.21E-05	5.75	0.00016
Hiwassee	218	DO = $a+b(1/Q)$	7.2694	1003.22	6.22	0.00019
Melton Hill	183	DO = $1/(a+bQ)$	0.1265	-1.55E-06	3.45	0.01165
Normandy	19	None	---	---	---	---
Norris	237	DO = $a+b(1/Q)$	6.4742	1269.02	3.23	0.00540
Nottely	163	DO = $a+b(\ln Q)$	10.4546	-0.8131	4.34	0.00741
Ocoee No. 1	232	DO = $a+bQ$	7.5617	8.08E-04	12.96	<0.00001
Ocoee No. 3	227	DO = $1/(a+bQ)$	0.1389	-1.28E-05	7.29	0.00004
Santeetlah	138	DO = $a+bQ$	6.6169	3.34E-04	15.86	<0.00001
South Holston	236	DO = $a+b(1/Q)$	6.5258	278.51	1.89	0.03431
Tims Ford	109	DO = $a+bQ$	4.8217	6.99E-04	3.64	0.04595
Watauga	235	DO = $a+b(1/Q)$	8.0116	188.08	4.56	0.00097
Wilbur	229	DO = $1/(a+bQ)$	8.5500	233.11	3.76	0.00315

Table 10. Results of Seasonal Kendall Trend Test for Dissolved Oxygen

Project	Span of Years	Slope of Trend (mg/l/yr)	Net Change Over Period (mg/l)	Probability	Significant at 95% Confidence
Ocoee No. 3	28	0.0006	<0.1	0.0006	Yes
Chilhowee	28	0.0453	1.3	0.0009	Yes
Fontana	28	0.0614	1.7	0.0016	Yes
Fort Loudoun	28	0.0339	0.9	0.0159	Yes
Watts Bar	30	0.0045	0.1	0.0288	Yes
Tims Ford	18	0.1195	2.2	0.0736	No
Boone	28	0.0033	0.1	0.0772	No
Normandy	14	0.0635	0.9	0.1587	No
Ocoee No. 1	28	0.0097	0.3	0.1689	No
Chickamauga	28	0.0013	<0.1	0.2203	No
Nickajack	22	0.0229	0.5	0.2363	No
Guntersville	30	0.0149	0.4	0.2477	No
Kentucky	28	0.0008	<0.1	0.5530	No
Santeetlah	22	-0.0059	-0.1	0.8555	No
Douglas	28	-0.0071	-0.2	0.5886	No
Wilbur	28	-0.0065	-0.2	0.5549	No
Wilson	28	-0.0018	-0.1	0.4642	No
Melton Hill	25	-0.0001	-0.1	0.4532	No
Wheeler	30	-0.0107	-0.3	0.3642	No
Blue Ridge	28	-0.0117	-0.3	0.3203	No
Cherokee	28	-0.0137	-0.4	0.2947	No
Watauga	28	-0.0145	-0.4	0.1964	No
Nottely	28	-0.0247	-0.7	0.1442	No
Pickwick	28	-0.0278	-0.8	0.0266	Yes
South Holston	28	-0.0339	-0.9	0.0140	Yes
Chatuge	28	-0.0549	-1.5	0.0137	Yes
Hiwassee	28	-0.0270	-0.8	0.0091	Yes
Apalachia	28	-0.0351	-1.0	0.0023	Yes
Norris	28	-0.0512	-1.4	0.0022	Yes
Fort Patrick Henry	28	-0.0020	-0.1	0.0001	Yes

Since 1975, the average global temperature has been increasing at a high rate (La Brecque, 1989). Due to this climate change, there exists the possibility that a trend in release water temperature may exist for the subject dams. Monthly mean release temperatures from the subject dams were tested for trends in the same manner as described for release DO. The selected equations from significant regressions that were used to compute residuals appear in table 11. Here again the discharge relationships explain a greater amount of variance for the downstream main river projects than for the tributary projects. The results of the trend tests for release temperature are shown in table 12. Although 3 projects show significant positive trends in temperature, the largest change has occurred in the Hiwassee Dam releases. This trend in increased temperature may be explained by a change in trophic state related to the development in the watershed (Mazumder, 1990). No explanation can be given for the apparent negative temperature trend detected in releases of Wilbur and Fort Patrick Henry Dams. Overall, no regional trends in temperature can be detected in the releases of the subject dams.

A trend analysis can also be conducted on the annual minimum DO to give an indication whether these extreme levels are improving or declining. For each dam, the annual minimum DO was regressed against two discharge values: the mean daily discharge for the date each minimum DO was measured, and the mean discharge for the 7 days preceding the measurement of the minimum DO. The annual minimum DO was used only if sufficient data was collected for a particular year to assure that a reasonable minimum was measured. The same regression models were used

Table 11. Selected Regression Equations of Monthly Mean Temperature
on Monthly Mean Discharge

Main River Projects	Degrees of freedom	Selected model	Model coefficients a	b	Percent explained variance	Probability
Kentucky	337	$T = a+b(\ln Q)$	89.0543	-6.6147	24.92	<0.00001
Pickwick	334	$T = a+b(\ln Q)$	97.3316	-7.3078	27.33	<0.00001
Wilson	335	$T = a+b(\ln Q)$	95.0414	-7.2559	28.49	<0.00001
Wheeler	359	$T = a+bQ$	25.0501	-1.32E-04	25.15	<0.00001
Guntersville	357	$T = a+bQ$	24.5319	-1.68E-04	22.29	<0.00001
Nickajack	258	$T = a+bQ$	23.0414	-1.68E-04	14.85	<0.00001
Chickamauga	328	$T = a+bQ$	23.1015	-1.69E-04	14.62	<0.00001
Watts Bar	341	$T = a+bQ$	21.2188	-1.70E-04	10.70	<0.00001
Fort Loudoun	333	$T = \exp(a+bQ)$	2.8961	-1.43E-05	4.16	0.00018
<u>Tributary Projects</u>						
Apalachia	333	$T = a+b(1/Q)$	13.9839	-1891.82	4.04	0.00022
Blue Ridge	276	$T = aQ^b$	12.1857	0.2189	15.46	<0.00001
Boone	336	$T = a+b(1/Q)$	12.0954	-2050.63	2.19	0.00655
Chatuge	257	None	-	-	-	-
Cherokee	326	$T = a+b(\ln Q)$	-6.3933	2.4073	8.20	<0.00001
Chilhowee	298	$T = a+bQ$	13.4862	-2.47E-04	1.51	0.03385
Douglas	332	$T = \exp(a+bQ)$	2.7007	-2.35E-05	1.76	0.01546
Fontana	327	$T = aQ^b$	0.7736	0.2987	16.61	<0.00001
Fort Patrick Henry	335	None	-	-	-	-
Hiwassee	299	$T = a+b(1/Q)$	13.2049	-1853.95	4.48	0.00022
Melton Hill	273	$T = a+bQ$	15.8855	-2.37E-04	2.44	0.00954
Normandy	40	None	-	-	-	-
Norris	332	$T = aQ^b$	37.6210	0.0963	4.96	0.00004
Nottely	248	$T = a+b(\ln Q)$	4.0533	1.3924	4.79	0.00050
Ocoee No. 1	324	$T = a+bQ$	19.1894	-2.76E-04	7.29	<0.00001
Ocoee No. 3	316	$T = a+bQ$	16.5667	-1.91E-03	2.24	0.00762
Santeeetlah	143	$T = a+b(\ln Q)$	27.5065	-2.6777	11.95	0.00002
South Holston	330	$T = aQ^b$	14.4871	0.1489	9.75	<0.00001
Tims Ford	203	None	-	-	-	-
Watauga	331	$T = aQ^b$	39.5449	0.0872	9.11	<0.00001
Wilbur	235	$T = a+b(1/Q)$	10.2091	-340.06	6.20	0.00011

Table 12. Results of Seasonal Kendall Trend Test for Temperature

Project	Span of Years	Slope of Trend (deg. C/yr)	Net Change Over Period (deg. C)	Probability	Significant at 95% Confidence
Fontana	28	0.0067	0.2	0.0012	Yes
Hiwassee	28	0.0372	1.0	0.0255	Yes
Blue Ridge	28	0.0031	0.1	0.0283	Yes
Normandy	14	0.1708	2.4	0.0667	No
Boone	28	0.0269	0.8	0.0804	No
Ocoee No. 3	28	0.0465	1.3	0.1022	No
Apalachia	28	0.0169	0.5	0.2891	No
Santeetlah	22	0.0736	1.6	0.3153	No
Fort Loudoun	29	0.0016	<0.1	0.3161	No
Ocoee No. 1	28	0.0097	0.3	0.5480	No
Melton Hill	25	0.0123	0.3	0.5710	No
Guntersville	30	0.0205	0.6	0.5767	No
Wilson	28	0.0166	0.5	0.6476	No
South Holston	28	0.0002	<0.1	0.9144	No
Chatuge	28	0.0000	<0.1	0.9229	No
Chickamauga	28	0.0017	<0.1	0.9593	No
Nottely	28	-0.0010	>-0.1	0.9518	No
Pickwick	28	-0.0050	-0.1	0.9203	No
Tims Ford	18	-0.0254	-0.5	0.7543	No
Nickajack	22	-0.0137	-0.3	0.7535	No
Norris	28	-0.0009	>-0.1	0.5504	No
Watts Bar	30	-0.0213	-0.6	0.4688	No
Wheeler	30	-0.0228	-0.7	0.4600	No
Cherokee	28	-0.0122	-0.3	0.4547	No
Chilhowee	28	-0.0118	-0.3	0.3960	No
Watauga	28	-0.0021	-0.1	0.2036	No
Douglas	28	-0.0024	-0.1	0.1017	No
Kentucky	28	-0.0725	-2.0	0.0722	No
Wilbur	28	-0.0550	-1.5	0.0134	Yes
Fort Patrick Henry	28	-0.0442	-1.2	0.0014	Yes

as before and regression equations were only selected if they were significant at a 95 percent confidence level. The results of these regressions are presented in the appendix and the selected equations are summarized in table 13. The percent of variance explained by these regressions were much higher than the relationships of monthly means, but far fewer were significant enough to be selected for computing residuals. Since the annual minimum DO values do not exhibit seasonality, the Mann-Kendall test was used for the detection of trends and the results are shown in table 14. Improvements in the annual minimum DO was detected for 6 projects over the period of record. Four of these were previously shown to also have positive trend in monthly mean release DO. Releases from Cherokee, Douglas, and Apalachia Dams appear to show negative trends in annual minimum DO, indicting the extreme levels have declined over the period of record.

Table 13. Selected Regression Equations of Annual Minimum Dissolved Oxygen on Discharge

Main river projects	Degrees of freedom	Selected model	Model coefficients		Percent explained variance	Probability
			a	b		
Kentucky	27	DO = aQ^b	8.98E-05	0.5313	38.53	0.00042
Pickwick	27	DO = $a+b(\ln Q7)$	-11.8723	1.6251	29.95	0.00258
Wilson	27	DO = $a+bQ$	3.026	3.38E-05	15.06	0.04128
Wheeler	29	None	-	-	-	-
Guntersville	29	DO = $1/(a+bQ)$	0.2401	-1.44E-06	34.40	0.00066
Nickajack	21	None	-	-	-	-
Chickamauga	27	DO = $a+b(\ln Q)$	-13.4061	1.74697	30.42	0.00235
Watts Bar	29	DO = $1/(a+bQ7)$	0.6246	-1.37E-05	50.33	0.00001
Fort Loudoun	27	DO = $a+bQ7$	1.1076	1.21E-04	48.66	0.00004
Tributary Projects						
Apalachia	28	None	-	-	-	-
Blue Ridge	28	DO = $aQ7^b$	1.51E-04	0.7268	65.78	<0.00001
Boone	28	DO = $a+b(1/Q7)$	3.7171	-2613.29	33.61	0.00098
Chatuge	27	None	-	-	-	-
Cherokee	27	DO = $a+b(\ln Q)$	-0.9008	0.1203	23.97	0.00818
Chilhowee	27	DO = $a+b(1/Q)$	3.9881	11302.4	41.57	0.00021
Douglas	27	DO = $1/(a+bQ)$	11.1812	-7.41E-04	14.32	0.04706
Fontana	28	DO = $a+b(1/Q7)$	1.0992	7723.83	19.58	0.01623
Fort Patrick Henry	28	DO = $a+bQ7$	0.6229	7.96E-04	28.91	0.00263
Hiwassee	28	None	-	-	-	-
Melton Hill	24	DO = $a+b(1/Q7)$	5.7199	-2859.16	29.49	0.00503
Normandy	7	None	-	-	-	-
Norris	28	None	-	-	-	-
Nottely	27	DO = aQ^b	0.0159	0.2409	15.27	0.03976
Ocoee No. 1	27	None	-	-	-	-
Ocoee No. 3	26	None	-	-	-	-
Santeetlah	12	None	-	-	-	-
South Holston	28	None	-	-	-	-
Tims Ford	17	None	-	-	-	-
Watauga	28	DO = $1/(a+bQ7)$	0.2145	1.61E-04	30.26	0.00199
Wilbur	19	None	-	-	-	-

Notes: Q = mean daily discharge for date of annual minimum DO.

Q7 = mean discharge for seven days preceding date of annual minimum DO.

Table 14. Results of Mann-Kendall Trend Test for Annual Minimum Dissolved Oxygen

Project	Span of Years	Slope of Trend (mg/l/yr)	Net Change Over Period (mg/l)	Probability	Significant at 95% Confidence
Fort Loudoun	28	0.0521	1.5	0.0032	Yes
Fontana	29	0.0982	2.8	0.0050	Yes
Chatuge	28	0.0251	0.7	0.0122	Yes
Blue Ridge	29	0.0217	0.6	0.0320	Yes
Chilhowee	29	0.0450	1.3	0.0350	Yes
Ocoee No. 3	28	0.0571	1.6	0.0386	Yes
Fort Patrick Henry	28	0.0703	2.0	0.0688	No
Nottely	28	0.0238	0.7	0.0980	No
Watauga	29	0.0466	1.4	0.1742	No
Guntersville	30	0.0042	0.1	0.1759	No
Wilbur	28	0.0400	1.1	0.5991	No
Santeetlah	22	0.0359	0.8	0.6249	No
Melton Hill	25	0.0200	0.5	0.6499	No
Wilson	28	0.0171	0.5	0.6721	No
Watts Bar	29	0.0005	<0.1	0.7858	No
Nickajack	22	0.0000	<0.1	0.9560	No
Pickwick	28	0.0026	0.1	0.9741	No
Normandy	14	0.0539	0.8	1.0000	No
Kentucky	28	-0.0003	>-0.1	0.6732	No
South Holston	29	-0.0066	-0.2	0.7623	No
Boone	29	-0.0098	-0.3	0.5661	No
Chickamauga	28	-0.0212	-0.6	0.2843	No
Ocoee No. 1	28	-0.0214	-0.6	0.2615	No
Tims Ford	18	-0.0945	-1.7	0.2515	No
Wheeler	30	-0.0321	-1.0	0.2248	No
Norris	29	-0.0143	-0.4	0.2133	No
Hiwassee	28	-0.0395	-1.1	0.0852	No
Cherokee	28	-0.0005	-0.0	0.0320	Yes
Douglas	28	-0.0143	-0.4	0.0313	Yes
Apalachia	29	-0.0571	-1.7	0.0143	Yes

STANDARDS AND CRITERIA

Monitoring programs frequently have the objective of determining compliance with water quality standards. Different methods of monitoring for compliance are used: sequential sampling, Markovian sampling, fixed frequency sampling, and exceedance driven sampling (Whitfield, 1988). The monitoring strategy selected depends on the behavior of the system relative to the objective of the standard or criteria. Each strategy has some restrictions to its application. The data collected with a particular sampling design may not be adequate to satisfy other objectives. It is essential that objectives be clearly identified before a monitoring program for compliance confirmation is designed.

The Tennessee River watershed extends into seven states. Each of these states define their own water quality standards and stream use classifications. The standards for DO of the Valley states are essentially the same, with just minor differences such as using instantaneous measurements or daily means (table 15). In general, waters classified for trout should have a minimum DO of 6.0 mg/l, and warm waters should have a DO of at least 5.0 mg/l. The tailwaters of releases from 12 dams are classified as trout waters (table 15). None of the tailwaters are in the states of Mississippi or Virginia. Although the tailwater of Ocoee No. 2 is classified as a trout water, other factors preclude that use. The tailwaters of Chatuge and Hiwassee Dams are not classified as trout waters, but are managed for that stream use. It was previously shown that release DO has been measured below these standards at nearly all of these dams and about one-third exceed state criteria every year (table 6).

Table 15. Dissolved Oxygen Standards for the State of the Tennessee River Watershed

State	Stream Use Classification	
	Trout waters *	Warm waters
Alabama	None	5.0 mg/l daily mean 4.0 mg/l instantaneous minimum
Georgia	6.0 mg/l daily mean 5.0 mg/l instantaneous minimum	5.0 mg/l daily mean 4.0 mg/l instantaneous minimum
Kentucky	6.0 mg/l daily mean 5.0 mg/l instantaneous minimum	5.0 mg/l daily mean 4.0 mg/l instantaneous minimum
Mississippi	None	5.0 mg/l daily mean 4.0 mg/l instantaneous minimum
North Carolina	6.0 mg/l instantaneous minimum	5.0 mg/l daily mean 4.0 mg/l instantaneous minimum
Tennessee	6.0 mg/l instantaneous minimum	5.0 mg/l daily mean 3.0 mg/l instantaneous minimum by exception determined on individual basis
Virginia	Put-and-Take Trout Waters 6.0 mg/l daily mean 5.0 mg/l instantaneous minimum Natural Trout Waters 7.0 mg/l daily mean 6.0 mg/l instantaneous minimum	5.0 mg/l daily mean 4.0 mg/l instantaneous minimum

*Dams with tailwaters classified as Trout Waters

Apalachia (TN)	Ocoee No. 3 (TN)
Blue Ridge (GA)	Santeetlah (NC)
Boone (TN)	South Holston (TN)
Fontana (NC)	Tims Ford (TN)
Fort Patrick Henry (TN)	Watauga (TN)
Norris (TN)	Wilbur (TN)

In 1987, the State of Tennessee Water Quality Control Board adopted a resolution specifying a strategy for a phased approach to comprehensive tailwater management (TDHE, 1987). The resolution presents a schedule of activities over five years for improving the water quality in tailwaters from TVA dams including engineering demonstrations, implementing nonpoint source control strategies, and developing long-term management plans. TVA's Reservoir Releases Improvements program has since been working with the State of Tennessee to progress the schedule declared in the resolution. In addition, a Draft Environmental Impact Statement prepared to evaluate options for operation of TVA dams proposed to raise to 5 mg/l tailwater DO concentrations at Watts Bar, Fort Loudoun, and four tributary dams classified as warm water, and to 6 mg/l for ten tributary dams with tailwater classified for trout (TVA, 1990). If this alternative is adopted by the TVA Board of Directors and fully implemented, it will bring the releases from TVA dams into compliance with the water quality standards. Dams in the Valley that are not operated by TVA (e.g., Santeetlah), will likely be required to comply with state standards when relicensed by the Federal Energy Regulatory Commission (Kim and Bohac, 1989).

The EPA has published national criteria for DO that account for the sensitivity of early life stages of freshwater aquatic life, primarily fish (Chapman, 1986). The DO criteria use combination of different averaging periods and instantaneous measurements for the different life stages and water use classifications (table 16). The criteria presented represent a nonregulatory, scientific assessment of ecological effects. These criteria must be adopted by a state under

Table 16. Water Quality Criteria for Ambient Dissolved Oxygen Concentration

	Coldwater Criteria		Warmwater Criteria	
	Early life stages ^{a,b}	Other life stages	Early life stages ^b	Other life stages
30-day mean	NA ^c	6.5	NA	5.5
7-day mean	9.5 (6.5)	NA	6.0	NA
7-day mean minimum	NA	5.0	NA	4.0
1-day minimum ^{d,e}	8.0 (5.0)	4.0	5.0	3.0

a. These are water column concentrations recommended to achieve the required intergravel dissolved oxygen concentrations shown in parentheses. The 3 mg/l differential is discussed in the criteria document. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.

b. Includes all embryonic and larval stages and all juvenile forms to 30-days following hatching.

c. NA (not applicable).

d. For highly manipulable discharges, further restrictions apply.

e. All minimums should be considered as instantaneous concentrations to be achieved at all times.

Source: Chapman (1986)

Section 303 of the Clean Water Act (PL 100-4) to become enforceable water quality standards.

The new criteria have been used in an extensive study of the Ohio River (ORERP, 1988). However, the Valley states have not adopted these new criteria as standards. The current DO standards of the Valley states are based on the previous EPA criterion of 5.0 mg/l (EPA, 1976). There are several practical problems associated with adopting the new criteria as standards. The monitoring effort to determine compliance is much greater than with the earlier criterion. The frequency of sampling depends on knowing the diel cycle of DO to compute the specified means. Also, the data collected must be normally distributed and exhibit no autocorrelation in order for the computed mean to be valid. Use of the median would be a more appropriate measure of central tendency. Criteria for early life stages are intended to apply only where and when these stages occur. This requires a biological assessment of the reproduction and recruitment of the aquatic life species in a particular stream in order to determine which new DO criterion to apply. These complicating factors will make it difficult for states to adopt and apply these criteria as enforceable standards. In fact, the data in the example by Chapman (1986) for daily minimum and daily mean DO are serially dependent and not normally distributed ($p = 0.6986$ and $p = 0.9875$, respectively). If the Valley states adopt the new DO criteria, the current monitoring strategy will need to be changed.

SUMMARY AND CONCLUSIONS

The historical database of DO and temperature from the releases of 30 dams in the Tennessee Valley was examined for appropriate sampling designs based on four different objectives. It is essential that a monitoring strategy has clearly defined objectives so that an suitable sampling design can be implemented. The objectives of monitoring the releases from TVA dams has changed over the years due to shifting priorities and information needs. Although the collected data has been useful for a number of different uses, the sampling design has not been evaluated for adequacy to satisfy various objectives. Different objectives many times require opposing sampling designs (Liebetrau, 1979).

The database of release DO and temperature was first assessed to determine whether the seasonal patterns were adequately known. The data were reduced to weekly estimates of central tendency and dispersion. In general, the median and mean were similar suggesting the weekly data were normally distributed. Also, the weekly variance was low, providing a small 95 percent confidence interval. Thus, the seasonal patterns of release DO and temperature are well-defined for each dam. Further weekly sampling is no longer needed to satisfy the objective of general surveillance to describe seasonal patterns.

Another objective for sampling is to compare information among the dams using descriptive statistics. Analysis of the database showed that the DO measurements from most dams are described by a normal distribution. However, annual minimum release DO is not normally distributed

and should be described with nonparametric statistics. Comparisons of the mean release DO show the effect of releases from Cherokee and Douglas Dams on Fort Loudoun and Watts Bar, with increasing DO levels in subsequent downstream dams. Evaluation of the dependence structure of the seasonal DO pattern showed the data to be autocorrelated. These results indicate that weekly sampling may bias the descriptive statistics. Thus, for an objective to characterize and compare releases among dams, a monthly sampling frequency is recommended to avoid problems with autocorrelation.

A primary goal often stated for long-term monitoring is the detection of trends over time. One must assure that the sampling design is appropriate for the method of trend detection that is to be used. Violating the assumptions of a particular trend test can yield results which are not valid (detecting a trend when there is none). It was shown that hydrologic conditions explain some of the variance associated with the release data. Thus, all measurements were adjusted with discharge relationships before testing for trend. Monthly means were used to reduce the autocorrelation of the data series. Both positive and negative trends in release DO were detected, some have causes which could be explained. No regional trend in release temperature was detected. A monthly sampling frequency is recommended for the objective of trend detection to reduce autocorrelation. For austerity, sampling does not need to be conducted during the winter months when the DO is high, since the seasonal Kendall trend test allows missing values.

Monitoring is commonly conducted to determine compliance with a water quality standard. The sampling frequency of compliance monitoring

is usually defined by the regulatory agency. The selected monitoring strategy depends on the system behavior relative to the objective of the standard. While a fair number of dams in the Tennessee Valley have releases that exceed state criteria for DO, many of the dams simply do not exceed the criteria often enough to justify sampling for the objective of determining compliance. Resources should be focused on those dams that have demonstrated low release DO concentrations. As plans for reaeration of the releases are implemented, intensive monitoring should be conducted to document the extent and duration of any improvements. If the Valley states adopt the new EPA DO criteria as standards, the monitoring frequency will have to be increase to at least twice a day. If continuous monitoring is conducted, frequent maintenance of the instrumentation will be needed for valid data (Enos and Piehl, 1989). The monitoring requirements for the objective of compliance will have to be determined on a site-by-site basis.

The monitoring strategy shifted in 1990. Monthly samples are now being collected from the forebay and transition zones of 14 major reservoirs in the Tennessee Valley for a variety of water quality variables and biological indicators. Measurement of DO and temperature in tailwaters was scaled back to include only those projects where data is needed to support TVA's Reservoir Releases program. Tailwater monitoring of the biological health of the 14 major reservoirs was initiated. Biological indicators include fish health assessments, fish and benthic community evaluations, fish standing stock, and fish flesh contamination. These biological indicators integrate the temporal and spatial variability of effects from the dam releases to infer the

biological integrity of the tailwater. Coupled with the water quality information from the reservoir forebay, will yield an improved understanding of the environmental effects created by the impoundments.

The following recommendations are offered:

1. Develop a design document specifying the goals and objectives for the monitoring of the releases from TVA dams. For each dam, this document should clearly state the monitoring objective, sampling protocols, sampling frequency, and data analysis techniques to be used. The design document would serve several purposes: (1) ensure that the sampling design was appropriate for the defined monitoring objective, (2) allow optimization of the overall sampling effort, and (3) record the reasoning behind the monitoring for future investigators.
2. Remove or flag the release DO data collected from 1977 to 1984 currently stored in EPA's water quality database. This database is accessed by investigators across the nation. TVA's reputation could be compromised if an outside researcher published a trend analysis similar to Meinert (1980), since several reports have documented this data to be invalid. It is essential that TVA maintain the quality of information that it provides to the nation's water resource professionals.

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APPENDIX

APPENDIX A

Figure A1. Location of Apalachia Dam

APALACHIA POWERHOUSE PENSTOCK

Distribution of Historical Measurements

Figure A2. Annual temperature pattern for Apalachia Powerhouse Penstock

APALACHIA POWERHOUSE PENSTOCK

Distribution of Historical Measurements

Figure A3. Annual dissolved oxygen pattern for Apalachia Powerhouse Penstock

APALACHIA POWERHOUSE PENSTOCK

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A4. Distribution of historical dissolved oxygen measurements from Apalachia Powerhouse Penstock

APALACHIA POWERHOUSE PENSTOCK

Distribution of Annual Minimum DO

Figure A5. Distribution of annual minimum dissolved oxygen measurements from Apalachia Powerhouse Penstock

APALACHIA POWERHOUSE PENSTOCK

Historical Releases

Figure A6. Discharge data from Apalachia Powerhouse Penstock

APALACHIA POWERHOUSE PENSTOCK

Regression of Monthly Means

Discharge (1/cfs)

Figure A7. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Apalachia Powerhouse Penstock ($DO = 7.6977 + 858.54/Q$; $R^2 = 0.0448$; $p = 0.00099$)

Table A-1. Apalachia Powerhouse Penstock Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1961	13	02-Oct	5.26	2,788	2,792
1962	45	17-Sep	4.71	1,976	2,077
1963	44	30-Sep	5.39	2,623	1,945
1964	40	14-Sep	4.02	2,618	2,841
1965	47	27-Sep	4.86	1,973	2,002
1966	28	26-Sep	5.72	2,720	2,720
1967	30	12-Sep	5.40	3,099	3,078
1968	42	21-Oct	4.60	2,445	2,298
1969	37	08-Sep	5.80	2,432	2,352
1970	28	28-Sep	5.20	1,852	2,004
1971	46	26-Sep	5.30	2,862	2,853
1972	29	03-Oct	4.40	2,381	2,415
1973	28	17-Sep	3.90	2,244	2,593
1974	47	09-Sep	5.20	2,457	2,659
1975	51	25-Aug	5.40	2,390	2,538
1976	48	20-Sep	5.10	2,852	2,460
1985	19	16-Oct	3.70	1,255	1,239
1986	31	01-Oct	3.70	887	899
1987	18	05-Oct	3.00	1,957	1,165
1988	17	03-Oct	4.10	277	348
1989	19	03-Oct	3.00	6,020	3,698

Regression of mean daily discharge (Q) on minimum DO

$$DO = 4.818 - 267.9*(1/Q)$$

$$R^2 = 0.0509 \quad p = 0.32520$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 0.1838 + 0.5871*(\ln Q7)$$

$$R^2 = 0.1335 \quad p = 0.10336$$

Figure A8. Location of Blue Ridge Dam

BLUE RIDGE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A9. Annual temperature pattern for Blue Ridge Dam Scroll Case

BLUE RIDGE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A10. Annual dissolved oxygen pattern for Blue Ridge Dam Scroll Case

BLUE RIDGE DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A11. Distribution of historical dissolved oxygen measurements from Blue Ridge Dam Scroll Case

BLUE RIDGE DAM SCROLL CASE

Distribution of Annual Minimum DO

Figure A12. Distribution of annual minimum dissolved oxygen measurements from Blue Ridge Dam Scroll Case

BLUE RIDGE DAM SCROLL CASE

Figure A13. Discharge data from Blue Ridge Dam Scroll Case

BLUE RIDGE DAM SCROLL CASE

Regression of Monthly Means

Discharge (ln cfs)

Figure A14. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Blue Ridge Dam Scroll Case ($DO = 13.9136 - 1.0132 \cdot \ln Q$; $R^2 = 0.0924$; $p = 0.00002$)

Table A-2. Blue Ridge Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1961	13	02-Oct	3.92	693	792
1962	51	10-Sep	0.10	12	12
1963	50	23-Sep	0.87	702	710
1964	36	21-Sep	3.70	1,240	1,303
1965	32	20-Sep	1.31	1	504
1966	26	19-Sep	0.61	1	578
1967	27	22-Aug	2.00	1	719
1968	22	16-Sep	2.40	692	703
1969	19	15-Sep	3.30	865	815
1970	19	31-Aug	3.50	992	878
1971	15	31-Aug	3.40	565	765
1972	16	25-Sep	3.50	813	766
1973	18	25-Sep	3.70	617	1,011
1974	34	10-Sep	3.40	874	896
1975	42	15-Sep	2.40	697	602
1976	43	13-Sep	4.00	871	887
1985	27	05-Sep	3.10	803	825
1986	38	14-Oct	1.70	120	197
1987	24	21-Sep	2.00	426	383
1988	24	12-Sep	1.90	1,268	1,064
1989	27	27-Sep	3.40	735	566

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1.361 + 1.973E-3*Q$$

$$R^2 = 0.4334 \quad p = 0.00118$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 9.632E-5*Q7^{0.07478}$$

$$R^2 = 0.7083 \quad p < 0.00001$$

Figure A15. Location of Boone Dam

BOONE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A16. Annual temperature pattern for Boone Dam Scroll Case

BOONE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A17. Annual dissolved oxygen pattern for Boone Dam Scroll Case

BOONE DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A18. Distribution of historical dissolved oxygen measurements from Boone Dam Scroll Case

BOONE DAM SCROLL CASE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A19. Distribution of annual minimum dissolved oxygen measurements from Boone Dam Scroll Case

BOONE DAM SCROLL CASE

Historical Releases

Figure A20. Discharge data from Boone Dam Scroll Case

BOONE DAM SCROLL CASE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A21. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Boone Dam Scroll Case ($DO = e^{(1.6124 + 1.09E-4Q)}$; $R^2 = 0.0878$; $p < 0.00001$)

Table A-3. Boone Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1961	12	23-Oct	3.75	3,429	2,938
1962	46	22-Oct	2.93	2,881	2,862
1963	45	19-Nov	1.90	670	1,273
1964	55	01-Jun	1.49	854	1,148
1965	50	05-Jul	1.73	1,215	1,957
1966	50	26-Sep	0.60	1,510	766
1967	50	24-Jul	0.40	4,599	1,250
1968	42	01-Oct	3.00	1,517	1,269
1969	45	06-Oct	2.10	2,856	2,660
1970	56	19-Oct	0.40	715	1,215
1971	58	22-Sep	1.60	1,093	2,657
1972	52	25-Sep	3.80	2,197	1,974
1973	47	30-Oct	1.90	3,307	1,658
1974	51	12-Nov	2.30	3,783	3,250
1975	54	06-Oct	2.60	1,947	1,851
1976	48	21-Jun	1.80	1,479	1,741
1985	29	26-Jun	0.85	2,084	1,327
1986	37	30-Jun	1.40	956	1,227
1987	21	25-Sep	1.90	2,010	1,953
1988	14	20-Sep	1.70	800	1,162
1989	28	21-Aug	3.30	4,275	3,651

Regression of mean daily discharge (Q) on minimum DO

$$DO = 2.645 - 1003*(1/Q)$$

$$R^2 = 0.1634 \quad p = 0.06918$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = -9.618 + 1.553*(\ln Q7)$$

$$R^2 = 0.4295 \quad p = 0.00126$$

Figure A22. Location of Chatuge Dam

CHATUGE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A23. Annual temperature pattern for Chatuge Dam Scroll Case

CHATUGE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A24. Annual dissolved oxygen pattern for Chatuge Dam Scroll Case

CHATUGE DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A25. Distribution of historical dissolved oxygen measurements from Chatuge Dam Scroll Case

CHATUGE DAM SCROLL CASE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A26. Distribution of annual minimum dissolved oxygen measurements from Chatuge Dam Scroll Case

CHATUGE DAM SCROLL CASE

Historical Releases

Figure A27. Discharge data from Chatuge Dam Scroll Case

CHATUGE DAM SCROLL CASE

Regression of Monthly Means

Discharge (ln cfs)

Figure A28. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Chatuge Dam Scroll Case ($DO = 10.8852 - 0.8481 \times \ln Q$; $R^2 = 0.0329$; $p = 0.01979$)

Table A-4. Chatuge Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	21	28-Oct	0.10	1	110
1963	21	24-Sep	0.41	1,312	1,018
1964	26	04-Sep	0.62	763	540
1965	23	01-Sep	0.40	652	378
1966	17	20-Sep	0.48	1,020	999
1967	9	03-Aug	0.10	1,042	741
1968	18	17-Sep	0.30	619	407
1969	19	25-Aug	1.00	1,454	882
1970	11	15-Sep	0.60	876	460
1971	16	27-Oct	0.30	759	611
1972	12	11-Sep	0.30	763	563
1973	19	25-Oct	1.60	624	427
1974	28	16-Sep	0.60	529	377
1975	42	16-Sep	0.45	722	517
1976	42	07-Sep	1.10	891	659
1985	27	16-Oct	0.80	363	241
1986	34	24-Sep	0.50	335	185
1987	29	19-Oct	1.20	164	264
1988	28	11-Oct	1.10	112	141
1989	26	27-Sep	0.90	881	740

Regression of mean daily discharge (Q) on minimum DO

$$DO = 0.0217 * Q^{0.1637}$$

$$R^2 = 0.1194 \quad p = 0.13562$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 0.7205 - 1.512E-4 * Q7$$

$$R^2 = 0.0104 \quad p = 0.66886$$

Figure A29. Location of Cherokee Dam

CHEROKEE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A30. Annual temperature pattern for Cherokee Dam Scroll Case

CHEROKEE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A31. Annual dissolved oxygen pattern for Cherokee Dam Scroll Case

CHEROKEE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A32. Distribution of historical dissolved oxygen measurements from Cherokee Dam Scroll Case

CHEROKEE DAM SCROLL CASE

Distribution of Annual Minimum DO

Figure A33. Distribution of annual minimum dissolved oxygen measurements from Cherokee Dam Scroll Case

CHEROKEE DAM SCROLL CASE

Historical Releases

Figure A34. Discharge data from Cherokee Dam Scroll Case

CHEROKEE DAM SCROLL CASE

Regression of Monthly Means

Discharge (ln cfs)

Figure A35. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Cherokee Dam Scroll Case ($DO = 15.3240 - 1.1303 \ln Q$; $R^2 = 0.0536$; $p = 0.00034$)

Table A-5. Cherokee Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	45	30-Jul	0.15	8,241	5,553
1963	41	26-Aug	0.14	7,992	6,270
1964	41	27-Jul	0.30	6,285	4,276
1965	43	19-Jul	0.11	7,332	6,156
1966	39	27-Jun	0.10	7,338	5,440
1967	47	16-Aug	0.10	7,963	4,781
1968	39	17-Jun	0.10	7,072	1,434
1969	38	07-Jul	0.10	6,273	3,790
1970	46	22-Jun	0.10	2,348	3,342
1971	33	21-Jul	0.10	4,815	3,596
1972	34	03-Jul	0.10	4,184	3,751
1973	34	23-Jul	0.20	8,831	6,796
1974	46	22-Jul	0.20	6,881	8,797
1975	49	07-Jul	0.15	9,231	7,799
1976	46	19-Jul	0.10	4,502	4,098
1985	27	18-Jul	0.10	1,784	2,577
1986	24	14-Jul	0.01	4,182	3,884
1987	30	19-Aug	0.02	6,927	7,784
1988	12	17-Aug	0.10	6,521	4,671
1989	31	07-Aug	0.10	9,672	5,610

Regression of mean daily discharge (Q) on minimum DO

$$DO = \exp(-2.934 + 9.7E-5*Q)$$

$$R^2 = 0.0801 \quad p = 0.22675$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 0.0799 + 7.782E-6*Q7$$

$$R^2 = 0.0541 \quad p = 0.32363$$

Figure A36. Location of Chickamauga Dam

CHICKAMAUGA DAM TAILRACE

Distribution of Historical Measurements

Figure A37. Annual temperature pattern for Chickamauga Dam Tailrace

CHICKAMAUGA DAM TAILRACE

Distribution of Historical Measurements

Figure A38. Annual dissolved oxygen pattern for Chickamauga Dam Tailrace

CHICKAMAUGA DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A39. Distribution of historical dissolved oxygen measurements from Chickamauga Dam Tailrace

CHICKAMAUGA DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A40. Distribution of annual minimum dissolved oxygen measurements from Chickamauga Dam Tailrace

CHICKAMAUGA DAM TAILRACE

Figure A41. Discharge data from Chickamauga Dam Tailrace

CHICKAMAUGA DAM TAILRACE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A42. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Chickamauga Dam Tailrace ($DO = e(1.8735 + 6.0E-6Q)$; $R^2 = 0.1490$; $p < 0.00001$)

Table A-6. Chickamauga Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	32	11-Jun	5.05	28,900	28,786
1963	27	08-Jul	5.07	26,000	19,443
1964	50	10-Aug	4.58	27,000	25,800
1965	52	28-Jun	5.20	28,400	22,943
1966	52	05-Jul	3.53	17,400	19,143
1967	52	03-Jul	5.20	20,600	23,314
1968	54	24-Jun	4.70	35,000	33,171
1969	54	07-Jul	3.20	27,900	20,571
1970	52	22-Sep	4.90	29,200	29,929
1971	52	13-Jul	4.80	29,100	26,429
1972	53	24-Jul	5.30	34,200	37,143
1973	59	13-Aug	5.60	44,700	39,971
1974	55	26-Aug	4.80	37,700	38,286
1975	57	08-Sep	5.40	19,200	28,257
1976	57	27-Sep	3.80	24,800	25,314
1985	23	01-Aug	4.50	28,283	26,323
1986	27	29-Jul	2.40	9,608	16,577
1987	29	19-Jun	5.30	18,921	21,118
1988	34	23-Aug	3.30	14,671	14,099
1989	31	24-Aug	4.50	40,308	37,388

Regression of mean daily discharge (Q) on minimum DO

$$DO = 5.827 - 30252 \cdot (1/Q)$$

$$R^2 = 0.4282 \quad p = 0.00175$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 6.460 - 47002 \cdot (1/Q7)$$

$$R^2 = 0.4291 \quad p = 0.00172$$

Figure A43. Location of Chilhowee Dam

CHILHOWEE DAM PENSTOCK

Distribution of Historical Measurements

Figure A44. Annual temperature pattern for Chilhowee Dam Penstock

CHILHOWEE DAM PENSTOCK

Distribution of Historical Measurements

Figure A45. Annual dissolved oxygen pattern for Chilhowee Dam Penstock

CHILHOWEE DAM PENSTOCK

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A46. Distribution of historical dissolved oxygen measurements from Chilhowee Dam Penstock

CHILHOWEE DAM PENSTOCK

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A47. Distribution of annual minimum dissolved oxygen measurements from Chilhowee Dam Penstock

CHILHOWEE DAM PENSTOCK

Historical Releases

Figure A48. Discharge data from Chilhowee Dam Penstock

CHILHOWEE DAM PENSTOCK

Regression of Monthly Means

Discharge (1/cfs)

Figure A49. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Chilhowee Dam Penstock ($DO = 8.1318 + 3244.18/Q$; $R^2 = 0.0537$; $p = 0.00086$)

Table A-7. Chilhowee Dam Penstock Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1961	13	06-Nov	5.96	6,462	4,452
1962	48	15-Oct	4.56	6,809	6,161
1963	50	28-Oct	6.18	4,726	4,541
1964	47	19-Oct	6.05	8,522	7,671
1965	47	18-Oct	5.79	5,594	5,926
1966	54	19-Sep	5.97	5,257	4,638
1967	40	02-Oct	5.60	7,583	7,254
1968	29	11-Nov	5.50	7,207	5,143
1969	28	10-Nov	6.50	4,392	5,251
1970	41	21-Sep	5.20	7,044	5,847
1971	34	04-Oct	5.90	5,454	6,185
1972	39	20-Nov	5.70	6,928	6,611
1973	42	08-Oct	5.60	4,266	3,893
1974	52	16-Sep	5.50	5,509	5,902
1975	53	08-Sep	7.30	5,523	5,124
1976	52	25-Oct	6.20	7,339	7,048
1986	12	07-Nov	8.90	3,167	2,424
1987	6	09-Sep	9.20	3,397	2,943
1988	6	19-Sep	8.10	2,673	3,230
1989	6	13-Sep	7.20	5,290	4,866

Regression of mean daily discharge (Q) on minimum DO

$$DO = 3.627 + 14032*(1/Q)$$

$$R^2 = 0.6103 \quad p = 0.00005$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 3.557 + 13409*(1/Q7)$$

$$R^2 = 0.6481 \quad p = 0.00002$$

Figure A50. Location of Douglas Dam

DOUGLAS DAM SCROLL CASE

Distribution of Historical Measurements

A51. Annual Temperature Pattern for Douglas Dam Scroll Case

DOUGLAS DAM SCROLL CASE

Distribution of Historical Measurements

Figure A52. Annual dissolved oxygen pattern for Douglas Dam Scroll Case

DOUGLAS DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A53. Distribution of historical dissolved oxygen measurements from Douglas Dam Scroll Case

DOUGLAS DAM SCROLL CASE

Distribution of Annual Minimum DO

Figure A54. Distribution of annual minimum dissolved oxygen measurements from Douglas Dam Scroll Case

DOUGLAS DAM SCROLL CASE

Historical Releases

Figure A55. Discharge data from Douglas Dam Scroll Case

DOUGLAS DAM SCROLL CASE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A56. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Douglas Dam Scroll Case ($DO = 5.1450 + 1.48E-4Q$; $R^2 = 0.0209$; $p = 0.02582$)

Table A-8. Douglas Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	53	20-Aug	0.10	5,698	5,825
1963	49	13-Aug	0.68	6,508	6,386
1964	51	10-Aug	0.71	8,550	5,117
1965	49	02-Aug	0.41	9,632	6,314
1966	51	18-Jul	0.71	6,710	4,893
1967	50	07-Aug	0.10	12,153	10,668
1968	36	23-Sep	0.50	2,173	1,836
1969	63	09-Jul	0.30	6,111	5,957
1970	64	30-Jun	0.40	5,237	5,038
1971	49	13-Sep	0.25	6,883	7,272
1972	47	28-Aug	0.40	8,938	9,318
1973	53	26-Jul	0.20	5,413	8,072
1974	57	12-Aug	0.30	10,848	9,261
1975	50	28-Jul	0.80	9,372	8,297
1976	55	09-Aug	0.40	9,735	9,457
1985	27	03-Jul	0.06	3,128	2,697
1986	25	14-Jul	0.04	2,606	3,885
1987	31	20-Aug	0.07	7,298	6,771
1988	10	17-Aug	0.10	6,023	4,791
1989	31	14-Aug	0.20	12,962	7,269

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1/(12.24 - 8.263E-4*Q)$$

$$R^2 = 0.1510 \quad p = 0.09042$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 1/(11.30 - 7.897E-4*Q7)$$

$$R^2 = 0.0835 \quad p = 0.21647$$

Figure A57. Location of Fontana Dam

FONTANA DAM SCROLL CASE

Distribution of Historical Measurements

Figure A58. Annual temperature pattern for Fontana Dam Scroll Case

FONTANA DAM SCROLL CASE

Distribution of Historical Measurements

Figure A59. Annual dissolved oxygen pattern for Fontana Dam Scroll Case

FONTANA DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A60. Distribution of historical dissolved oxygen measurements from Fontana Dam Scroll Case

FONTANA DAM SCROLL CASE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A61. Distribution of annual minimum dissolved oxygen measurements from Fontana Dam Scroll Case

FONTANA DAM SCROLL CASE

Historical Releases

Figure A62. Discharge data from Fontana Dam Scroll Case

FONTANA DAM SCROLL CASE

Regression of Monthly Means

Figure A63. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Fontana Dam Scroll Case ($DO = 20.5231 - 1.6255 \ln Q$; $R^2 = 0.1258$; $p < 0.00001$)

Table A-9. Fontana Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1961	13	17-Oct	1.38	6,495	6,339
1962	49	23-Oct	0.51	6,739	6,477
1963	47	22-Oct	0.98	4,386	4,264
1964	47	17-Nov	4.28	7,764	7,337
1965	49	12-Oct	1.16	5,829	5,068
1966	50	11-Oct	1.61	4,830	4,917
1967	45	17-Oct	2.40	7,247	6,317
1968	38	14-Oct	1.70	4,679	3,876
1969	35	30-Sep	2.50	4,808	3,442
1970	36	28-Sep	1.80	3,431	4,401
1971	44	08-Nov	0.40	4,746	5,142
1972	49	19-Oct	1.60	4,522	3,807
1973	51	05-Nov	2.20	5,732	5,477
1974	51	14-Oct	1.90	3,720	4,889
1975	53	06-Oct	3.40	4,146	3,336
1976	51	12-Oct	3.40	7,171	6,243
1985	18	07-Oct	4.10	4,792	4,109
1986	17	30-Oct	4.30	2,467	2,277
1987	18	20-Oct	4.50	3,529	3,345
1988	14	27-Oct	5.30	1,925	2,060
1989	17	27-Sep	5.40	5,254	5,226

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1.018 + 7037*(1/Q)$$

$$R^2 = 0.1794 \quad p = 0.05568$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 0.6756 + 8159*(1/Q7)$$

$$R^2 = 0.2248 \quad p = 0.02990$$

Figure A64. Location of Fort Loudoun Dam

FORT LOUDOUN DAM TAILRACE

Distribution of Historical Measurements

Figure A65. Annual temperature pattern for Fort Loudoun Dam Tailrace

FORT LOUDOUN DAM TAILRACE

Distribution of Historical Measurements

Figure A66. Annual dissolved oxygen pattern for Fort Loudoun Dam Tailrace

FORT LOUDOUN DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A67. Distribution of historical dissolved oxygen measurements from Fort Loudoun Dam Tailrace

FORT LOUDOUN DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A68. Distribution of annual minimum dissolved oxygen measurements from Fort Loudoun Dam Tailrace

FORT LOUDOUN DAM TAILRACE

Figure A69. Discharge data from Fort Loudoun Dam Tailrace

FORT LOUDOUN DAM TAILRACE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A70. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Fort Loudoun Dam Tailrace ($DO = 5.2326 + 1.22E-4Q$; $R^2 = 0.0989$; $p < 0.00001$)

Table A-10. Fort Loudoun Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	51	31-Oct	1.99	12,000	12,600
1963	50	03-Jul	0.65	7,100	4,357
1964	51	05-Aug	1.51	13,400	12,086
1965	50	23-Jun	1.48	5,800	3,100
1966	52	27-Jul	1.22	20,800	12,257
1967	50	19-Jul	1.90	10,300	7,957
1968	44	21-Aug	3.20	21,900	20,543
1969	48	20-Aug	1.70	11,100	8,257
1970	50	16-Sep	2.40	15,500	10,600
1971	60	28-Jul	2.40	3,200	7,929
1972	50	09-Aug	3.80	16,700	13,514
1973	51	18-Jul	3.50	15,500	12,886
1974	50	14-Aug	3.20	18,800	18,286
1975	45	06-Aug	3.10	18,800	16,586
1976	49	01-Jun	2.20	2,200	5,157
1985	26	23-Jul	2.20	19,046	11,977
1986	24	25-Jun	2.40	8,979	8,790
1987	31	21-Aug	3.40	9,650	16,673
1988	33	14-Jun	3.50	12,979	8,090
1989	29	01-Sep	4.90	29,767	25,779

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1.416 + 8.166E-5*Q$$

$$R^2 = 0.2918 \quad p = 0.01394$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 0.9633 + 1.322E-4*Q7$$

$$R^2 = 0.5272 \quad p = 0.00029$$

Figure A71. Location of Fort Patrick Henry Dam

FORT PATRICK HENRY DAM SCROLL CASE

Distribution of Historical Measurements

Figure A72. Annual temperature pattern for Fort Patrick Henry Dam Scroll Case

FORT PATRICK HENRY DAM SCROLL CASE

Distribution of Historical Measurements

Figure A73. Annual dissolved oxygen pattern for Fort Patrick Henry Dam Scroll Case

FORT PATRICK HENRY DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A74. Distribution of historical dissolved oxygen measurements from Fort Patrick Henry Dam Scroll Case

FORT PATRICK HENRY DAM SCROLL CASE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A75. Distribution of annual minimum dissolved oxygen measurements from Fort Patrick Henry Dam Scroll Case

FORT PATRICK HENRY DAM SCROLL CASE

Figure A76. Discharge data from Fort Patrick Henry Dam Scroll Case

FORT PATRICK HENRY DAM SCROLL CASE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A77. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Fort Patrick Henry Dam Scroll Case ($DO = e^{(1/(0.2399 - 2.21E-5Q))}$; $R^2 = 0.0575$; $p = 0.00016$)

Table A-11. Fort Patrick Henry Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	50	10-Jun	1.50	561	1,843
1963	51	10-Sep	0.30	2,280	1,677
1964	52	30-Jun	1.80	528	1,119
1965	51	24-Aug	1.10	2,599	1,513
1966	52	26-Jul	0.60	4,468	2,085
1967	55	08-Aug	0.60	1,727	1,733
1968	43	17-Sep	2.00	753	777
1969	47	11-Aug	0.10	4,205	3,345
1970	53	08-Sep	1.40	4,420	2,037
1971	50	28-Sep	1.10	3,294	1,285
1972	51	26-Sep	3.70	2,861	2,128
1973	50	02-Oct	3.40	3,302	2,195
1974	47	18-Sep	3.40	3,125	2,834
1975	50	14-Oct	3.20	2,287	1,839
1976	53	22-Jun	1.70	2,948	1,827
1985	29	18-Jul	1.90	1,272	1,729
1986	39	07-Jul	1.60	1,916	1,492
1987	22	30-Sep	2.70	1,830	1,829
1988	36	21-Sep	0.80	1,148	1,149
1989	28	28-Jun	4.80	3,732	3,474

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1/(-0.0709 + 5.497E-4*Q)$$

$$R^2 = 0.0990 \quad p = 0.17670$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 1/(-1.146 + 1.282E-3*Q7)$$

$$R^2 = 0.1621 \quad p = 0.07841$$

Figure A78. Location of Guntersville Dam

GUNTERSVILLE DAM TAILRACE

Distribution of Historical Measurements

Figure A79. Annual temperature pattern for Gunterville Dam Tailrace

GUNTERSVILLE DAM TAILRACE

Distribution of Historical Measurements

Figure A80. Annual dissolved oxygen pattern for Gunterville Dam Tailrace

GUNTERSVILLE DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A81. Distribution of historical dissolved oxygen measurements from Gunterville Dam Tailrace

GUNTERSVILLE DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A82. Distribution of annual minimum dissolved oxygen measurements from Guntersville Dam Tailrace

GUNTERSVILLE DAM TAILRACE

Historical Releases

Figure A83. Discharge data from Guntersville Dam Tailrace

GUNTERSVILLE DAM TAILRACE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A84. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Gunterville Dam Tailrace ($DO = 6.9827 + 3.9E-5Q$; $R^2 = 0.2079$; $p < 0.00001$)

Table A-12. Guntersville Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1960	47	12-Aug	5.80	29,200	23,943
1961	47	04-Aug	5.60	42,400	36,943
1962	51	25-May	3.85	24,900	26,343
1963	50	12-Jul	4.96	29,600	25,800
1964	53	10-Aug	5.19	35,800	26,643
1965	53	30-Aug	5.24	35,600	30,014
1966	47	25-Jul	5.23	28,800	23,800
1967	50	26-Jun	6.20	38,800	30,929
1968	44	26-Aug	5.80	38,000	38,129
1969	53	16-Jun	4.30	30,700	28,414
1970	37	28-Sep	4.70	19,400	25,100
1971	49	28-Jun	5.20	38,400	27,414
1972	49	11-Oct	5.10	36,100	39,329
1973	52	09-Jul	6.20	41,900	38,343
1974	50	22-Jul	6.10	41,300	40,071
1975	48	08-Sep	6.00	22,200	30,471
1976	52	16-Aug	5.00	36,800	35,800
1985	30	26-Jul	5.50	29,106	25,776
1986	32	03-Jul	4.50	3,626	9,522
1987	28	23-Sep	6.40	34,508	20,284
1988	38	09-Jun	4.40	9,462	8,475
1989	18	12-Sep	6.40	47,665	39,930

Regression of mean daily discharge (Q) on minimum DO

$$DO = \exp(1.412 + 8.103E-6*Q)$$

$$R^2 = 0.3832 \quad p = 0.00213$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = \exp(1.444 + 7.814E-6*Q7)$$

$$R^2 = 0.2414 \quad p = 0.02022$$

Figure A85. Location of Hiwassee Dam

HIWASSEE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A86. Annual temperature pattern for Hiwassee Dam Scroll Case

HIWASSEE DAM SCROLL CASE

Distribution of Historical Measurements

Figure A87. Annual dissolved oxygen pattern for Hiwassee Dam Scroll Case

HIWASSEE DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A88. Distribution of historical dissolved oxygen measurements from Hiwassee Dam Scroll Case

HIWASSEE DAM SCROLL CASE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A89. Distribution of annual minimum dissolved oxygen measurements from Hiwassee Dam Scroll Case

HIWASSEE DAM SCROLL CASE

Historical Releases

Figure A90. Discharge data from Hiwassee Dam Scroll Case

HIWASSEE DAM SCROLL CASE

Regression of Monthly Means

Discharge (1/cfs)

Figure A91. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Hiwassee Dam Scroll Case ($DO = 7.2694 + 1003.22/Q$; $R^2 = 0.0622$; $p = 0.00019$)

Table A-13. Hiwassee Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	49	01-Oct	3.67	2,316	2,329
1963	44	14-Oct	3.88	2,723	2,407
1964	46	05-Oct	4.10	1,877	2,269
1965	39	30-Aug	2.92	1,797	1,426
1966	40	12-Sep	5.01	2,493	2,427
1967	43	09-Oct	4.60	3,047	2,850
1968	26	12-Aug	1.30	2,649	2,578
1969	19	07-Oct	4.70	2,473	2,407
1970	12	27-Oct	4.30	1,618	1,448
1971	25	29-Mar	4.40	1	908
1972	24	25-Sep	1.10	2,447	2,467
1973	15	01-Oct	3.55	1,997	2,421
1974	27	01-Oct	3.50	2,409	2,004
1975	41	01-Oct	2.70	1,043	1,382
1976	33	20-Sep	3.40	2,744	2,270
1985	19	16-Oct	3.50	1,232	1,270
1986	33	20-Oct	2.10	365	52
1987	18	05-Oct	3.10	1,783	1,072
1988	16	21-Sep	3.60	1,129	1,221
1989	20	03-Oct	3.10	6,211	3,175

Regression of mean daily discharge (Q) on minimum DO

$$DO = 3.375 + 1.022*(1/Q)$$

$$R^2 = 0.0479 \quad p = 0.35373$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 3.535 - 73.59*(1/Q7)$$

$$R^2 = 0.0869 \quad p = 0.20700$$

Figure A92. Location of Kentucky Dam

KENTUCKY DAM TAILRACE

Distribution of Historical Measurements

Figure A93. Annual temperature pattern for Kentucky Dam Tailrace

KENTUCKY DAM TAILRACE

Distribution of Historical Measurements

Figure A94. Annual dissolved oxygen pattern for Kentucky Dam Tailrace

KENTUCKY DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A95. Distribution of historical dissolved oxygen measurements from Kentucky Dam Tailrace

KENTUCKY DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A96. Distribution of annual minimum dissolved oxygen measurements from Kentucky Dam Tailrace

KENTUCKY DAM TAILRACE

Historical Releases

Figure A97. Discharge data from Kentucky Dam Tailrace

KENTUCKY DAM TAILRACE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A98. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Kentucky Dam Tailrace ($DO = 5.19E-5Q^{0.2399}$; $R^2 = 0.3296$; $p < 0.00001$)

Table A-14. Kentucky Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	50	27-Jul	5.40	41,900	37,286
1963	46	05-Jul	5.30	40,800	42,500
1964	48	27-Jul	5.10	34,400	41,129
1965	39	24-Aug	5.50	39,800	40,000
1966	43	18-Jul	4.50	30,400	30,429
1967	35	03-Jul	5.80	48,300	42,771
1968	34	27-Aug	5.10	31,100	34,757
1969	46	14-Jul	4.60	30,400	31,771
1970	47	22-Jun	4.60	40,500	38,086
1971	48	13-Sep	5.20	28,900	29,729
1972	48	05-Sep	5.20	25,900	30,471
1973	51	10-Sep	5.10	35,000	38,271
1974	51	15-Jul	5.00	34,000	35,143
1975	51	28-Jul	5.60	40,400	41,229
1976	54	26-Jul	5.20	38,100	42,443
1985	28	16-Jul	5.50	25,850	33,837
1986	29	21-Jul	2.50	18,113	18,117
1987	28	18-Aug	4.50	31,771	30,841
1988	34	27-Jun	2.30	12,000	12,000
1989	18	21-Aug	5.10	36,663	36,304

Regression of mean daily discharge (Q) on minimum DO

$$DO = 6.727 - 56376 \cdot (1/Q)$$

$$R^2 = 0.7474 \quad p < 0.00001$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 8.255E-7 \cdot Q^{0.7340}$$

$$R^2 = 0.8647 \quad p < 0.00001$$

Figure A99. Location of Melton Hill Dam

MELTON HILL DAM TAILRACE

Distribution of Historical Measurements

Figure A100. Annual temperature pattern for Melton Hill Dam Tailrace

MELTON HILL DAM TAILRACE

Distribution of Historical Measurements

Figure A101. Annual dissolved oxygen pattern for Melton Hill Dam Tailrace

MELTON HILL DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A102. Distribution of historical dissolved oxygen measurements from Melton Hill Dam Tailrace

MELTON HILL DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A103. Distribution of annual minimum dissolved oxygen measurements from Melton Hill Dam Tailrace

MELTON HILL DAM TAILRACE

Historical Releases

Figure A104. Discharge data from Melton Hill Dam Tailrace

MELTON HILL DAM TAILRACE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A105. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Melton Hill Dam Tailrace ($DO = e^{((0.1265 - 1.55E-6Q))}$; $R^2 = 0.0345$; $p = 0.01165$)

Table A-15. Melton Hill Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1965	43	20-Sep	5.10	5,940	6,308
1966	48	02-Jun	4.80	3,873	1,702
1967	56	09-Jun	5.00	5,628	3,827
1968	49	21-Jun	4.00	6,834	3,624
1969	31	07-Nov	6.60	2,613	2,452
1970	43	11-Sep	5.30	8,213	4,787
1971	49	29-Oct	5.30	5,397	6,688
1972	48	22-Sep	6.20	1,659	3,170
1973	42	30-Aug	2.50	9,013	8,179
1974	48	30-Aug	5.40	6,353	6,091
1975	55	02-Sep	5.60	5,800	6,081
1976	46	20-Sep	3.20	3,717	3,842
1985	27	05-Jun	5.50	3,783	2,794
1986	26	25-Aug	4.50	2,917	2,438
1987	26	06-Jul	6.20	6,383	3,100
1988	10	01-Jun	3.00	1,517	798
1989	28	09-Aug	5.70	4,150	4,736

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1/(0.1905 + 5.457E-6*Q)$$

$$R^2 = 0.0291 \quad p = 0.51249$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 5.368 - 1308*(1/Q7)$$

$$R^2 = 0.0897 \quad p = 0.24282$$

Figure A106. Location of Nickajack Dam

NICKAJACK DAM TAILRACE

Distribution of Historical Measurements

Figure A107. Annual temperature pattern for Nickajack Dam Tailrace

NICKAJACK DAM TAILRACE

Distribution of Historical Measurements

Figure A108. Annual dissolved oxygen pattern for Nickjack Dam Tailrace

NICKAJACK DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A109. Distribution of historical dissolved oxygen measurements from Nickajack Dam Tailrace

NICKAJACK DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A110. Distribution of annual minimum dissolved oxygen measurements from Nickajack Dam Tailrace

NICKAJACK DAM TAILRACE

Historical Releases

Figure All1. Discharge data from Nickajack Dam Tailrace

NICKAJACK DAM TAILRACE

Regression of Monthly Means

Discharge (1000 cfs)

Figure All2. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Nickajack Dam Tailrace ($DO = 6.3665 + 4.9E-5Q$; $R^2 = 0.1863$; $p < 0.00001$)

Table A-16. Nickajack Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1968	48	24-Jun	5.00	31100	32,986
1969	53	23-Jun	4.50	22000	16,771
1970	52	21-Sep	4.80	24400	28,857
1971	54	19-Jul	5.00	22400	25,743
1972	51	19-Sep	4.50	36200	31,614
1973	53	11-Oct	5.10	33000	28,214
1974	42	26-Aug	4.80	37500	38,271
1975	49	03-Sep	5.20	38900	29,829
1976	50	02-Aug	5.50	30500	34,771
1985	24	26-Jul	4.70	31642	22,976
1986	27	10-Jun	5.20	7383	6,598
1987	29	18-Sep	5.10	16904	20,588
1988	34	24-Aug	4.00	13842	12,888
1989	31	14-Sep	3.50	43958	38,107

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1/(0.1946 + 6.26E-7*Q)$$

$$R^2 = 0.0577 \quad p = 0.40799$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 1/(0.2049 + 2.70E-7*Q)$$

$$R^2 = 0.0088 \quad p = 0.75013$$

Figure A113. Location of Normandy Dam

NORMANDY DAM TAILRACE

Distribution of Historical Measurements

Figure All4. Annual temperature pattern for Normandy Dam Tailrace

NORMANDY DAM TAILRACE

Distribution of Historical Measurements

Figure All5. Annual dissolved oxygen pattern for Normandy Dam Tailrace

NORMANDY DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A116. Distribution of historical dissolved oxygen measurements from Normandy Dam Tailrace

NORMANDY DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A117. Distribution of annual minimum dissolved oxygen measurements from Normandy Dam Tailrace

NORMANDY DAM TAILRACE

Figure A118. Discharge data from Normandy Dam Tailrace

NORMANDY DAM TAILRACE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A119. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Normandy Dam Tailrace ($DO = e^{((0.1077 - 6.37E-6Q))}$; $R^2 = 0.0147$; $p = 0.61115$)

Table A-17. Normandy Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1976	7	08-Sep	8.10	132	123
1986	12	21-Jul	7.90	153	153
1989	11	21-Aug	8.80	139	124

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1/(0.0845 + 2.597E-4*Q)$$

$$R^2 = 0.1689 \quad p = 0.73034$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 1/(0.0861 + 2.637E-4*Q7)$$

$$R^2 = 0.4424 \quad p = 0.53673$$

Figure A120. Location of Norris Dam

NORRIS DAM SCROLL CASE

Distribution of Historical Measurements

Figure A121. Annual temperature pattern for Norris Dam Scroll Case

NORRIS DAM SCROLL CASE

Distribution of Historical Measurements

Figure A122. Annual dissolved oxygen pattern for Norris Dam Scroll Case

NORRIS DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A123. Distribution of historical dissolved oxygen measurements from Norris Dam Scroll Case

NORRIS DAM SCROLL CASE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A124. Distribution of annual minimum dissolved oxygen measurements from Norris Dam Scroll Case

NORRIS DAM SCROLL CASE

Historical Releases

Figure A125. Discharge data from Norris Dam Scroll Case

NORRIS DAM SCROLL CASE

Regression of Monthly Means

Discharge (1/cfs)

Figure A126. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Norris Dam Scroll Case ($DO = 6.4742 + 1269/Q$; $R^2 = 0.0323$; $p = 0.00540$)

Table A-18. Norris Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1961	13	02-Oct	0.57	5,477	4,050
1962	50	15-Oct	0.40	3,765	3,356
1963	50	14-Oct	0.70	5,190	5,116
1964	47	26-Oct	0.99	3,953	5,204
1965	49	04-Oct	0.55	3,371	4,484
1966	43	03-Oct	1.00	3,292	3,577
1967	50	26-Sep	0.90	7,630	7,696
1968	40	14-Oct	1.00	3,776	3,491
1969	45	14-Oct	1.20	2,054	1,559
1970	48	28-Sep	0.30	3,560	3,812
1971	46	03-Nov	0.60	7,315	6,595
1972	46	11-Sep	0.40	3,251	5,753
1973	46	15-Oct	1.20	4,458	4,226
1974	46	16-Sep	1.60	4,269	4,607
1975	50	07-Sep	0.40	3,847	5,130
1976	50	18-Oct	0.20	3,806	3,062
1985	29	28-Oct	0.60	1,445	1,007
1986	32	17-Oct	0.02	1,106	1,084
1987	27	25-Sep	0.20	2,577	3,594
1988	13	28-Nov	0.70	967	382
1989	29	11-Oct	0.20	7,769	7,751

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1/(11.39 - 1.776E-3*Q)$$

$$R^2 = 0.1048 \quad p = 0.15223$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 1/(11.26 - 1.688E-3*Q7)$$

$$R^2 = 0.1031 \quad p = 0.15577$$

Figure A127. Location of Nottely Dam

NOTTELY DAM PENSTOCK

Distribution of Historical Measurements

Figure A128. Annual temperature pattern for Nottely Dam Penstock

NOTTELY DAM PENSTOCK

Distribution of Historical Measurements

Figure A129. Annual dissolved oxygen pattern for Nottely Dam Penstock

NOTTELY DAM PENSTOCK

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A130. Distribution of historical dissolved oxygen measurements from Nottely Dam Penstock

NOTTELY DAM PENSTOCK

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A131. Distribution of annual minimum dissolved oxygen measurements from Nottely Dam Penstock

NOTTELY DAM PENSTOCK

Historical Releases

Figure A132. Discharge data from Nottely Dam Penstock

NOTTELY DAM PENSTOCK

Regression of Monthly Means

Discharge (ln cfs)

Figure A133. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Notteley Dam Penstock ($DO = 10.4546 - 0.8131 \ln Q$; $R^2 = 0.0434$; $p = 0.00741$)

Table A-19. Nottely Dam Penstock Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	18	04-Sep	0.10	1,004	811
1963	20	27-Aug	0.58	199	176
1964	26	18-Aug	0.10	1	591
1965	25	07-Sep	0.30	491	157
1966	18	06-Sep	1.39	839	453
1967	16	21-Aug	1.50	591	670
1968	15	03-Sep	0.90	190	52
1969	14	25-Aug	1.70	821	741
1970	10	29-Sep	0.50	289	359
1971	15	12-Oct	0.90	786	619
1972	14	11-Sep	1.20	709	541
1973	17	04-Sep	1.10	934	667
1974	24	24-Sep	1.40	996	346
1975	42	15-Sep	0.91	635	509
1976	46	07-Sep	0.80	910	756
1985	25	03-Oct	0.90	229	170
1986	34	17-Sep	1.10	245	124
1987	25	19-Oct	1.40	465	421
1988	29	17-Oct	1.10	119	116
1989	27	27-Sep	0.40	749	651

Regression of mean daily discharge (Q) on minimum DO

$$DO = 0.0133 * Q^{0.2656}$$

$$R^2 = 0.2482 \quad p = 0.02538$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 1 / (0.6144 + 3.35E-3 * Q7)$$

$$R^2 = 0.0869 \quad p = 0.20710$$

Figure A134. Location of Ocoee No. 1 Dam

OCOEE NO. 1 DAM SCROLL CASE

Distribution of Historical Measurements

Figure A135. Annual temperature pattern for Ocoee No. 1 Dam Scroll Case

OCOEE NO. 1 DAM SCROLL CASE

Distribution of Historical Measurements

Figure A136. Annual dissolved oxygen pattern for Ocoee No. 1 Dam Scroll Case

OCOEE NO. 1 DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A137. Distribution of historical dissolved oxygen measurements from Ocoee No. 1 Dam Scroll Case

OCOEE NO. 1 DAM SCROLL CASE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A138. Distribution of annual minimum dissolved oxygen measurements from Ocoee No. 1 Dam Scroll Case

OCOEE NO. 1 DAM SCROLL CASE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A140. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Ocoee No. 1 Dam Scroll Case ($DO = 7.5617 + 8.08E-4Q$; $R^2 = 0.1296$; $p < 0.00001$)

Table A-20. Ocoee No. 1 Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	46	23-Jul	6.31	1,329	1,050
1963	50	02-Jul	7.23	2,770	1,947
1964	50	13-Jul	7.19	1,156	981
1965	50	09-Aug	6.50	1,120	1,057
1966	46	01-Aug	6.24	1,439	914
1967	50	11-Sep	5.80	1,447	1,518
1968	39	12-Aug	6.30	1,235	1,197
1969	48	30-Jun	6.00	911	1,099
1970	37	23-Nov	6.10	902	361
1971	43	27-Jul	7.20	2,454	1,189
1972	53	24-Jan	5.90	2,086	2,115
1973	55	17-Sep	7.00	1,355	1,328
1974	55	12-Aug	2.60	1,262	1,317
1975	53	11-Aug	1.40	1,681	1,142
1976	53	23-Aug	7.00	1,492	1,491
1985	16	03-Dec	6.10	1,014	839
1986	27	19-Nov	5.10	917	991
1987	16	02-Sep	6.70	492	609
1989	18	12-Sep	7.00	1,304	1,384

Regression of mean daily discharge (Q) on minimum DO

$$DO = 5.673 + 2.23E-4*Q$$

$$R^2 = 0.0065 \quad p = 0.74373$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 5.818 + 1.388E-4*Q7$$

$$R^2 = 0.0014 \quad p = 0.87898$$

Figure A141. Location of Ocoee No. 3 Dam

OCOEE NO. 3 POWERHOUSE SCROLL CASE

Distribution of Historical Measurements

Figure A142. Annual temperature pattern for Ocoee No. 3 Powerhouse Scroll Case

OCOEE NO. 3 POWERHOUSE SCROLL CASE

Distribution of Historical Measurements

Figure A143. Annual dissolved oxygen pattern for Ocoee No. 3 Powerhouse Scroll Case

OCOEE NO. 3 POWERHOUSE SCROLL CASE

Distribution of Historical Measurements

Figure A144. Distribution of historical dissolved oxygen measurements from Ocoee No. 3 Powerhouse Scroll Case

OCOEE NO. 3 DAM SCROLL CASE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A145. Distribution of annual minimum dissolved oxygen measurements from Ocoee No. 3 Powerhouse Scroll Case

OCOEE NO. 3 DAM SCROLL CASE

Historical Releases

Figure A146. Discharge data from Ocoee No. 3 Powerhouse Scroll Case

OCOEE NO. 3 POWERHOUSE SCROLL CASE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A147. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Ocoee No. 3 Powerhouse Scroll Case ($DO = e(0.1389 - 1.28E-5Q)$; $R^2 = 0.0729$; $p = 0.00004$)

Table A-21. Ocoee No. 3 Powerhouse Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	44	20-Aug	5.85	1,253	1,232
1963	49	26-Aug	6.04	947	1,051
1964	49	14-Sep	5.70	1,290	1,316
1965	48	28-Sep	5.16	886	707
1966	48	11-Jul	5.34	875	853
1967	51	18-Jul	4.10	1,232	1,262
1968	41	26-Aug	5.60	890	1,038
1969	46	19-May	4.10	927	934
1970	36	14-Sep	5.10	1,100	1,072
1971	45	13-Sep	6.10	899	897
1972	56	03-Oct	5.10	866	961
1973	56	17-Sep	5.20	1,325	1,227
1974	55	29-Jul	5.80	926	939
1975	47	28-Jul	6.80	888	888
1976	55	12-Oct	5.90	1,330	1,220
1985	17	04-Sep	7.00	1,010	1,062
1986	15	19-Aug	5.80	505	467
1987	16	14-Sep	6.90	547	542
1989	17	12-Sep	7.40	1,284	1,301

Regression of mean daily discharge (Q) on minimum DO

$$DO = 5.232 + 470.6*(1/Q)$$

$$R^2 = 0.0310 \quad p = 0.47120$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 5.395 + 316*(1/Q7)$$

$$R^2 = 0.0170 \quad p = 0.59450$$

Figure A148. Location of Pickwick Dam

PICKWICK DAM TAILRACE

Distribution of Historical Measurements

Figure A149. Annual temperature pattern for Pickwick Dam Tailrace

PICKWICK DAM TAILRACE

Distribution of Historical Measurements

Figure A150. Annual dissolved oxygen pattern for Pickwick Dam Tailrace

PICKWICK DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A151. Distribution of historical dissolved oxygen measurements from Pickwick Dam Tailrace

PICKWICK DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A152. Distribution of annual minimum dissolved oxygen measurements from Pickwick Dam Tailrace

PICKWICK DAM TAILRACE

Historical Releases

Figure A153. Discharge data from Pickwick Dam Tailrace

PICKWICK DAM TAILRACE

Regression of Monthly Means

Discharge (ln cfs)

Figure A154. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Pickwick Dam Tailrace
($DO = 11.47 + 1.8919 \ln Q$; $R^2 = 0.3579$; $p < 0.00001$)

Table A-22. Pickwick Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	52	17-Jul	5.90	29,800	35,857
1963	53	09-Jul	5.70	32,400	31,086
1964	53	05-Aug	5.20	31,300	29,557
1965	51	16-Jun	6.90	61,700	40,157
1966	55	21-Jul	4.10	30,500	24,614
1967	49	02-Aug	6.50	80,800	70,843
1968	50	03-Sep	2.40	25,500	24,043
1969	48	08-Jul	5.10	24,000	22,157
1970	48	21-Jul	5.80	23,900	29,500
1971	36	24-Aug	5.90	40,100	38,271
1972	50	31-Oct	5.50	65,300	56,514
1973	51	11-Sep	6.00	38,800	36,743
1974	47	14-Aug	6.50	45,300	43,371
1975	48	16-Sep	6.40	35,100	42,414
1976	50	16-Nov	5.60	44,000	42,529
1985	27	12-Jun	4.90	10,650	19,843
1986	30	04-Aug	3.00	15,938	14,973
1987	28	29-Jul	4.70	31,088	28,275
1988	33	02-Aug	4.40	17,550	14,352
1989	19	20-Sep	6.20	45,300	53,668

Regression of mean daily discharge (Q) on minimum DO

$$DO = -10.0 + 1.48*(\ln Q)$$

$$R^2 = 0.3846 \quad p = 0.00353$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = -15.8 + 2.04*(\ln Q7)$$

$$R^2 = 0.5414 \quad p = 0.00022$$

Figure A155. Location of Santeeetlah Dam

SANTEETLAH DAM TAILRACE

Distribution of Historical Measurements

Figure A156. Annual temperature pattern for Santeetlah Dam Tailrace

SANTEETLAH DAM TAILRACE

Distribution of Historical Measurements

Figure A157. Annual dissolved oxygen pattern for Santeetlah Dam Tailrace

SANTEETLAH DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A158. Distribution of historical dissolved oxygen measurements from Santeetlah Dam Tailrace

SANTEETLAH DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A159. Distribution of annual minimum dissolved oxygen measurements from Santeetlah Dam Tailrace

SANTEETLAH DAM TAILRACE

Historical Releases

Figure A160. Discharge data from Santeetlah Dam Tailrace

SANTEETLAH DAM TAILRACE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A161. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Santeetlah Dam Tailrace (DO = $6.6169 + 3.34E-4Q$; $R^2 = 0.1586$; $p < 0.00001$)

Table A-23. Santeetlah Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1968	26	04-Nov	5.20	430	284
1969	16	05-Nov	6.70	571	485
1970	16	29-Sep	4.40	289	244
1971	25	03-Nov	3.20	240	192
1972	36	02-Oct	3.60	259	479
1973	19	02-Oct	3.50	632	565
1974	22	01-Oct	3.80	226	232
1975	37	18-Sep	3.95	279	221
1976	46	29-Sep	3.70	316	300
1985	17	07-Oct	4.30	250	218
1986	14	18-Nov	4.90	215	198
1987	17	20-Oct	4.30	382	280
1989	17	27-Sep	5.10	1	1

Regression of mean daily discharge (Q) on minimum DO

$$DO = 4.29 + 0.802*(1/Q)$$

$$R^2 = 0.0556 \quad p = 0.43797$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 4.29 + 0.804*(1/Q7)$$

$$R^2 = 0.0559 \quad p = 0.43688$$

Figure Al62. Location of South Holston Dam

SOUTH HOLSTON DAM SCROLL CASE

Distribution of Historical Measurements

Figure A163. Annual temperature pattern for South Holston Dam Scroll Case

SOUTH HOLSTON DAM SCROLL CASE

Distribution of Historical Measurements

Figure A164. Annual dissolved oxygen pattern for South Holston Dam Scroll Case

SOUTH HOLSTON DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A165. Distribution of historical dissolved oxygen measurements from South Holston Dam Scroll Case

SOUTH HOLSTON DAM SCROLL CASE

Distribution of Annual Minimum DO

Figure Ai66. Distribution of annual minimum dissolved oxygen measurements from South Holston Dam Scroll Case

SOUTH HOLSTON DAM SCROLL CASE

Figure A167. Discharge data from South Holston Dam Scroll Case

SOUTH HOLSTON DAM SCROLL CASE

Regression of Monthly Means

Discharge (1/cfs)

Figure A168. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from South Holston Dam Scroll Case ($DO = 6.5258 + 278.51/Q$; $R^2 = 0.0189$; $p = 0.03431$)

Table A-24. South Holston Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1961	13	10-Oct	1.49	2,127	1,423
1962	51	09-Oct	1.69	1,745	1,247
1963	50	19-Nov	0.34	1	379
1964	46	03-Nov	2.41	781	377
1965	43	22-Oct	2.44	1,825	1,372
1966	39	04-Oct	1.51	2,007	685
1967	44	24-Oct	2.80	1,197	886
1968	39	20-Aug	0.60	1,555	1,448
1969	35	25-Nov	2.30	168	962
1970	39	22-Sep	1.00	1,601	1,638
1971	39	17-Nov	2.00	1,911	1,270
1972	42	17-Oct	1.40	2,384	1,725
1973	37	02-Oct	1.20	1,474	1,174
1974	34	23-Sep	1.40	1,421	965
1975	44	14-Oct	0.70	1,286	1,348
1976	39	22-Sep	3.00	953	954
1985	27	13-Nov	1.60	969	510
1986	35	03-Nov	1.40	840	842
1987	25	20-Oct	0.80	997	989
1988	13	19-Oct	3.40	361	285
1989	24	12-Oct	1.10	1,840	1,818

Regression of mean daily discharge (Q) on minimum DO

$$DO = 0.253 * Q^{0.1418}$$

$$R^2 = 0.1696 \quad p = 0.06362$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 2.34 - 6.496E-4 * Q7$$

$$R^2 = 0.1242 \quad p = 0.11714$$

Figure A169. Location of Tims Ford Dam

TIMS FORD DAM SCROLL CASE

Distribution of Historical Measurements

Figure A170. Annual temperature pattern for Tims Ford Dam Scroll Case

TIMS FORD DAM SCROLL CASE

Distribution of Historical Measurements

Figure A171. Annual dissolved oxygen pattern for Tims Ford Dam Scroll Case

TIMS FORD DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A172. Distribution of historical dissolved oxygen measurements from Tims Ford Dam Scroll Case

TIMS FORD DAM SCROLL CASE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A173. Distribution of annual minimum dissolved oxygen measurements from Tims Ford Dam Scroll Case

TIMS FORD DAM SCROLL CASE

Figure A174. Discharge data from Tims Ford Dam Scroll Case

TIMS FORD DAM SCROLL CASE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A175. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Tims Ford Dam Scroll
Case (DO = 4.8217 + 6.99E-4Q; $R^2 = 0.0364$; $p = 0.04595$)

Table A-25. Tims Ford Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1972	30	18-Sep	0.10	2,721	2,607
1973	48	24-Jul	0.10	33	1,205
1974	62	29-Oct	0.10	400	863
1975	60	06-Oct	0.20	1,010	1,389
1976	37	04-Oct	0.60	325	317
1985	13	04-Nov	0.50	1,279	645
1986	16	26-Nov	0.90	27	661
1987	20	01-Dec	1.10	1,025	475
1989	17	15-Sep	0.50	125	86

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1/(3.725 + 1.32E-3*Q)$$

$$R^2 = 0.0776 \quad p = 0.46796$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 1/(1.17 + 3.897E-3*Q7)$$

$$R^2 = 0.5104 \quad p = 0.03058$$

Figure A176. Location of Watauga Dam

WATAUGA POWERHOUSE PENSTOCK

Distribution of Historical Measurements

Figure A177. Annual temperature pattern for Watauga Powerhouse Penstock

WATAUGA POWERHOUSE PENSTOCK

Distribution of Historical Measurements

Figure A178. Annual dissolved oxygen pattern for Watauga Powerhouse Penstock

WATAUGA POWERHOUSE PENSTOCK

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A179. Distribution of historical dissolved oxygen measurements from Watauga Powerhouse Penstock

WATAUGA POWERHOUSE PENSTOCK

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A180. Distribution of annual minimum dissolved oxygen measurements from Watauga Powerhouse Penstock

WATAUGA POWERHOUSE PENSTOCK

Historical Releases

Figure A181. Discharge data from Watauga Powerhouse Penstock

WATAUGA POWERHOUSE PENSTOCK

Regression of Monthly Means

Discharge (1/cfs)

Figure A182. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Watauga Powerhouse Penstock ($DO = 8.0116 + 118.8/Q$; $R^2 = 0.0456$; $p = 0.00097$)

Table A-26. Watauga Powerhouse Penstock Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1961	11	13-Nov	2.33	288	746
1962	48	20-Nov	2.18	332	557
1963	47	02-Dec	2.79	425	189
1964	48	09-Nov	4.05	27	787
1965	47	22-Nov	2.57	1,002	899
1966	45	17-Oct	3.26	712	407
1967	46	13-Nov	3.60	1,651	970
1968	32	29-Oct	3.80	1,740	888
1969	31	11-Nov	3.70	50	198
1970	29	29-Sep	2.50	422	589
1971	28	22-Nov	4.70	1,228	692
1972	33	23-Oct	4.70	1,462	709
1973	28	29-Oct	4.60	1,777	380
1974	43	04-Nov	2.20	379	356
1975	42	11-Nov	3.60	456	168
1976	42	12-Oct	4.00	1,191	773
1985	18	08-Nov	6.00	118	107
1986	30	23-Oct	5.75	366	351
1987	16	05-Nov	4.10	401	441
1988	13	18-Oct	5.00	126	81
1989	16	03-Nov	1.90	558	702

Regression of mean daily discharge (Q) on minimum DO

$$DO = 1/(0.3269 - 3.59E-5*Q)$$

$$R^2 = 0.0402 \quad p = 0.38362$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 3.14 + 172*(1/Q7)$$

$$R^2 = 0.1881 \quad p = 0.04948$$

Figure A183. Location of Watts Bar Dam

WATTS BAR DAM TAILRACE

Distribution of Historical Measurements

Figure A184. Annual temperature pattern for Watts Bar Dam Tailrace

WATTS BAR DAM TAILRACE

Distribution of Historical Measurements

Figure A185. Annual dissolved oxygen pattern for Watts Bar Dam Tailrace

WATTS BAR DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A186. Distribution of historical dissolved oxygen measurements from Watts Bar Dam Tailrace

WATTS BAR DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A187. Distribution of annual minimum dissolved oxygen measurements from Watts Bar Dam Tailrace

WATTS BAR DAM TAILRACE

Historical Releases

Figure A188. Discharge data from Watts Bar Dam Tailrace

WATTS BAR DAM TAILRACE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A189. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Watts Bar Dam Tailrace ($DO = e(1.7234 + 9.79E-6Q)$; $R^2 = 0.1261$; $p < 0.00001$)

Table A-27. Watts Bar Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1961	19	14-Jun	5.60	25,300	17,500
1962	51	27-Aug	2.93	15,400	20,243
1963	50	08-Jul	2.34	17,400	12,629
1964	52	10-Aug	3.18	18,200	19,114
1965	50	19-Jul	2.73	16,300	24,657
1966	50	11-Jul	2.13	23,700	17,700
1967	48	26-Jun	3.90	21,000	23,543
1968	46	10-Jun	3.30	22,700	15,886
1969	38	17-Jun	2.20	7,700	16,486
1970	51	14-Sep	2.90	28,600	22,671
1971	53	26-Jul	3.00	18,400	21,757
1972	52	07-Aug	4.10	22,700	26,357
1973	56	24-Sep	4.20	21,600	21,600
1974	58	28-Jul	5.20	28,900	30,786
1975	54	25-Aug	3.90	18,300	27,029
1976	58	16-Jun	3.90	21,800	21,543
1985	31	20-Jun	2.10	5,567	8,370
1986	29	25-Jun	1.90	15,850	10,198
1987	48	25-Aug	3.80	23,446	20,982
1988	41	05-Jul	1.70	13,517	9,666
1989	40	29-Aug	6.40	37,567	31,777

Regression of mean daily discharge (Q) on minimum DO

$$DO = 0.681 + 1.347E-4*Q$$

$$R^2 = 0.5834 \quad p = 0.00006$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 1/(0.628 - 1.475E-5*Q7)$$

$$R^2 = 0.6394 \quad p = 0.00001$$

Figure A190. Location of Wheeler Dam

WHEELER DAM TAILRACE

Distribution of Historical Measurements

Figure A191. Annual temperature pattern for Wheeler Dam Tailrace

WHEELER DAM TAILRACE

Distribution of Historical Measurements

Figure A192. Annual dissolved oxygen pattern for Wheeler Dam Tailrace

WHEELER DAM TAILRACE Distribution of Historical Measurements

Figure A193. Distribution of historical dissolved oxygen measurements from Wheeler Dam Tailrace

WHEELER DAM TAILRACE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A194. Distribution of annual minimum dissolved oxygen measurements from Wheeler Dam Tailrace

WHEELER DAM TAILRACE

Historical Releases

Figure A195. Discharge data from Wheeler Dam Tailrace

WHEELER DAM TAILRACE

Regression of Monthly Means

Discharge (ln cfs)

Figure A196. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Wheeler Dam Tailrace
($DO = -13.6847 + 2.0852 \ln Q$; $R^2 = 0.3240$; $p < 0.00001$)

Table A-28. Wheeler Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1960	40	05-Aug	5.30	26,400	26,986
1961	41	08-Sep	5.90	50,100	46,557
1962	41	10-Aug	5.35	33,700	31,757
1963	36	16-Aug	5.39	28,200	28,000
1964	41	23-Jun	5.41	34,100	36,657
1965	37	26-Aug	5.94	41,200	37,171
1966	39	08-Jul	4.02	37,900	23,214
1967	40	12-Sep	3.35	56,900	55,900
1968	51	27-Sep	5.40	22,600	15,157
1969	47	16-Jun	4.80	33,600	33,943
1970	49	04-Aug	5.00	40,300	35,414
1971	40	21-Jun	4.50	45,500	40,771
1972	48	24-Jul	5.60	36,400	42,629
1973	54	17-Sep	5.50	27,600	34,143
1974	58	03-Sep	5.20	35,300	32,486
1975	56	02-Sep	5.00	33,800	33,786
1976	55	26-Jul	5.60	43,000	41,571
1985	29	16-Jul	3.70	18,471	20,434
1986	29	30-Jun	3.20	27,813	14,672
1987	28	11-Aug	4.10	34,328	33,715
1988	33	29-Jun	4.40	16,840	11,752
1989	18	28-Aug	5.50	48,609	45,031

Regression of mean daily discharge (Q) on minimum DO

$$DO = 5.464 - 17575*(1/Q)$$

$$R^2 = 0.0529 \quad p = 0.30312$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 5.55 - 17882*(1/Q7)$$

$$R^2 = 0.1450 \quad p = 0.08039$$

Figure A197. Location of Wilbur Dam

WILBUR DAM SCROLL CASE

Distribution of Historical Measurements

Figure A198. Annual temperature pattern for Wilbur Dam Scroll Case

WILBUR DAM SCROLL CASE

Distribution of Historical Measurements

Figure A199. Annual dissolved oxygen pattern for Wilbur Dam Scroll Case

WILBUR DAM SCROLL CASE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A200. Distribution of historical dissolved oxygen measurements from Wilbur Dam Scroll Case

WILBUR DAM SCROLL CASE

Distribution of Annual Minimum DO

Dissolved Oxygen (mg/l)

Figure A201. Distribution of annual minimum dissolved oxygen measurements from Wilbur Dam Scroll Case

WILBUR DAM SCROLL CASE

Figure A202. Discharge data from Wilbur Dam Scroll Case

WILBUR DAM SCROLL CASE

Regression of Monthly Means

Discharge (1/cfs)

Figure A203. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Wilbur Dam Scroll Case ($DO = e(8.55 + 233.11Q)$; $R^2 = 0.0376$; $p = 0.00315$)

Table A-29. Wilbur Dam Scroll Case Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	44	21-Oct	5.70	195	697
1963	45	05-Nov	5.10	172	664
1964	46	21-Sep	3.90	1,550	680
1965	44	18-Oct	4.20	1,730	953
1966	40	07-Sep	4.10	619	894
1967	42	05-Sep	0.70	1,177	355
1968	35	11-Nov	4.80	1,820	366
1969	27	14-Apr	4.30	1,220	262
1970	26	29-Sep	0.80	534	659
1971	23	20-Sep	4.10	1,500	782
1972	33	13-Nov	6.10	66	81
1973	30	04-Jun	4.90	1,540	2,483
1974	40	22-Apr	1.10	1,180	1,668
1975	43	28-Oct	4.80	999	454
1976	43	27-Sep	3.90	785	365
1985	18	16-Oct	7.40	1,538	430
1986	29	13-Aug	7.20	764	733
1987	16	05-Nov	6.00	472	483
1989	15	13-Nov	3.20	578	465

Regression of mean daily discharge (Q) on minimum DO

$$DO = 3.98 + 153.6*(1/Q)$$

$$R^2 = 0.0779 \quad p = 0.24705$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 3.94 + 164.6*(1/Q7)$$

$$R^2 = 0.0494 \quad p = 0.36046$$

Figure A204. Location of Wilson Dam

WILSON DAM TAILRACE

Distribution of Historical Measurements

Figure A205. Annual temperature pattern for Wilson Dam Tailrace

WILSON DAM TAILRACE

Distribution of Historical Measurements

Figure A206. Annual dissolved oxygen pattern for Wilson Dam Tailrace

WILSON DAM TAILRACE

Distribution of Historical Measurements

Dissolved Oxygen (mg/l)

Figure A207. Distribution of historical dissolved oxygen measurements from Wilson Dam Tailrace

WILSON DAM TAILRACE

Distribution of Annual Minimum DO

Figure A208. Distribution of annual minimum dissolved oxygen measurements from Wilson Dam Tailrace

WILSON DAM TAILRACE

Historical Releases

Figure A209. Discharge data from Wilson Dam Tailrace

WILSON DAM TAILRACE

Regression of Monthly Means

Discharge (1000 cfs)

Figure A210. Regression curve and 95 percent confidence and prediction levels for monthly mean dissolved oxygen on monthly mean discharge from Wilson Dam Tailrace ($DO = 0.0037 Q^{0.2210}$; $R^2 = 0.2488$; $p < 0.00001$)

Table A-30. Wilson Dam Tailrace Annual Minimum Dissolved Oxygen and Associated Discharge

Year	Number of Dissolved Oxygen Measurements	Date of Minimum Dissolved Oxygen	Minimum Dissolved Oxygen (mg/l)	Mean Daily Discharge on Date (cfs)	Mean 7-day Preceding Discharge (cfs)
1962	47	03-Aug	6.20	31,500	29,771
1963	50	13-Sep	1.14	30,000	34,586
1964	53	17-Aug	4.60	58,600	34,486
1965	50	06-Jul	2.40	26,400	26,957
1966	52	07-Jul	4.50	22,600	19,243
1967	51	21-Aug	6.20	59,200	48,043
1968	49	25-Jun	4.10	40,000	36,786
1969	53	24-Jun	4.70	31,500	22,014
1970	54	28-Sep	4.50	25,300	25,400
1971	51	28-Jun	4.10	40,700	30,300
1972	50	07-Aug	4.90	38,000	48,114
1973	53	18-Sep	5.10	27,500	32,571
1974	53	03-Sep	4.80	36,100	32,786
1975	52	15-Jul	5.50	46,700	52,014
1976	53	12-Jul	5.20	47,200	68,386
1985	26	27-Aug	4.90	54,908	42,367
1986	30	28-Jul	4.10	15,643	18,202
1987	29	29-Jun	3.20	32,227	23,452
1988	33	11-Jul	3.90	10,575	13,476
1989	17	12-Sep	5.40	52,870	49,532

Regression of mean daily discharge (Q) on minimum DO

$$DO = 3.095 + 3.785E-5*Q$$

$$R^2 = 0.1892 \quad p = 0.05529$$

Regression of mean 7-day preceding discharge (Q7) on minimum DO

$$DO = 3.26 + 3.52E-5*Q7$$

$$R^2 = 0.1609 \quad p = 0.07965$$

END

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