Yadkin Project
FERC No. 2197

YADKIN WATER QUALITY

DRAFT STUDY REPORT
DO NOT CITE

MARCH 2005

YADKIN PROJECT
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YADKIN WATER QUALITY MONITORING REPORT

DRAFT STUDY REPORT
DO NOT CITE

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SUMMARY

The Water Quality Monitoring Report summarizes the results of five years of water quality monitoring that has been conducted in the four Yadkin Project reservoirs and tailwaters. The water quality monitoring and the analysis of water quality conditions were conducted by Normandeau Associates, Inc. (NAI) as part of the FERC relicensing process for the Yadkin Project. The water quality data analysis and report were prepared in accordance with the Final Water Quality Monitoring Study Plan that was developed by Yadkin in consultation with the Water Quality Issue Advisory Group (IAG). Specific objectives identified in the Final Study Plan included:

- Continue the collection of reservoir water quality data at sampling stations used in previous years in order to characterize the baseline water quality of the four Project reservoirs and four tailwater areas.
- Evaluate the effects of current Project operations, including reservoir water level fluctuations on reservoir water quality.
- Conduct continuous monitoring of dissolved oxygen (DO) and temperature conditions in all four Project tailwaters during the warm water months (May through November) in order to evaluate existing water quality conditions in the tailwaters and how these conditions may be affected by Project operations.

NAI has been collecting water quality data at the Yadkin Project since June 1999. Monthly water quality sampling has been conducted at 16 reservoir locations and at each of the four tailraces below the dams. In addition, the tailraces of the Falls and Narrows developments were continuously monitored for dissolved oxygen and temperature for extended periods in 2000-2004. The tailraces of the High Rock and Tuckertown developments were continuously monitored for dissolved oxygen and temperature for extended periods in 2003-2004. Yadkin's five year water quality monitoring effort is summarized in the table below.

In terms of general trends in Project water quality, the results of the monitoring study showed the Yadkin Project waters experience varying degrees of eutrophication as a result of elevated concentrations of nutrients and chlorophyll a (an indicator of algal growth) and reduced levels of dissolved oxygen. Among the four Project reservoirs, water quality is generally poorest in the High Rock Reservoir and best in Falls Reservoir. Concentrations of nutrients, suspended solids and chlorophyll were all found on average to decrease from High Rock downstream through Falls Reservoir. In High Rock Reservoir itself, water quality in several of the tributary arms, particularly the Swearing Creek, Crane Creek and Abbotts Creek arms, was somewhat poorer than that observed in the mainstem of the reservoir.

Of the four Project reservoirs, only Narrows was found to experience strong seasonal thermal stratification. Coincident with the thermal stratification, top to bottom differences in reservoir dissolved oxygen concentrations are significant at Narrows during much of the summer and fall. High Rock and Tuckertown Reservoirs were found to weakly stratify during some periods of the summer and top to bottom dissolved oxygen concentrations are variable for much of the summer. Falls Reservoir experiences no thermal stratification.

There are also water quality concerns in the Yadkin Project tailwaters, located immediately downstream of the dams. The primary water quality concern in the tailwaters is the concentration

Summary of Water Quality Monitoring Conducted by APGI at the Yadkin Project

Monitoring Location	1999	2000	2001	2002	2003	2004
High Rock Reservoir 10 stations	Monthly Jun-Dec	Monthly Jan-Dec	Monthly Jan-Dec	Monthly Jan-Dec	Monthly Jan-Dec	
Tuckertown Reservoir 2 stations	Monthly Jun-Dec	Monthly Jan-Dec	Monthly Jan-Dec	Monthly Jan-Dec	Monthly Jan-Dec	
Narrows Reservoir 3 stations	Monthly Jun-Dec	Monthly Jan-Dec	Monthly Jan-Dec	Monthly Jan-Dec	Monthly Jan-Dec	
Falls Reservoir 1 station	Monthly Jun-Dec	Monthly Jan-Dec	Monthly Jan-Dec	Monthly Jan-Dec	Monthly Jan-Dec	
High Rock Tailwater 1 station	Monthly Jun-Dec	Monthly Jun-Dec	Monthly Jun-Dec	Monthly Jun-Dec	Monthly Jan-Dec Continuous DO/Temp May-Nov	Continuous DO/Temp May-Nov
Tuckertown Tailwater 1 station	Monthly Jun-Dec	Monthly Jun-Dec	Monthly Jun-Dec	Monthly Jun-Dec	Monthly Jan-Dec Continuous DO/Temp May-Nov	Continuous DO/Temp May-Nov
Narrows Tailwater 1 station	Monthly Jan-Dec	Monthly Jan-Dec	Monthly Jan-Dec Continuous DO/Temp May-Nov	Monthly Jan-Dec Continuous DO/Temp May-Nov	Monthly Jan-Dec Continuous DO/Temp May-Nov	Continuous DO/Temp May-Nov
Falls Tailwater 1 station	Monthly Jan-Dec	Monthly Jan-Dec	Monthly Jan-Dec Continuous DO/Temp May-Nov	Monthly Jan-Dec Continuous DO/Temp May-Nov	Monthly Jan-Dec Continuous DO/Temp May-Nov	Continuous DO/Temp May-Nov

of dissolved oxygen. The water quality monitoring study found that dissolved oxygen levels in the all four project tailwater areas are frequently at or below the state standards throughout much of the summer and fall (May through November). Low dissolved oxygen concentrations in the tailwaters is a result of the release of low dissolved oxygen reservoir water into the tailrace. Elevated concentrations of nutrients, organic matter and algae found in the tailwater areas also contribute to this problem.

The study examined the influence of flows through the Project on water quality. For a large reservoir like High Rock, retention time can vary considerably depending on flow conditions. At High Rock, estimated retention times average between 4 and 50 days, depending on river flows. At Narrows the average retention time is estimated to be about 2 days. At the two smaller reservoirs, Tuckertown and Falls, the average retention time is estimated to be about 22 hours and 2 hours, respectively. Longer reservoir retention times such as those experienced by High Rock and, to a lesser extent Narrows, have the effect of allowing algae to utilize available nutrients and to grow in greater concentrations. From this perspective, flow in the Yadkin River has a strong influence on the water quality of the upper portion of High Rock Reservoir where the study recorded low levels of chlorophyll a (an indicator of algal concentrations) in the presence of high nutrient concentrations. This is a condition that would be expected in a riverine environment where most of the algae is attached to substrates and not present in the open water. The upper portion of High Rock Reservoir was also observed to have high concentrations of suspended solids which limit light availability to algae. Based on the water quality data collected, the "riverine" effects of the mainstem Yadkin River on water quality conditions were observed to at least six miles along the mainstem in the upper portion of High Rock Reservoir.

The study also examined whether flow through the Project developments affects water quality. This study examined the relationship of flows and water quality statistically through the use of correlation analysis. Results of a correlation analysis between flows at each of the dams with water quality suggest that in general water quality conditions are weakly correlated with flows. Overall, observed relationships between flows and water quality were primarily related to retention time in the reservoirs and transport and deposition of suspended solids.

The study also examined the potential influence of reservoir water levels on both reservoir and tailwater water quality conditions. In terms of the influence of reservoir water levels on reservoir surface water quality, correlation results were generally poor. NAI found that most correlation coefficients (which express the strength of the relationship between the factors being correlated) were low indicating that poor, if any, relationships exist between reservoir water levels and water quality. In general, where correlations were observed they were negative, indicating that as reservoir water levels drop concentrations of the water quality parameter tend to increase, an effect that may also be caused by seasonal changes in reservoir water quality as by reservoir water levels. In High Rock Reservoir, which experiences the greatest changes in reservoir water levels, the strongest correlations to water levels were seen in total dissolved solids and total phosphorus concentrations which were both negatively correlated with reservoir water levels; meaning that the concentrations of those parameters increased as water levels decreased.

The influence of Project operations on tailwater dissolved oxygen levels was another important issue addressed by this study. Modifications to Narrows Unit 4 in 2001 included the addition of two air injection valves intended to introduce air into the flow during generation. The ability of the Unit 4 aeration valves to increase tailwater dissolved oxygen concentrations was the subject of an earlier study conducted by APGI and reported to FERC (NAI, 2002). In the current study, additional testing was done to further examine the effect of project operations on tailwater dissolved oxygen. The objectives of the additional testing were:

- To further evaluate the effectiveness of the air injection valves at Narrows Unit 4 to increase tailwater dissolved oxygen levels,
- To determine how increases in dissolved oxygen concentrations in the Narrows tailwater impact the dissolved oxygen concentrations in the Falls tailwater, and
- To determine if an increase in dissolved oxygen concentrations in the High Rock tailwater impacts the dissolved oxygen concentration in the Tuckertown tailwater.

The additional tailwater DO testing was scheduled for August and September of 2004. However, high flows due to successive hurricanes in September forced APGI to cancel the September test, so only the August tests were completed. At Narrows, tests of the effect of the two aeration valves on Unit 4 generally confirmed earlier results (2001) that with both valves operating and just Unit 4 operating, about 2 mg/l of dissolved oxygen is added to the tailwaters. The tests also demonstrated that increases in Narrows tailwater dissolved oxygen levels are generally translated to similar increases in dissolved oxygen concentrations below Falls dam. This result supports the conclusion that if dissolved oxygen levels in the Narrows tailwaters are raised, similar increases in Falls tailwater dissolved oxygen concentrations would be expected.

Tailwater testing in the High Rock tailwater focused on determining if increasing High Rock tailwater dissolved oxygen concentrations would result in an observable increase in dissolved oxygen levels in the Tuckertown Reservoir. Since there is currently no aeration equipment in place at High Rock, APGI attempted to raise High Rock tailwater dissolved oxygen levels temporarily by operating the High Rock units at a unusually low gated setting that was hoped would allow maximum air intake through an existing system of piping and valves through the bearing riser.[1] Despite APGI's best efforts, no significant increase in High Rock tailwater dissolved oxygen concentrations were observed to occur during the test. Dissolved oxygen concentrations did increase somewhat over the three-day test period, but NAI concluded that this increase was the result of improved reservoir dissolved oxygen conditions and diurnal cycles in the dissolved oxygen and temperature rather than air introduced through the High Rock units. As the test failed to produce a significant increase in High Rock tailwater dissolved oxygen concentrations, not surprisingly, there was no measurable response in dissolved oxygen levels in the Tuckertown tailwater.

Finally, the water quality monitoring study examined a couple of biological water quality issues that were raised by the Water Quality IAG. The question of mercury in fish tissue was examined in the study by collecting fish tissue samples in several locations throughout the Project. Fish were captured by NAI using a combination of gill nets and electrofishing. Mercury concentrations in all of the fish samples collected were below the detection limit of 0.145 mg/kg, which is well below the U.S. Environmental Protection Agency's action level of 1 mg/kg.

Concerns about levels of fecal coliform in the Project waters were also addressed in this study. Monitoring for fecal coliform in the Project reservoirs is handled by both the North Carolina Division of Water Quality and, as needed, by the local county health departments. In this study NAI compiled fecal coliform data that had been collected in High Rock, Tuckertown and Narrows reservoirs for the years 1999 to 2001. For the most part fecal coliform counts were generally less than 10 per 100 ml. All of the samples had concentrations below the State standard for Class C waters of 200 per 100 ml.

[1] This method of operation can only be used on a short-term basis. Long-term operation of the High Rock units in this manner would result in damage to the units.

1.0 INTRODUCTION

Alcoa Power Generating Inc. is currently licensed by the Federal Energy Regulatory Commission to operate four hydroelectric facilities (FERC No. 2197 NC) on the Yadkin River in central North Carolina. The current license will expire in 2008. To continue operations, Alcoa has applied for a new license. As part of the relicensing process, Alcoa sought comment from agencies, municipalities, organizations and the public on concerns related to the water quality at the Project. The principal concerns are the current status of water quality in the reservoirs and tailwaters and the effects of hydroelectric facility operations on water quality. Alcoa initiated water quality monitoring in the reservoirs and tailwaters in 1999 to establish baseline water quality conditions and assess the current status of water quality. Additional studies have been conducted through 2004 (Normandeau 2001, 2003, 2004). Water quality study results through 2001 are summarized in Normandeau 2002 and APGI 2002. Manipulations of flow rate, generation, spill and lake level during the operation of the hydroelectric facilities may influence water quality.

The four hydroelectric facilities that are currently licensed are High Rock, Tuckertown, Narrows, and Falls. All four developments are located on a 38-mile stretch of the Yadkin River and support the electric power needs of Alcoa's Badin Works or sold on the open market. The plants are generally operated during peak power hours. During periods of high inflow, the system is operated continuously. The High Rock and Narrows Reservoirs are storage facilities that are operated in a store and release mode, with storage volumes of 234,863 and 128,926 acre-feet, respectively. The Tuckertown and Falls developments have storage volumes of 6,897 and 1,825 acre-feet, respectively, and are operated as essentially run-of-river. The uppermost development, High Rock, serves as the principal storage facility for the Yadkin/Pee Dee River. The characteristics of the four Project impoundments and facilities are summarized in Table 1.0-1.

The area immediately surrounding the reservoirs is predominately rural, although several small cities, including Albemarle, Badin, Lexington, and Salisbury are located within 30 miles. Farms and timberlands are predominant in this area, but residential development, particularly along the reservoir shorelines, has increased significantly in the last 10 years. The two largest reservoirs, High Rock and Narrows, have considerable development along the shoreline and receive significant levels of recreational use. The two smaller reservoirs, Falls and Tuckertown, have shorelines that are generally undeveloped and receive less recreational use (Yadkin, Inc., 1999).

The Yadkin River watershed has a drainage area of 4,190 square miles above Falls Dam. The drainage area is located primarily in the northern piedmont of North Carolina, with a small portion extending into southern Virginia. The predominant land use has historically been agriculture and forestry. Currently, land use within the watershed is approximately 58% forested, 31% agricultural, 7% urban, and about 4% rangeland (NCDEM Report NO. 89-04). Some of North Carolina's largest cities, including Charlotte, Winston-Salem, and Greensboro, are located within an hour of travel time. Average rainfall in the Yadkin basin ranges between 44 to 56 inches per year. The Yadkin River rises in the Appalachian Mountains in North Carolina and picks up additional tributaries as it flows parallel to the mountains in a northeasterly direction. Northwest of Winston-Salem, the river turns south and flows through flatter terrain until it enters High Rock Reservoir, the most upstream of the four developments. A major tributary, the South Yadkin River, joins the mainstem of the Yadkin River north of Salisbury in Rowan County, a short distance upstream of High Rock Reservoir. Other major tributaries draining into the four reservoirs include Abbotts Creek, Swearing Creek, Dutch Second

Table 1.0-1. Characteristics of the four Yadkin APGI reservoirs and projects.

Project	Surface Area at Full Pond (acres)	Maximum Reservoir and (Mean) depth-m	Normal Full Pond Elevation (m)	Intake Elevation			Number of Units Operating	Normal Hydraulic Capacity (cfs)
				Top (m)	CL (m)	Bottom (m)		
High Rock	15,180	19 (5)	190.2	184.7	179.1	173.4		
							1	2,597
							2	5,193
							3	7,790
Tuckertown	2,560	17 (5)	172.2	162.3	158.2	154.0		
							1	2,673
							2	5,347
							3	8,020
Narrows	5,355	53 (14)	155.4	146.0	140.6	135.3		
							1	1,947
							2	3,893
							3	5,840
							4	8,185
Falls	204	16 (8)	101.5	99.3	94.5	89.6		
							1	2,608
							2	5,215
							3	7,455

Creek, Crane Creek, Flat Swamp Creek and Panther Creek which drain into High Rock Reservoir; Lick Creek, Cabin Creek, Flat Creek, Ellis Creek and Riles Creek which drain into Tuckertown Reservoir; and Beaver Dam Creek along with Garr Creek which discharge into Narrows Reservoir. There are no tributaries of significant size that drain to Falls Reservoir. The Yadkin River and its tributaries are part of the Yadkin-Pee Dee River Basin, which extends from the eastern slopes of the Blue Ridge Mountains to the Atlantic coast near Georgetown, South Carolina. The Yadkin River's name changes to the Pee Dee River at its confluence with the Uwharrie River. The Pee Dee River continues its southeastern flow to Winyah Bay, where it meets the Atlantic Ocean.

Hydrometeorologic Conditions

Critical to understanding the water quality dynamics in the tailraces of the dams in the Yadkin system are the hydrometeorologic conditions throughout the sampling period. Total flow from the Yadkin and South Yadkin rivers above High Rock Lake is presented in Figure 1.0-1 for the period 1999 through 2004. The monitoring program at Falls and Narrows encompassed several years with very different hydrometeorologic conditions. Flows during the sampling years 2000 and 2001 were lower than average, but 2002 was an extremely dry year, particularly during the summer. 2003 was an abnormally wet year. Average flows returned in 2004 with the exception of two hurricanes in August and September that temporarily increased flows and flushed water through the reservoirs, breaking thermal stratification and replenishing dissolved oxygen in deeper waters. Impoundment water levels also fluctuated throughout the study period. Daily water levels through 2004 are presented in Figures 1.0-2 through 1.0-5. Long-term average water levels are also included. Pool levels in Tuckertown and Falls fluctuated little throughout the monitoring period while pool levels in High Rock and

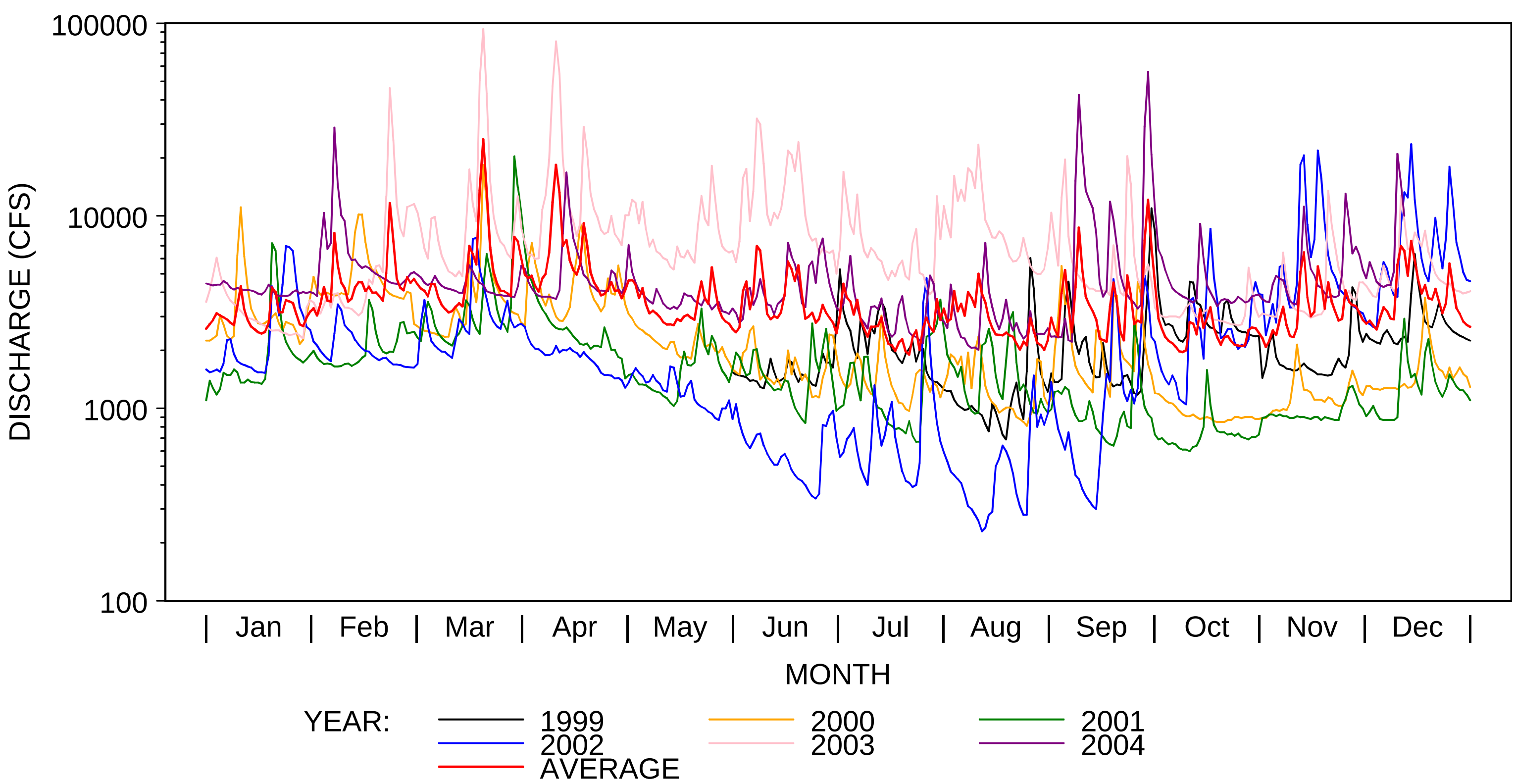


Figure 1.0-1. Inflow to High Rock Reservoir, 1999-2004.

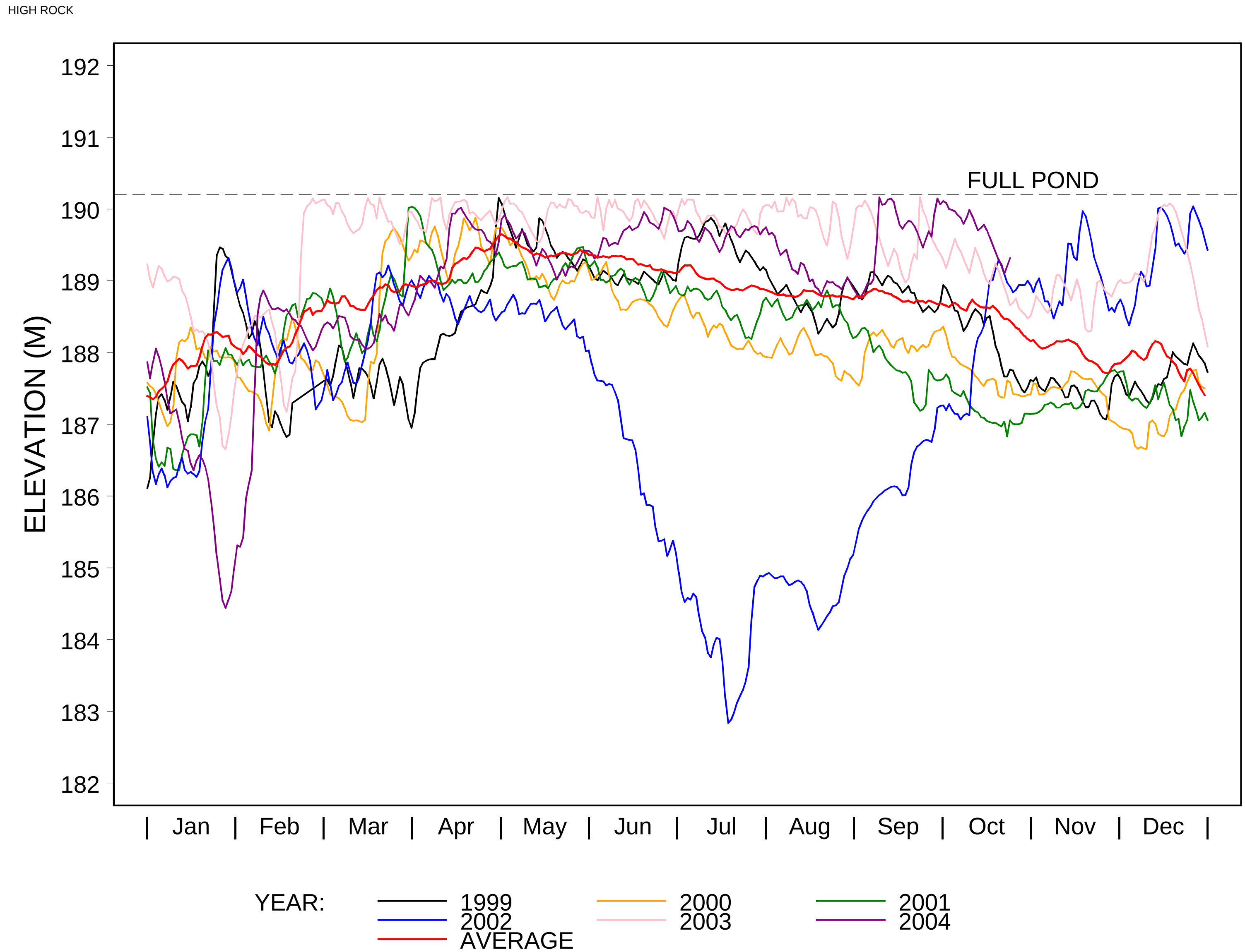


Figure 1.0-2. High Rock water level 1999 – 2004.

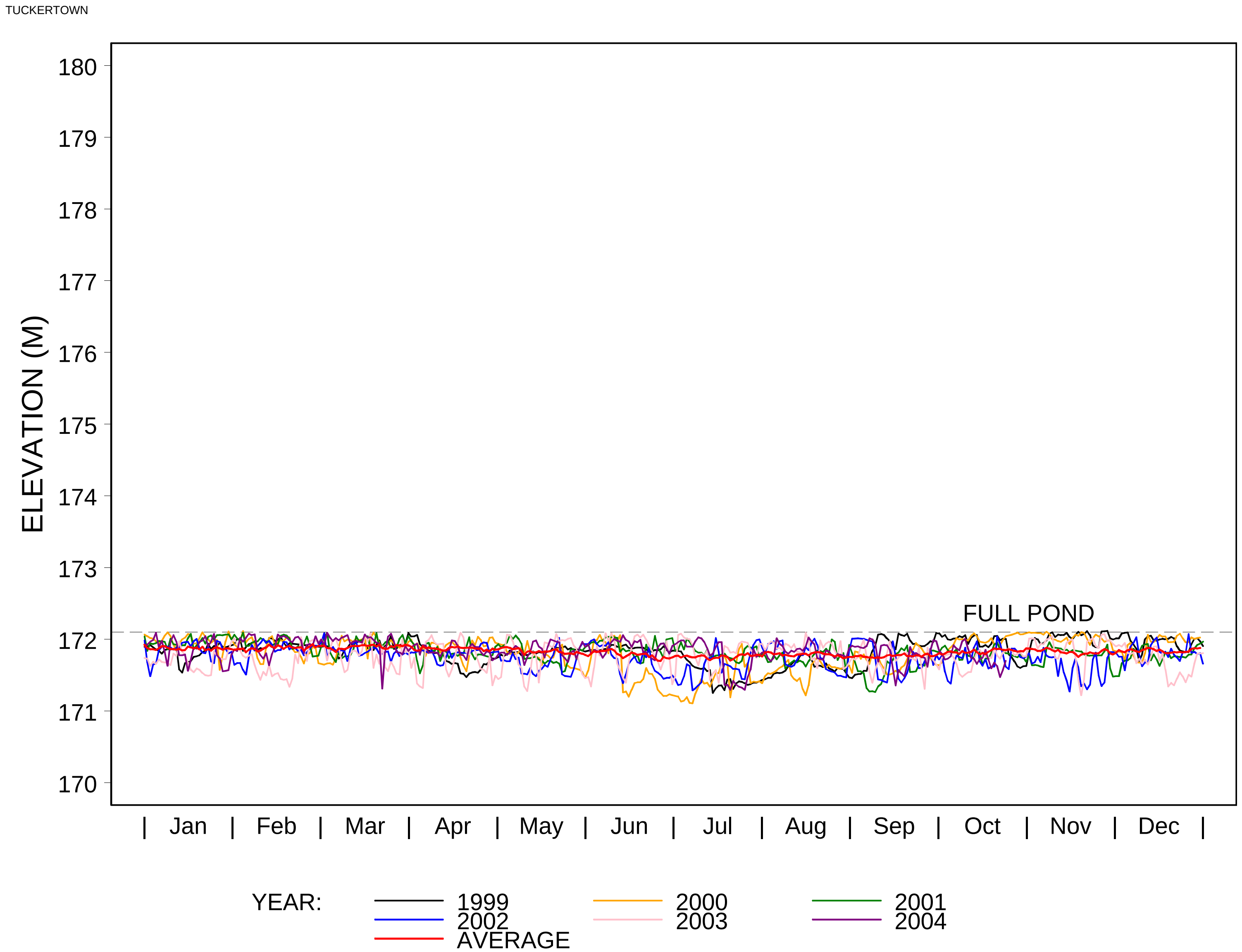


Figure 1.0-3. Tuckertown water level, 1999 – 2004.

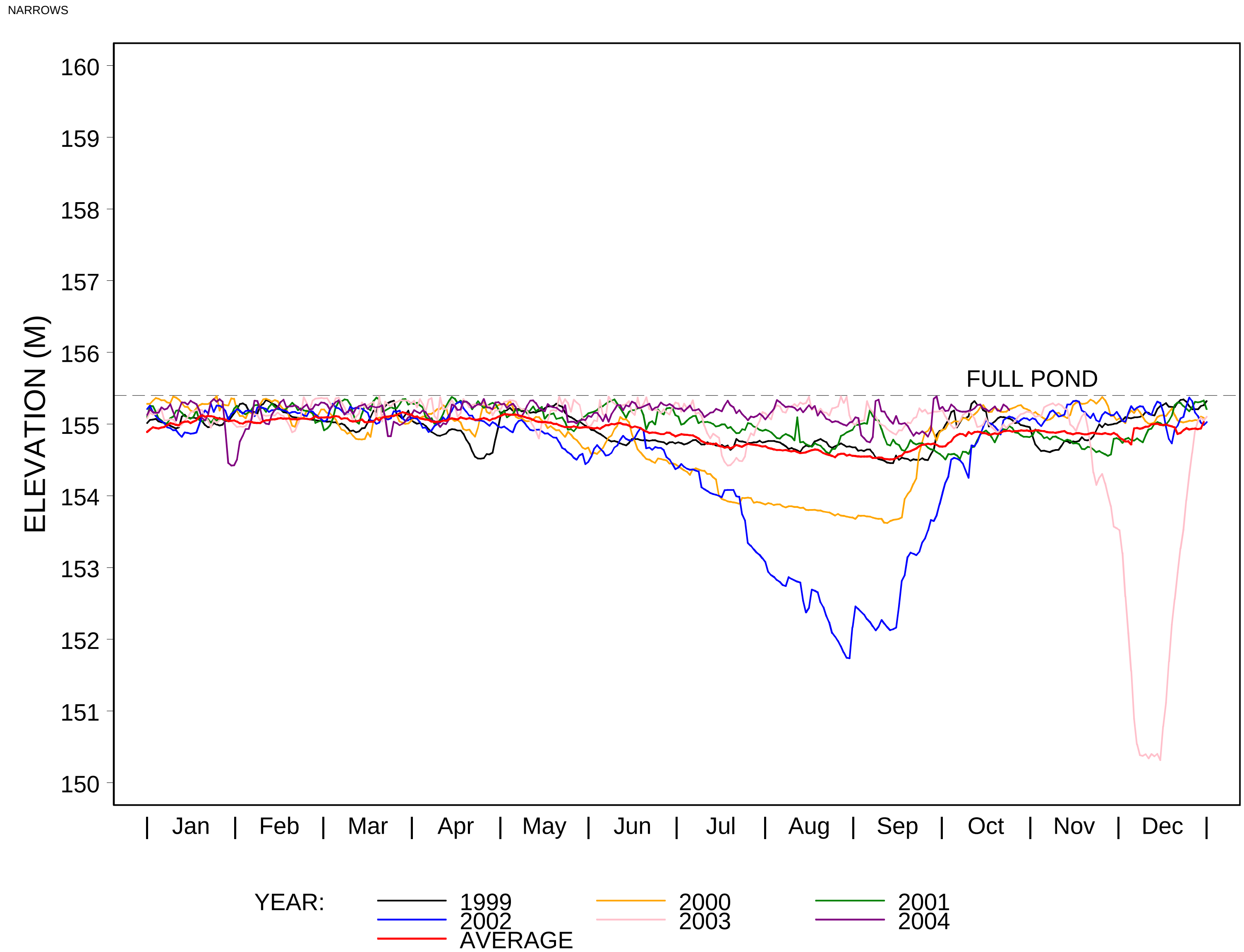


Figure 1.0-4. Narrows water level, 1999 – 2004.

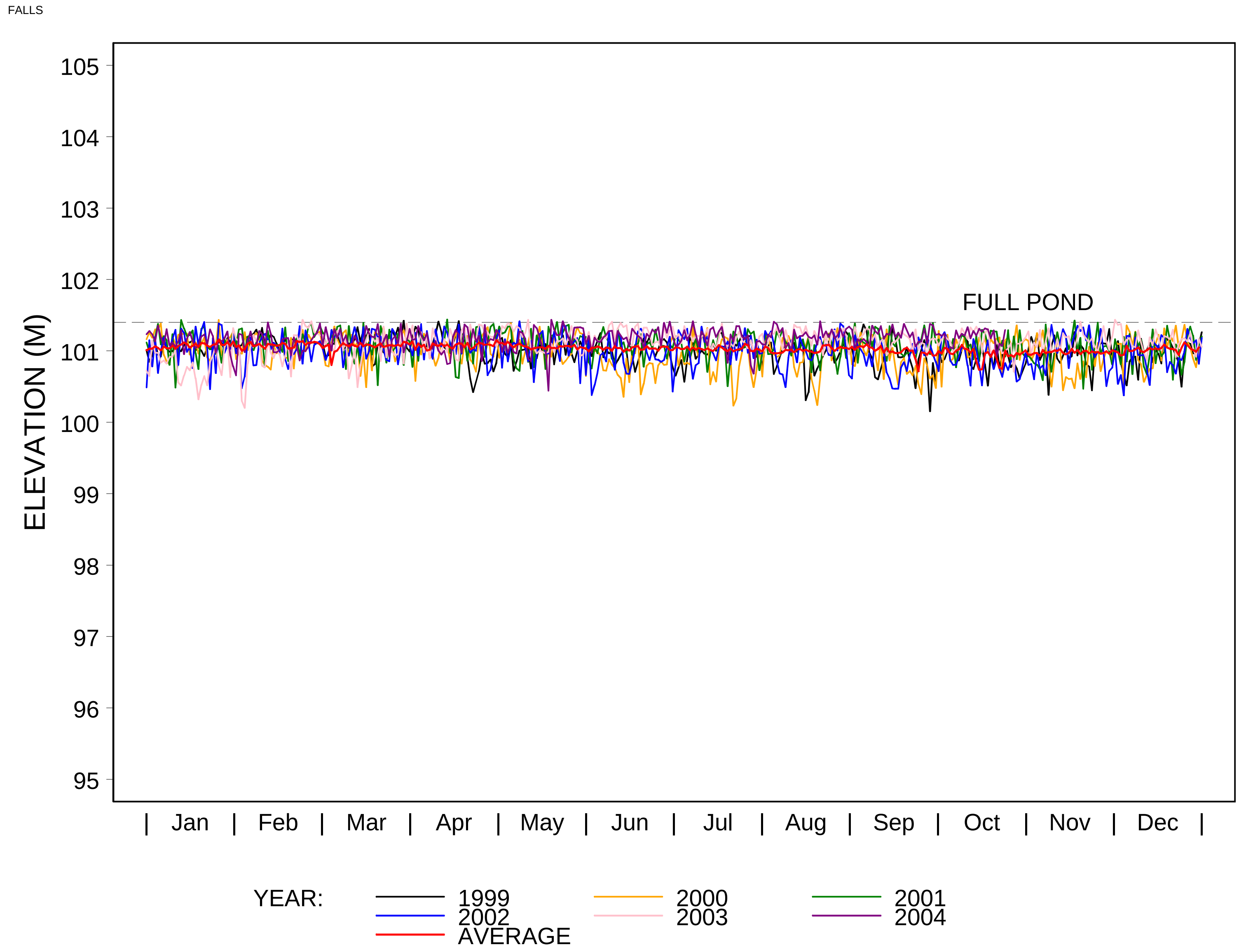


Figure 1.0-5. Falls water level, 1999 – 2004.

Narrows exhibited significant fluctuations, particularly in 2002, the drought year. This impact of these fluctuations on dissolved oxygen and other water quality parameters in the reservoirs and tailraces is discussed throughout this report.

2.0 CURRENT STATUS OF WATER QUALITY IN THE RESERVOIRS AND TAILRACES (1999-2003)

2.1 METHODS

Water Quality Monitoring

To assess the current status of water quality in the four Alcoa reservoirs on the Yadkin River, twenty stations were selected for monthly sampling. A station was located in the tailrace of each of the four dams (Figures 2.1-1 and 2.1-2; Table 2.1-1). Ten stations were located in High Rock Reservoir, including Station H1 near the entrance of the Yadkin River into the reservoir. Due to its dendritic shape, stations were located in the major reservoir arms and along the mainstem reservoir channel. Two stations were sampled in Tuckertown Reservoir. Three stations were sampled in Narrows Reservoir, including one station in the reservoirs major arm. One station was sampled in Falls Reservoir. A Station (T4) was added in Lick Creek upstream of its confluence with Tuckertown Reservoir in July 2003 (Figure 2.1-3). Additional dissolved oxygen and temperature measurements were collected at two sites in the Lick Creek Arm of Tuckertown Reservoir and at seven stations below the High Rock Dam tailrace in the upper portion of Tuckertown Reservoir beginning in July 2003.

Stations were sampled monthly from June 1999 to December 2003. On each collection date, temperature, pH, dissolved oxygen and specific conductance were measured *in situ* using a calibrated YSI 6920 field meter at one meter intervals from the surface to the bottom. Beginning in April 2001, turbidity was also measured *in situ* at one meter intervals. To determine the vertical distribution of nutrients, solids and metals under stratified and unstratified conditions, surface and bottom samples were collected monthly at each station. From June 1999 to January 2001, surface samples were collected by immersing the sampling bottle below the surface. Beginning in February 2001, a composite sample of the photic zone, defined as twice the Secchi transparency depth, replaced the surface grab sample for all chemical parameters except for metals. The composite sample was collected by a pump and hose that was lowered through the photic zone at a constant rate. Bottom samples were collected using a pump and hose, except for Station N4 where a Van Dorn Bottle was used. Chlorophyll *a* samples were only collected from the photic zone. Secchi transparency was measured at each station. A list of the chemical parameters analyzed in the laboratories and their detection limits are presented (Table 2.1-2). All sampling and analysis was conducted in accordance with North Carolina water quality monitoring protocols and procedures (NCDEM 2004)**.** Notes from field personnel and a list of missing data are presented in Appendix A.

Data Analysis

All water quality data was entered or imported into a SAS database (SAS 2004). Monthly water quality data is presented in Appendix B stations within each reservoir were compared by tabulating median values. The median was used, rather than the mean, because the median is more resistant to extreme values. As is typical in water quality data, most of the parameters measured in this study had skewed distributions. Also, the median is a more appropriate measure of central tendency when some of the results are reported as below a detection limit (Helsel and Hirsch, 1991). Variability was assessed by plotting quartiles and the 5 and 95 percentiles of the data. All stations and sampling dates were used to compute the medians and percentiles for each reservoir.

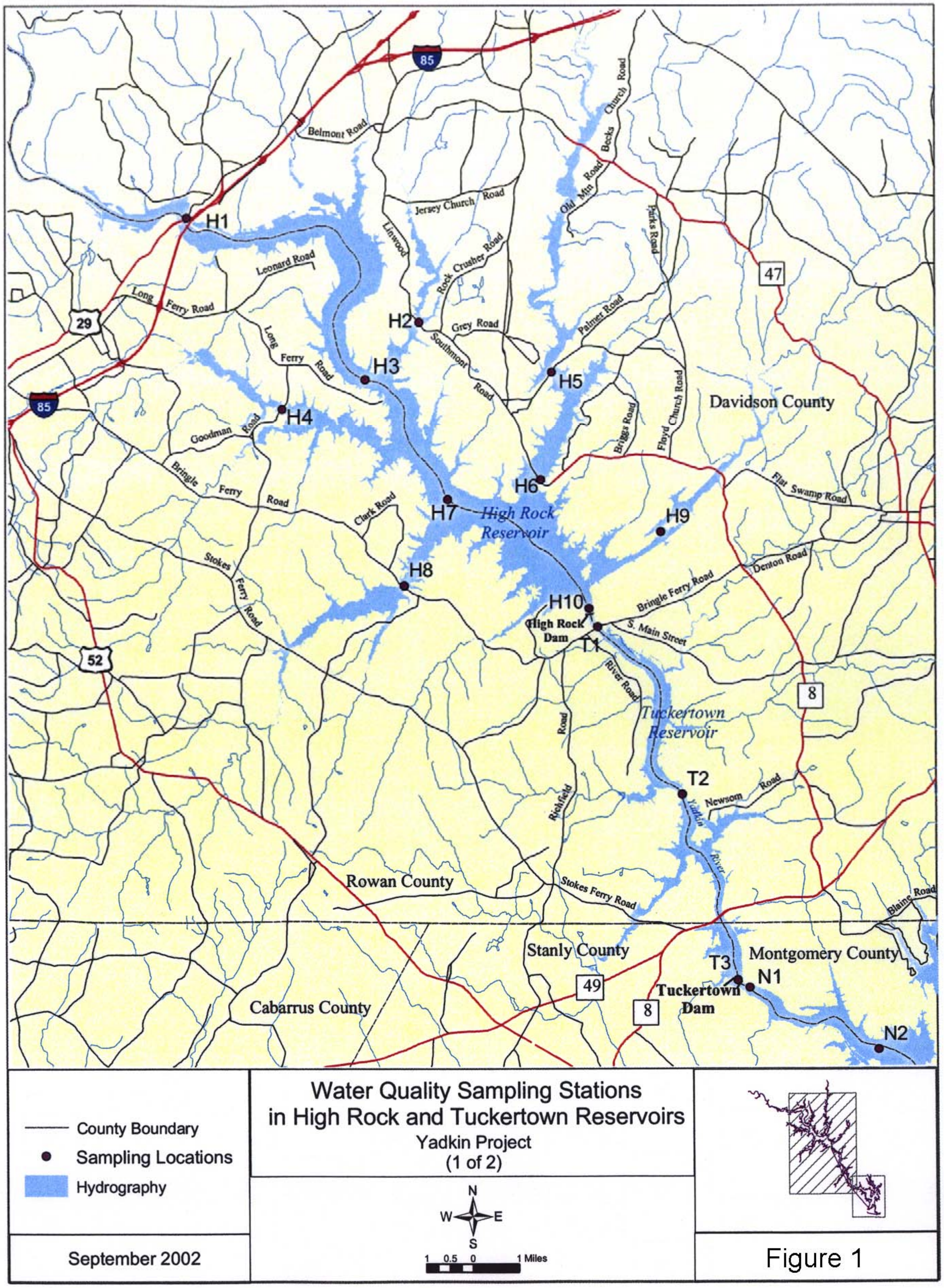


Figure 2.1-1. Upper Impoundments and Sampling Stations.

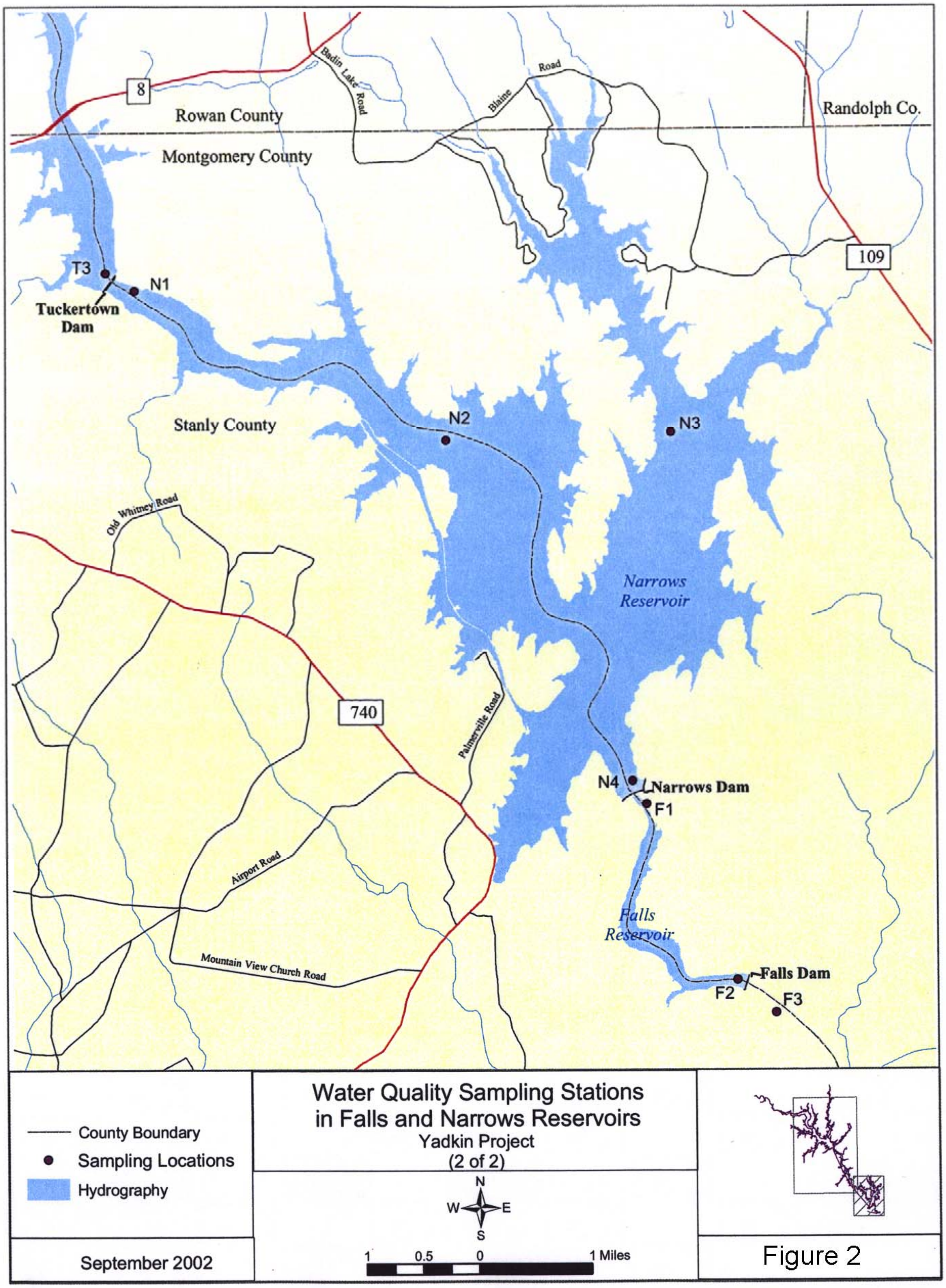


Figure 2.1-2. Lower Impoundments and Sampling Stations.

Table 2.1-1. Sampling locations of the current study in the four reservoirs of the Yadkin Project.

Station	Station Description	StationType	WaterBody	Lat/Long
H1	Upper High Rock Reservoir near the mouth of Yadkin River	Reservoir Mainstem	High Rock Reservoir	N 35 43 23.113 W 80 23 28.829
H2	Upper High Rock Reservoir/Swearing Creek Arm	Reservoir Arm	High Rock Reservoir	N 35 41 29.732 W 80 18 06.378
H3	Upper High Rock Reservoir middle of Section 3	Reservoir Mainstem	High Rock Reservoir	N 35 40 24.383 W 80 19 19.823
H4	Upper High Rock Reservoir/Crane Creek Arm	Reservoir Arm	High Rock Reservoir	N 35 39 49.391 W 80 21 13.557
H5	High Rock Reservoir/Upper Abbotts Creek Arm	Reservoir Arm	High Rock Reservoir	N 35 40 35.077 W 80 15 01.513
H6	High Rock Reservoir/Lower Abbotts Creek Arm	Reservoir Arm	High Rock Reservoir	N 35 38 33.445 W 80 15 15.309
H7	High Rock Reservoir middle of Section 2	Reservoir Mainstem	High Rock Reservoir	N 35 38 09.509 W 80 17 23.973
H8	High Rock Reservoir/Second Creek Arm	Reservoir Arm	High Rock Reservoir	N 35 36 32.056 W 80 18 22.933
H9	High Rock Reservoir/Flat Swamp Creek Arm	Reservoir Arm	High Rock Reservoir	N 35 37 36.284 W 80 12 28.825
H10	High Rock Reservoir near Dam	Reservoir Mainstem	High Rock Reservoir	N 35 36 08.535 W 80 14 06.263
T1	High Rock Dam Tailrace	Tailrace	Tuckertown Reservoir	N 35 35 48.279 W 80 13 54.184
T2	Tuckertown Reservoir at middle constriction	Reservoir	Tuckertown Reservoir	N 35 32 40.214 W 80 11 55.960
T3	Tuckertown Reservoir near Dam	Reservoir	Tuckertown Reservoir	N 35 29 09.958 W 80 10 37.942
T4	Lick Creek	Stream	Lick Creek	N 35 36 58.900 W 80 10 32.200
N1	Tuckertown Dam Tailrace	Tailrace	Narrows Reservoir	N 35 29 01.739 W 80 10 21.234
N2	Narrows Reservoir middle of Section 3	Reservoir	Narrows Reservoir	N 35 27 53.724 W 80 07 23.843
N3	Narrows Reservoir by Gladys Fork	Reservoir Arm	Narrows Reservoir	N 35 27 58.795 W 80 05 16.426
N4	Narrows Reservoir near Dam	Reservoir	Narrows Reservoir	N 35 25 16.385 W 80 05 36.485
F1	Narrows Dam Tailrace	Tailrace	Falls Reservoir	N 35 25 05.637 W 80 05 28.767
F2	Falls Reservoir near Dam	Reservoir	Falls Reservoir	N 35 23 43.671 W 80 04 36.692
F3	Falls Dam Tailrace	Tailrace	Yadkin River/ Lake Tillery	N 35 23 28.734 W 80 04 14.938

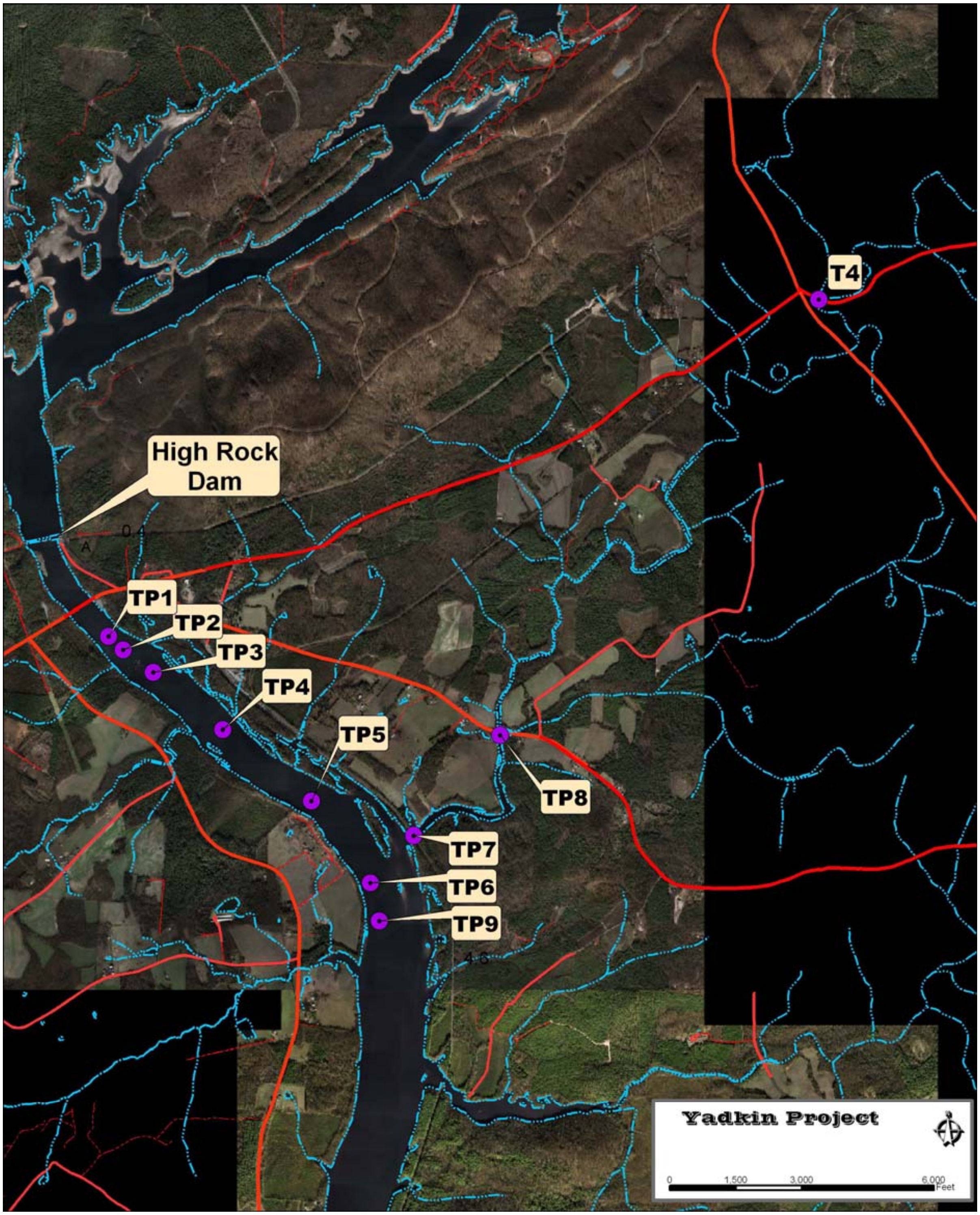


Figure 2.1-3. Lick Creek and Tuckertown Reservoirs. Supplemental water quality stations.

Table 2.1-2. Selected water quality parameters, the EPA method and detection limit.

Parameter	EPA Method	Detection Limit	Units
Chlorophyll *a*	SM 10200H #2	0.2	µg/l
Alkalinity, Total	SM 2320B		mg/l
Biological Oxygen Demand	405.1	2	mg/l
Cadmium	200.8/6020	0.5	µg/l
Carbon, Total Organic	SM 5310C/9060		mg/l
Chemical Oxygen Demand	410.4/7196	20	mg/l
Copper	200.8/6020	10	µg/l
Cyanide, Total	335.4/9012	0.005	mg/l
Lead	200.8/6020	2	µg/l
Mercury	245.1/7470A	0.2	µg/l
Nitrogen, Ammonia	350.1	0.05	mg/l
Nitrogen, NO3+NO2(as N)	353.2/9200	0.05	mg/l
Nitrogen, Total Kjeldahl	351.2	0.5	mg/l
Phosphorus, Total	SM4500-P-E2	0.02	mg/l
Residue, Total	160.3	20	mg/l
Residue, Filterable	160.1	20	mg/l
Residue, Nonfilterable	160.2	5	mg/l

For analytical purposes, tailrace stations (T1, N1, F1) were analyzed separately from the reservoir stations. Median values computed for tailrace stations were not included in reservoir averages. Mainstem and arm stations from High Rock Reservoir were presented separately. Temperature and dissolved oxygen profiles were presented as contour plots of depth by month for stations near the dams in each reservoir.

Reservoirs are complex systems with a variety of physical and biological processes occurring simultaneously. To identify the relationships among the stations and reservoirs and determine the factors that have the most influence on the system, a Principal Component Analysis (PCA)-ordination was performed on water quality parameters from surface collections (Clarke and Warwick, 1994). Bottom samples were not included in the PCA-ordination because the effects of bottom-typical dissolved oxygen depletion could possibly obscure other trends. PCA-ordination was used to plot the position of individual station on the axis that account for the greatest amount of variation in the data. This essentially creates a map of the differences among stations. Stations that are located in close proximity on the PCA plot are more similar to each other than stations that are plotted further away. Underlying factors were determined based on the distribution of stations. The responses of individual parameters on each principal component was determined. The PCA-ordination is based on overall station means. Mean values for each station were computed after a log(x+1) transformation was applied to the monthly data. Because units are not similar, the data were standardized prior to analysis. Surface dissolved oxygen, temperature, pH and conductivity were computed from the 1-meter profile depth for the PCA-ordination. To illustrate the results of the PCA, Box-plots along with the 5% and 95% percentiles were plotted for groups defined by the principal component axes. The parameters that were used and the results of the PCA are presented in Appendix C.

Seasonal trends of temperature and dissolved oxygen were assessed from contour plots. Seasonal plots of water quality parameters were generated using locally weighted scatter plot smoothing (LOWESS). LOWESS is an exploratory technique that produces a best fit line to scatter plot data

(Helsel and Hirsch, 1991). The shape of the trend line is determined by the data, no assumptions are made about the form of the line. A smoothing factor is used to control the smoothness of the line. For these plots, the three preceding and three succeeding months were weighted to determine the slope of the line at each point. This produced trend lines that were based on season, relatively resistant to extreme values and provided a good fit to the data without over-smoothing the line or obscuring short-term trends.

Median values along with their 5 and 95 percentiles were tabulated for each parameter for each tailrace. Seasonal LOWESS plots of monthly data were presented for parameters that were selected based on the PCA-ordination.

Since differences between surface and bottom collections are likely to vary seasonally, monthly surface and bottom medians were computed for each station and parameter. Reservoir stations were grouped based on results of the PCA-ordination and monthly group medians were computed from the monthly station medians. PCA-defined group surface and bottom medians were plotted for parameters where large differences were observed.

Kendall's tau correlation coefficients were computed to examine whether relationships exist between water quality and flow. Correlation coefficients were computed to examine whether relationships between lake level and water quality exist in the reservoirs. Tailrace water quality was compared with lake level in the upstream reservoir. Kendall's tau correlation is based on the ranking of the data and is appropriate when the data includes values below a detection limit.

A Wilcoxon signed-rank test was used to test for differences between historical and current data. Since historical data were limited, only comparable stations and months were used in the analysis. Results of the Wilcoxon signed-rank test were only presented for High Rock Reservoir because there was insufficient data in the other reservoirs. The Wilcoxon signed-rank test is a non-parametric test that determines if significant differences exist between the distribution of ranks of two sets of samples (Helsel and Hirsch 1991).

2.2 GENERAL TRENDS AMONG RESERVOIRS AND STATIONS

As the upper-most reservoir, High Rock receives its flow from the mainstem Yadkin River, the South Yadkin River and several other sizeable tributaries. The principal flow source is the mainstem Yadkin River, which drains a largely forested and agricultural region with some small towns and cities. Proceeding downstream, water passes through Tuckertown, Narrows and Falls Reservoirs before exiting the system. Tuckertown, Narrows and Falls reservoirs receive most of their water from the preceding reservoir. Tailraces, or short sections of free-flowing river, exist below each dam, but the water is quickly impounded as it enters the next reservoir. High Rock has a dendritic form, with numerous large arms. Tuckertown and Falls Reservoirs have a linear shape and are essentially a deepening of the original river channel. Narrows Reservoir has a somewhat dendritic shape, but is best described as having two large basins. Reservoirs are essentially lake environments and physical and biological processes in lakes differ from rivers and creeks (Wetzel 2001).

The quality of the surface water in the Yadkin APGI system is primarily affected by the passage of water through the reservoirs and also by local factors like the influence of the Yadkin River and the discharge from the four dams/powerhouses. The quality of bottom waters is not considered in this section. Bottom waters are discussed in greater detail in Section 2.3.7. The factor that has the greatest influence on surface water quality is the upstream to downstream passage of water from the upper end of High Rock Reservoir to Narrows Dam (Figure 2.2-1). The passage of water through the system can take weeks, which allows sufficient time for physical and biological processes to modify water quality. In addition to the effects of downstream passage, water quality is affected by local environmental factors. The Yadkin River influences the two stations near its confluence with High Rock Reservoir. Tailrace stations are similar to the dam stations of the preceding reservoir in their nutrient and solids concentrations (the first principal component), but differ considerably in temperature, pH, dissolved oxygen, nitrate and ammonia (the second principal component). The only station in Falls Reservoir is closely allied to the tailrace stations, which suggests that in terms of water quality, the entire Falls Reservoir (F2) could be considered similar to the tailrace of Narrows Dam (F1). Relatively homogeneous conditions within Tuckertown and Narrows reservoirs are indicated by the close grouping of stations (N1-N4, T1-T3). In contrast, High Rock Reservoir is an extremely diverse waterbody. Large differences exist between the upper and lower mainstem stations and among the arms (H1-H10). Tuckertown Reservoir is closely allied with the mainstem stations in the lower portion of High Rock Reservoir (T1-T3), which suggests that water quality in Tuckertown Reservoir is strongly influenced by conditions in High Rock Reservoir.

In general, the passage of water through the reservoirs results in improvement to the overall water quality due to the reduction of suspended sediments, the increase in water clarity, and the gradual reduction of algal biomass and nutrients. High Rock Reservoir is a very turbid reservoir with large concentrations of suspended sediments and poor water clarity (Figure 2.2-2). The average Secchi depth in High Rock Reservoir is about a half meter which means that light penetration and algal productivity is probably limited to the top one meter. Being the furthest upstream reservoir, High Rock is receiving a heavy load of solids from the mainstem river and tributaries that flow into it, which has resulted in poor water clarity. Most of the suspended solids settle in High Rock Reservoir and turbidity and suspended solids concentrations are much lower in Tuckertown Reservoir. There is further reduction of suspended solids in Tuckertown and suspended solids are near the detection limit in Narrows and Falls reservoirs. Secchi depth increases considerably in Narrows and Falls reservoirs where the photic zone probably extends to a depth of over 3 meters. The concentrations of dissolved solids are generally not affected by the passage of water through the four reservoirs. Sedimentation is discussed further in Section 3.6.

Heavy sediment loads are likely to carry greater concentrations of nutrients and other substances. Both total phosphorus and total nitrogen concentrations are greatest in High Rock Reservoir and the concentrations of phosphorus are at levels that can readily promote algal blooms and support a large algal standing crop (Figure 2.2-3). The overall ratio of nitrogen to phosphorus is about 11, (occasionally lower in the arms as discussed in Section 2.3.1) which indicates that conditions favoring cyanobacteria (bluegreen algae) may exist at times (NALMS 1990). Phosphorus concentrations decrease in the downstream reservoirs, but concentrations remain at levels that are capable of supporting considerable algal growth. Total nitrogen concentrations decrease only slightly as water passes through the four reservoirs. The availability of nutrients in High Rock Reservoir has created a large standing crop of algae as indicated by the large chlorophyll *a* concentrations, a surrogate measure for algal biomass. Algal biomass decreases in the downstream reservoirs in a pattern that is similar to the reduction in phosphorus concentrations which suggests that the magnitude of the algal standing crop is largely determined by the phosphorus load in the reservoirs. Severe algal bloom conditions, generally >30 µg/l, are typically not observed in Narrows and Falls reservoirs and the nitrogen to phosphorus ratio favors eukaryotic algae (non-bluegreen). Large algal standing crop and a

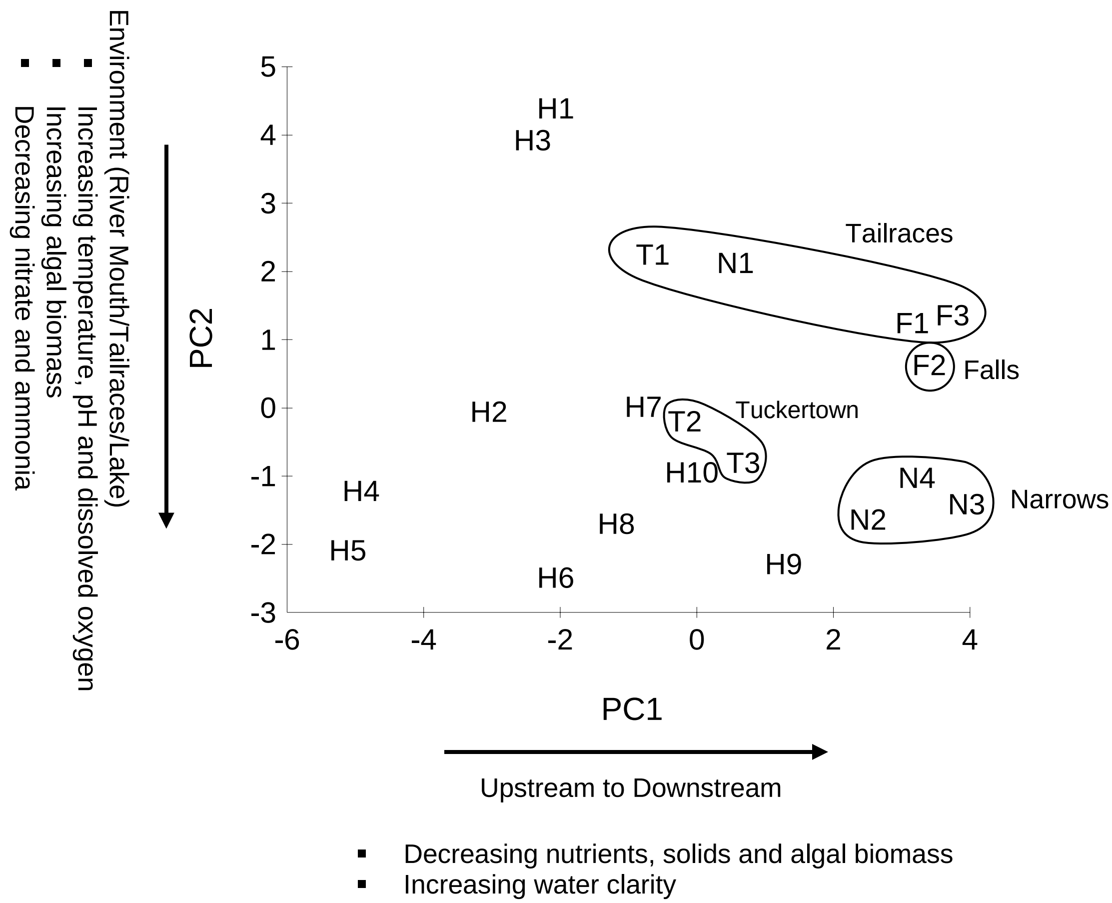


Figure 2.2-1. The relationships among reservoirs and stations based on PCA-ordination of log (x+1) water quality parameters collected from surface samples, June 1999 to December 2003.

shallow photic zone tend to produce near-saturated to supersaturated oxygen levels in the photic zone, but as the micro-organisms settle into the underlying water, respiration and decomposition quickly deplete oxygen concentrations, creating anoxic conditions. These anoxic conditions can influence many other water quality parameters.

Based on the second principal component (Figure 2.2-1), the stations can be divided into three groups. The upper High Rock Reservoir stations H1 and H3 form the first group. These stations are located near the mouth of the Yadkin River in a relatively narrow and shallow stretch of the mainstem of the reservoir. The four tailraces along with the Falls Reservoir station form the second group. The remaining reservoir stations, which generally represent a lake-like environment, form the third group. These groups were separated based on differences in physical properties, algal biomass and nitrate and ammonia concentrations. Surface temperatures in the lake stations are slightly higher than at the upper High Rock mainstem and tailrace stations (Figure 2.2-4). Due to the wide seasonal variation,

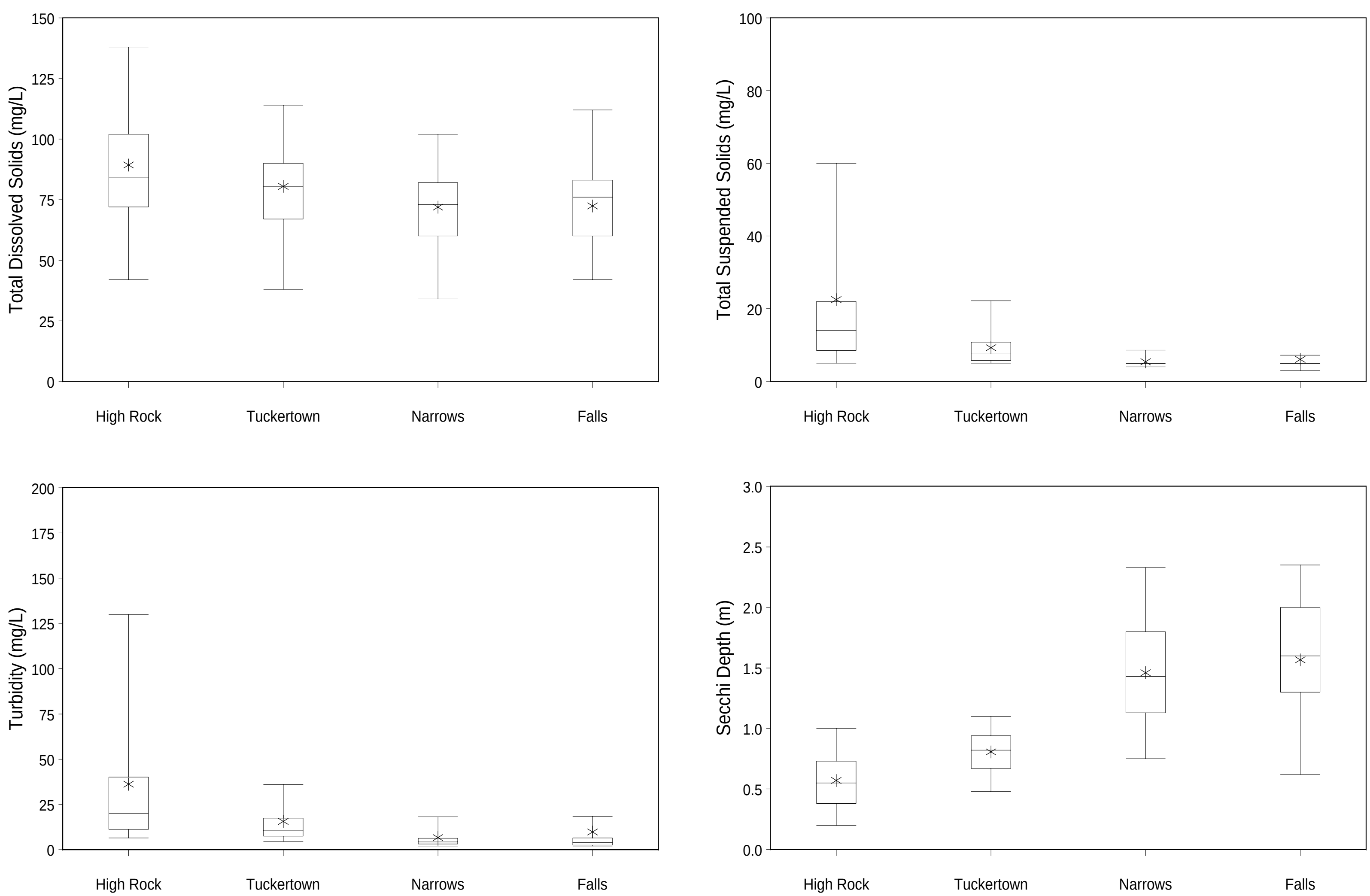


Figure 2.2-2. The median, 5, 25, 75, 95 percentiles and the mean of total dissolved solids, turbidity, total suspended solids and Secchi Depth in High Rock, Tuckertown, Narrows and Falls Reservoirs.

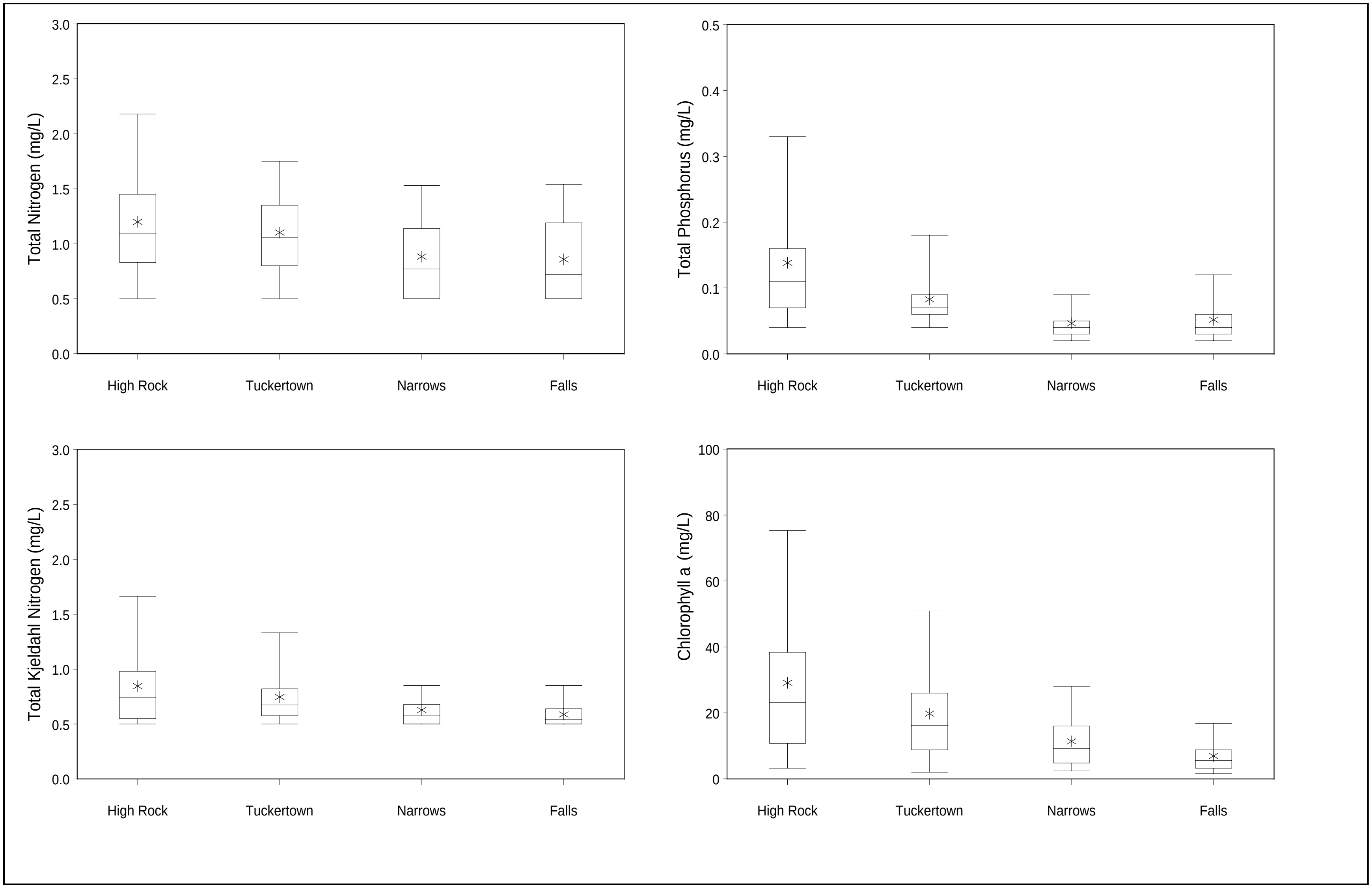


Figure 2.2-3. The median, 5, 25, 75, 95 percentiles and the mean of total nitrogen, total kjeldahl nitrogen, total phosphorus and chlorophyll *a* in High Rock, Tuckertown, Narrows and Falls Reservoirs.

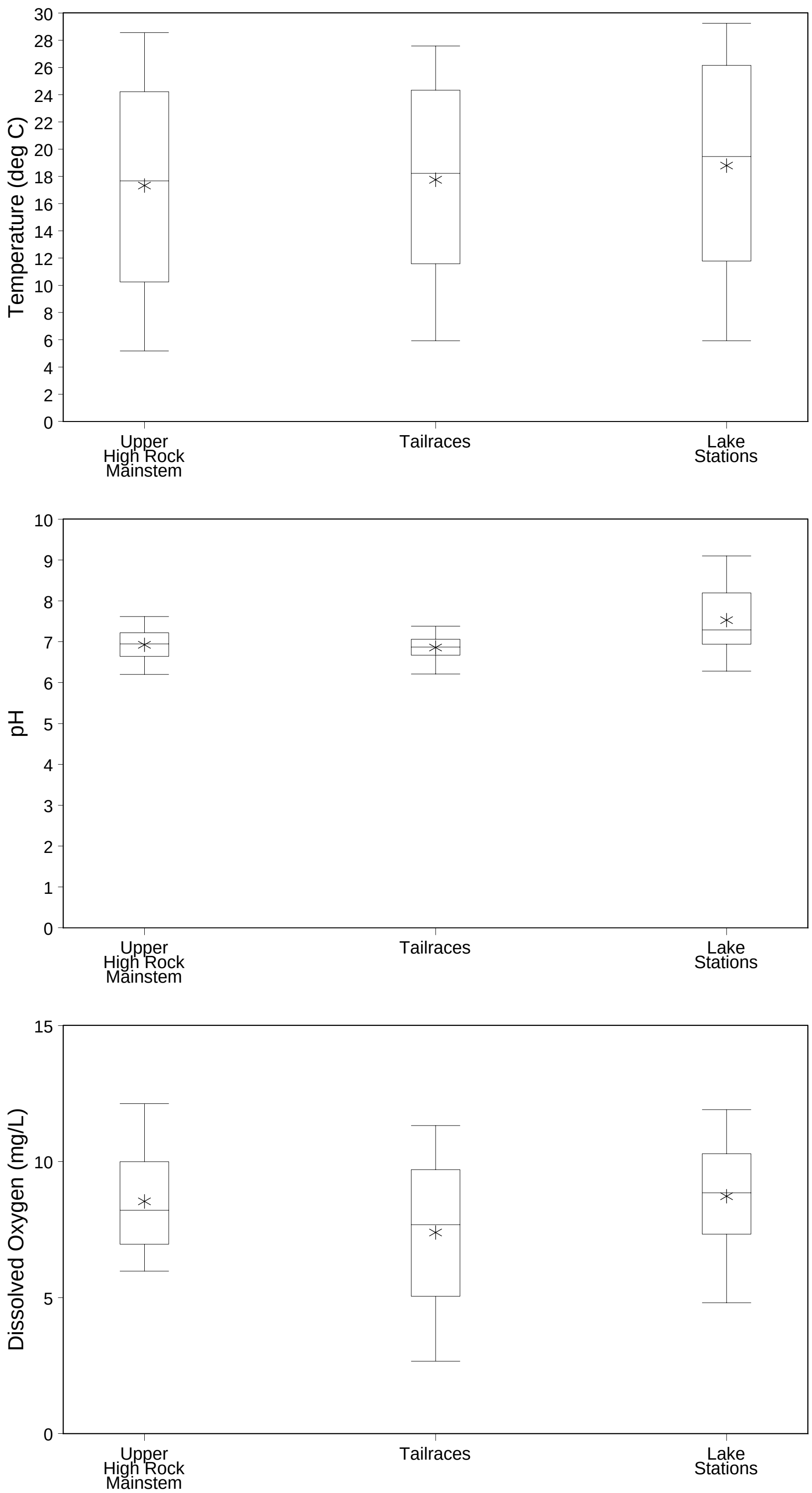


Figure 2.2-4. Median, 5, 25, 75, and 95 percentiles and mean temperature, pH and dissolved oxygen in the upper mainstem of High Rock Reservoir, tailraces and reservoir stations.

the differences appear small, but surface temperatures at the lake stations average about 1°C warmer. Differences in pH are also small, but surface pH is greater at the lake stations, where algal productivity is likely to increase pH as carbon dioxide is utilized during photosynthesis. Surface dissolved oxygen concentrations are considerably lower at the tailrace stations, with concentrations less than 5 mg/l occurring in about 25% of the samples. Dam operations entrain both surface and bottom water which are mixed during passage through the dam causing lower dissolved oxygen concentrations in the tailrace if the bottom water of the upstream reservoir is oxygen depleted.

Surface dissolved oxygen concentrations are greatest at the lake stations, again a by-product of algal productivity, but the range is greater than at the upper High Rock mainstem stations, and includes some occurrences of concentrations below 5 mg/l. Algal populations in rivers and streams are typically dominated by species that are attached to the bottom or other substrates. Species adapted to open water, the phytoplankton, typically account for a small portion of stream algae. In contrast, phytoplankton are the dominant algal species in lake environments (Wetzel 2001). The relatively low chlorophyll *a* concentrations in the upper High Rock mainstem (Figure 2.2-5) indicate that phytoplankton populations have not had sufficient time to develop and that this stretch may be more like a river than a lake. The low chlorophyll *a* concentration in the tailraces is probably due to the mixing of surface water and water below the photic zone with low algal biomass due to light limitation. Nitrate concentrations are greater at the upper High Rock mainstem stations. Nitrate is readily assimilated by phytoplankton and the greater concentrations observed at the upper High Rock mainstem station can be attributed to the smaller algal population found there. Ammonia concentrations are greatest in the tailraces. Although surface water concentrations of ammonia at the lake stations are low, bottom water (Section 2.3.6) ammonia concentrations are seasonally greater. The blending of surface and bottom water during passage through the powerhouse/dam results in greater surface ammonia concentrations in the tailrace. Total Kjedahl nitrogen, a rough estimate of organic nitrogen, is greater at the lake stations.

2.3 WATER QUALITY OF THE RESERVOIRS

2.3.1 High Rock Reservoir

The U.S. Army Corps of Engineer's Kerr-Scott Reservoir is the only impoundment upstream of High Rock. However, it is located approximately 50 miles upstream and exerts no water quality influence on High Rock Reservoir. The large basin covers most of the Piedmont region in north-central North Carolina and drains a predominantly agricultural and forested region with rather highly erodible soils. The dam forms a 15,180 acre reservoir, the largest of the four Alcoa reservoirs on the Yadkin River, with a mean depth of 17 feet. The reservoir includes flooded portions of Swearing, Crane, Second, Abbotts and Flat Swamp Creeks creating major arms. High Rock has a dendritic shape. Each major arm receives runoff from at least one municipality, except for the Flat Swamp Creek Arm, which has a relatively undeveloped watershed. Residence time of water entering High Rock Reservoir varies considerably, ranging from 4 to 50 days (APGI 2002). It is the primary water storage body for the Yadkin/Pee Dee System and seasonal drawdowns of 12 to14 feet are typical.

High Rock Reservoir is a turbid lake with a shallow photic zone. Nutrient concentrations throughout the reservoir are at levels that can support nuisance algae blooms and algal biomass is often at high levels (>30 Fg/l)(Table 2.3-1). Thermal stratification is absent, except for a slight warming of the top few meters during the summer. Oxygen depletion below the photic zone occurs during the warmer months. High Rock Reservoir is a very diverse waterbody. In general, the upper portion of the lake

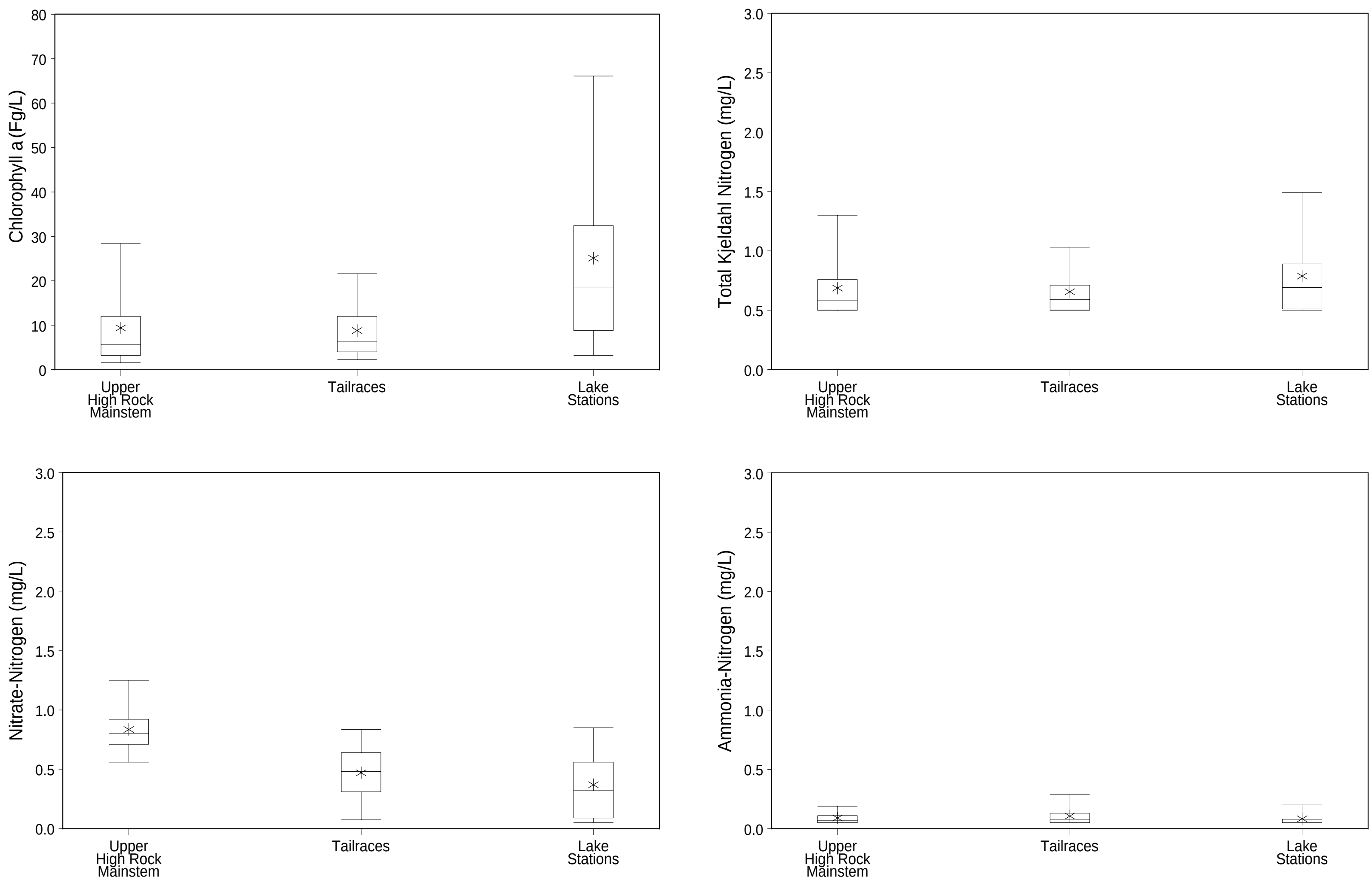


Figure 2.2-5. The median, 5, 25, 75 and 95 percentiles and the mean of chlorophyll *a*, nitrate, total kjeldahl nitrogen and ammonia in the upper mainstem of High Rock Reservoir, tailraces and reservoir stations.

Table 2.3-1. Median values of water quality parameters from June 1999 to December 2003 at each High Rock Reservoir station

High Rock		Alkalinity (mg/l)	Biological Oxygen Demand (mg/l)	Chlorophyll *a* (Fg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Secchi Depth (m)	Total Kjeldahl Nitrogen (mg/l)	Total Nitrogen (mg/l)	Total Organic Carbon (mg/l)	Total Phosphorus (mg/l)	Total Dissolved Solids (mg/l)	Total Solids (mg/l)	Total Suspended Solids (mg/l)	Turbidity (NTU)
Arms	H2	31	3	27.20	0.06	0.14	0.38	0.84	1.03	4.90	0.14	90	114	27	47
	H4	37	4	33.60	<0.05	0.12	0.35	0.94	1.13	6.20	0.18	100	131	28	45
	H5	38	3	34.80	0.08	0.18	0.53	1.06	1.36	6.70	0.15	109	127	21	33
	H6	33	3	26.80	0.10	0.21	0.64	0.88	1.19	5.15	0.11	94	107	15	23
	H8	29	3	30.00	0.07	0.23	0.57	0.80	1.05	4.30	0.10	80	98	16	25
	H9	25	2	21.80	0.06	0.25	0.82	0.65	0.87	4.10	0.06	75	85	10	13
Mainstem	H1	24	<2	4.00	0.06	0.81	0.47	0.59	1.40	3.20	0.21	84	108	24	38
	H3	24	<2	9.65	0.09	0.76	0.39	0.63	1.45	3.25	0.18	81	94	12	19
	H7	27	2	25.40	0.08	0.55	0.60	0.72	1.17	3.65	0.12	84	118	28	48
	H10	27	2	20.80	0.10	0.44	0.80	0.66	1.12	3.80	0.09	79	98	15	26

is more turbid and has greater nutrient concentrations than the lower regions. The major arms of the reservoir typically have greater algal biomass than the mainstem and there are also differences among the major arms (5). The Yadkin River has a strong influence on water quality in the upper portion of the mainstem. Total solids, suspended solids, turbidity and the nutrients total phosphorus and total nitrogen are greatest in the upper portion of the reservoir. This includes the upper two mainstem stations and the arm stations of Swearing and Crane Creeks. Solids and nutrients are also greater in the upper portion of Abbotts Creek Arm. These are stations that are most likely to be impacted by surface runoff and river discharge. These are also shallow stations and wind-driven mixing of the water column may be re-suspending bottom sediments.

When compared to the mainstem stations, arm stations typically have greater concentrations of alkalinity, biological oxygen demand, chlorophyll *a*, total Kjeldahl nitrogen, total organic carbon and total dissolved solids. These are all measures that are directly or indirectly affected by algal productivity and suggest that productivity in the arms is very high. Average chlorophyll *a* concentrations, the surrogate measure for algal biomass, for all arm stations is 29 µg/l, which is almost double the average concentration in the mainstem of the reservoir. The large algal standing crop in the arms contributes to larger concentrations of total organic carbon and total Kjeldahl nitrogen, which is a rough estimate of organic nitrogen. Metabolic activity by algae and other microorganisms increase total dissolved solids, biological oxygen demand and alkalinity. Nitrate concentrations in the arms are much lower than in the mainstem. Nitrate is a form of nitrogen that is readily available to algae and the lower nitrate concentrations in the arms are probably caused by the assimilation of nitrate by algae. Stations in the arms are generally located near the mid-point, but the extent to which water in the arms mix with mainstem waters, flushing rates and the effects of the creek water on the arms is not known. The general trend suggests longer residence time in the arms, which allows the algal community more time to exploit the high nutrient levels entering from tributary streams.

There are some differences among the major arms of High Rock Reservoir. The Flat Swamp Creek Arm, which has a relatively undeveloped watershed, has the best water quality observed in High Rock Reservoir and is considerably different from the other arms. Flat Swamp Creek Arm has the greatest water clarity, the lowest concentrations of dissolved and suspended solids, chlorophyll *a* and the nutrients, total phosphorus and total nitrogen. Chlorophyll *a* concentrations are similar to concentrations seen in the lower mainstem stations, and much lower than in the other arm stations. Differences among the remaining arm stations are relatively small and comparisons of arms should be made with some caution because of the lack of station replication in the arms.

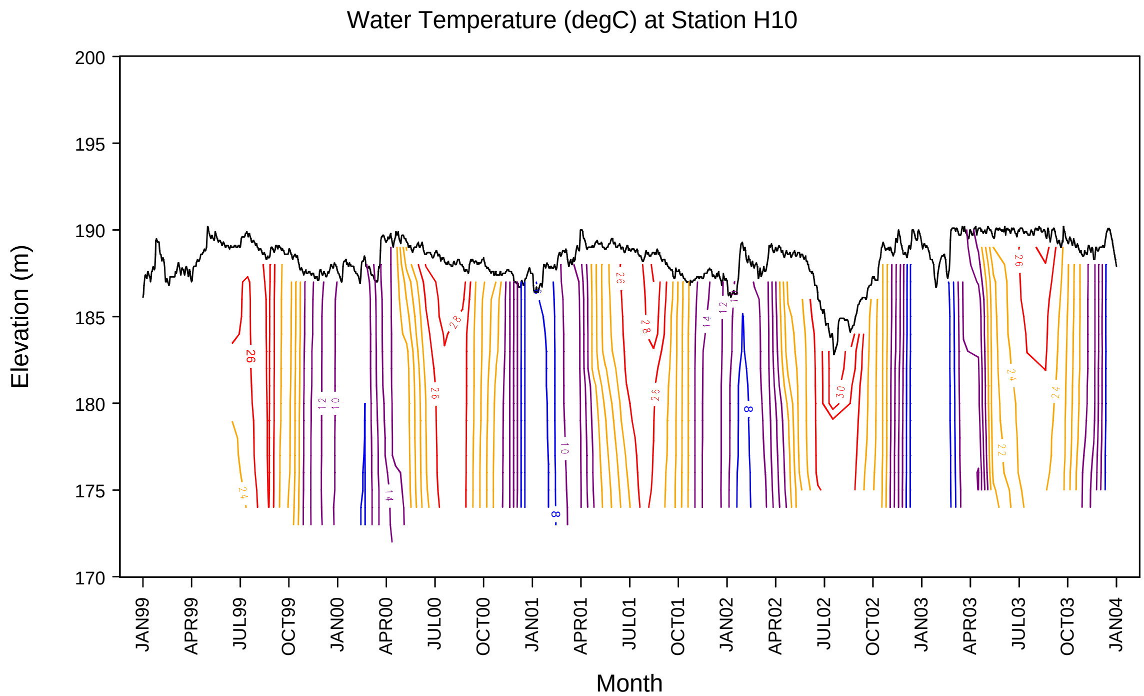
The Swearing Creek and Crane Creek Arms are the most turbid arms in High Rock due to higher concentrations of suspended solids and algae. The photic zone averages about 0.75 meters in these two arms. The Crane Creek Arm has the greatest biological oxygen demand of all the arms. Based on the single station, the Crane Creek Arm, due to its higher nutrient, algae and sediment concentrations, probably has the worst water quality of all the arms, but Swearing Creek is only slightly better. Th Abbotts Creek Arm is similar to the other arms, except that total nitrogen, and all the forms of nitrogen which include ammonia, nitrate and organic nitrogen are slightly greater, but difference is relatively small. Water clarity is better than in the Swearing and Crane Creek Arms, but the photic zone is still shallow, averaging slightly over a meter. There are two stations in Abbotts Creek Arm and the concentrations of suspended solids, nutrients and algal biomass are lower in the downstream portion of the Arm. This is the same pattern that was observed in the upstream to downstream passage of water through the reservoirs (previous section). The Second Creek Arm, with its more rural watershed has slightly better water quality than Swearing, Crane and Abbotts Creek Arms. In this arm, the photic zone averages about 1.2 meters. Nutrient concentrations and algal the biomass are similar to the other arms, but suspended solids concentrations are slightly lower. The nitrogen to phosphorus ratios are very low (<9) in Swearing, Crane and the upper portion of Abbotts Creek arms, conditions that favor the growth of cyanobacteria (bluegreen algae) rather than eukaryotic species (non-bluegreen algae).

The Yadkin River has a strong influence on the water quality of the two upper mainstem stations (H1 and H3). What makes these stations unique is the low chlorophyll *a* concentrations in the presence of high nutrient levels, which is a condition that would be expected in a riverine environment where most of the algae is attached to substrates and not present in the open water. The upper mainstem stations of High Rock Reservoir also have high concentrations of suspended solids, which limit light availability to algae. The water column at Station H1 near the mouth of the Yadkin River (in the vicinity of the Interstate 85 bridge) is usually well-mixed (Section 2.3.6) and slight current has been reported there on a few occasions which suggests that Station H1 is somewhat riverine. It is clear that the Yadkin River is delivering very turbid water with high concentrations of nutrients, especially nitrates and phosphorus, along with suspended solids and small amounts of algal biomass to High Rock Reservoir. This is discussed further in Section 3.5. The water quality at Station H3 is very similar to Station H1 except that chlorophyll *a* concentrations are slightly greater. The effects of the Yadkin River discharge extend at least six miles along the mainstem in the upper portion of High Rock Lake.

Algal populations effectively begin to utilize the nutrient source provided by the Yadkin River somewhere between the mainstem stations H3 and H7. There is a large increase in chlorophyll *a* and a corresponding decrease of both total phosphorus and total nitrogen, mostly nitrate, in this stretch of the impoundment. These reductions are likely due to sinking of suspended solids including algal cells. Nutrients which are transported through the upper mainstem of the reservoir sustain a large algal population in the lower portion of the reservoir. With a more stable water column and lake-like conditions prevailing, algal populations in the lower mainstem portion of High Rock Reservoir have sufficient time to more fully exploit the nutrient source. There is also likely to be some contribution from the algal standing crop in the Swearing and Crane Creek Arms, which discharge into the mainstem in this stretch.

Thermal stratification is typically absent near the dam in High Rock Reservoir (Station H10) except for a slight warming of the surface few meters during the summer. Water temperatures from surface to bottom follow an annual cycle with a seasonal low of about 6-8 °C in the winter and highs in summer from 28-30°C (Figure 2.3-1). Weak temperature gradients of a few degrees occur during the summer. The surface layer is only a few meters thick and surface temperatures are typically about 2 to 4 °C warmer than the bottom. The strongest thermal stratification observed at this station occurred during the drought year of 2002.

Despite the lack of thermal stratification at this station, there is severe oxygen depletion, especially at lower depths during the warmer months. Here, oxygen depletion is independent of thermal stratification and simply extends from the reservoir bottom up to the lower limit of the photic zone. In a typical year, lower bottom dissolved oxygen concentrations first appear around May and extend through October or November (Figure 2.3-1). By July, low dissolved oxygen concentrations (<5 ppm) typically extend from the bottom to within a meter or two of the surface. Surface dissolved oxygen concentrations below 5 ppm occurred at the surface in mid-summer of 1999 and 2001 and



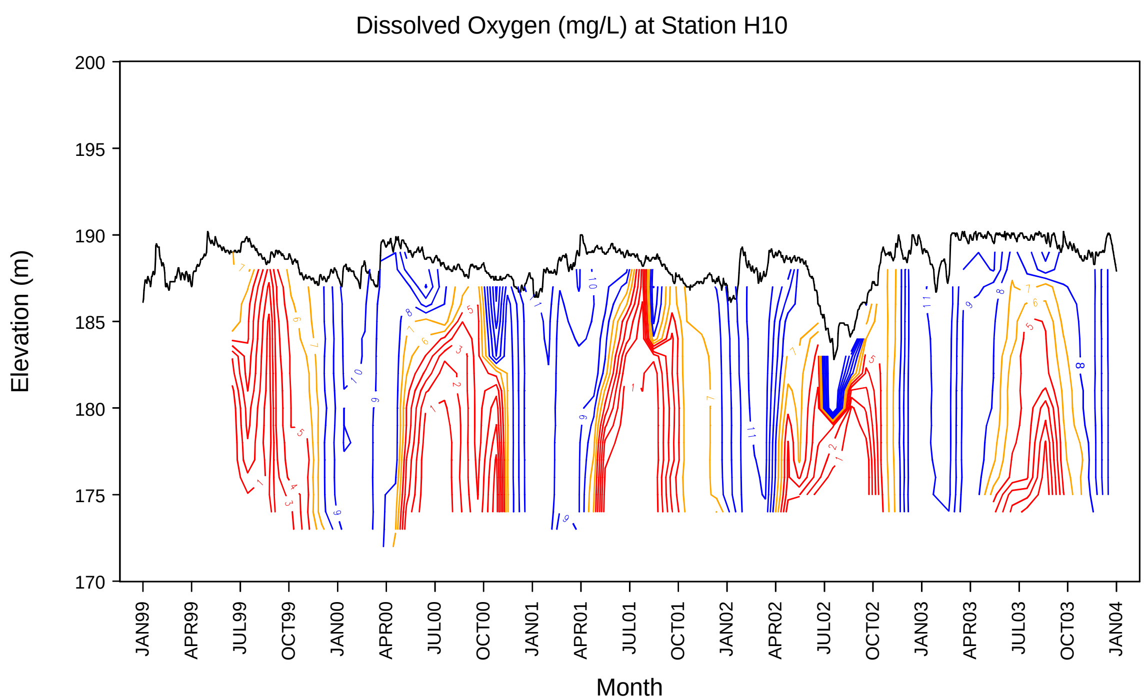


Figure 2.3-1. Temperature and dissolved oxygen profiles in High Rock Reservoir near the dam from 1999 to 2003.

briefly in 2002. Reduced flows and warmer water temperature during the extreme low lake levels of 2002 promoted intense algal production creating supersaturated conditions in the photic zone. In 2003, high flows and a full pool during the summer reduced the effects of oxygen depletion in High Rock Reservoir. Dissolved oxygen concentrations were greater than 5 mg/l in the top four meters and anoxic conditions were limited to the near bottom depths from July to September.

Spatially, dissolved oxygen characteristics vary in High Rock Reservoir. Low dissolved oxygen concentrations are more likely to occur in the arms rather than the mainstem of High Rock Reservoir (Table 2.3-2). The upper mainstem stations generally have adequate dissolved oxygen concentrations, but low surface dissolved oxygen is a chronic problem in the Swearing Creek and Crane Creek Arms of High Rock Reservoir. In the Crane Creek Arm, surface dissolved oxygen concentrations were below 5 mg/l on 17 sampling dates (31%). Due to a large algal standing crop and high levels of suspended solids, these two arms have a very shallow photic zone, averaging less than a meter. Biological oxygen demand is also high in these arms, which suggests that these are very productive areas and that oxygen can be consumed very quickly through microbial respiration. The shallow water will also allow more frequent mixing of the photic zone with the oxygen depleted water below resulting in an overall decrease in dissolved oxygen concentrations at the surface. Conversely, extended periods of calm weather reduce mixing and result in the isolation of bottom water and the development of anoxic conditions. The lower portion of High Rock where total depth and the photic zone are deeper are less susceptible to the severe reduction of surface dissolved oxygen due to the mixing of photic zone and bottom waters. The bottom water however remains isolated from the surface and anoxia in the lower depths occurs more frequently. Dissolved oxygen profiles for Stations H1 to H9 are presented in Appendix D.

Table 2.3-2. Dissolved oxygen characteristics of stations in High Rock Reservoir.

	Number of sampling dates where:[a]	
Station	**Anoxia (<1 mg/l) in deeper water**	**Low DO (<5 mg/l) in surface 2 meters**
Arms		
H2	4	17
H4	3	12
H5	10	5
H6	18	3
H8	9	7
H9	10	2
Mainstem		
H1	0	0
H3	0	2
H7	3	2
H10	16	5

[a] Total number of sampling dates varies from 53 to 55.

2.3.2 Tuckertown

Tuckertown Reservoir lies immediately downstream of the High Rock Dam tailrace. It is a relatively small reservoir of 2560 acres, with a linear basin shape and two small arms. Average residence time in the reservoir is estimated at about 22 hours. Average depth is 16 feet with a maximum depth of 55 feet near the Tuckertown Dam. The shoreline is generally undeveloped and Tuckertown Reservoir receives almost all of its flow from High Rock Reservoir.

The water quality in Tuckertown Reservoir is similar to the water quality in the lower portion of High Rock Reservoir (Section 2.3.1). The short residence time in Tuckertown Reservoir does not allow sufficient time for physical and biological processes to change water quality. In general it is a relatively turbid reservoir with a shallow photic zone (Table 2.3-3). Nutrient concentrations are still at levels that can promote nuisance algae blooms and algal biomass remains at high levels.

Chlorophyll *a* concentrations in the reservoir are slightly greater than those observed in the High Rock Dam tailrace (Section 2.4) indicating that some productivity is occurring in the reservoir. Although the suspended solids concentrations are much lower than High Rock Reservoir, they are still greater than levels typically seen in lakes and reservoirs (Wetzel 2001).

As in High Rock, weak thermal stratification of the water column occurs during the summer months in Tuckertown Reservoir. The difference between surface and bottom temperatures, a few degrees, is generally limited to the top five meters (Figure 2.3-2). Pool elevation was maintained at a near constant level during the drought year of 2002 and high flow year of 2003 and vertical thermal gradients were similar in both years.

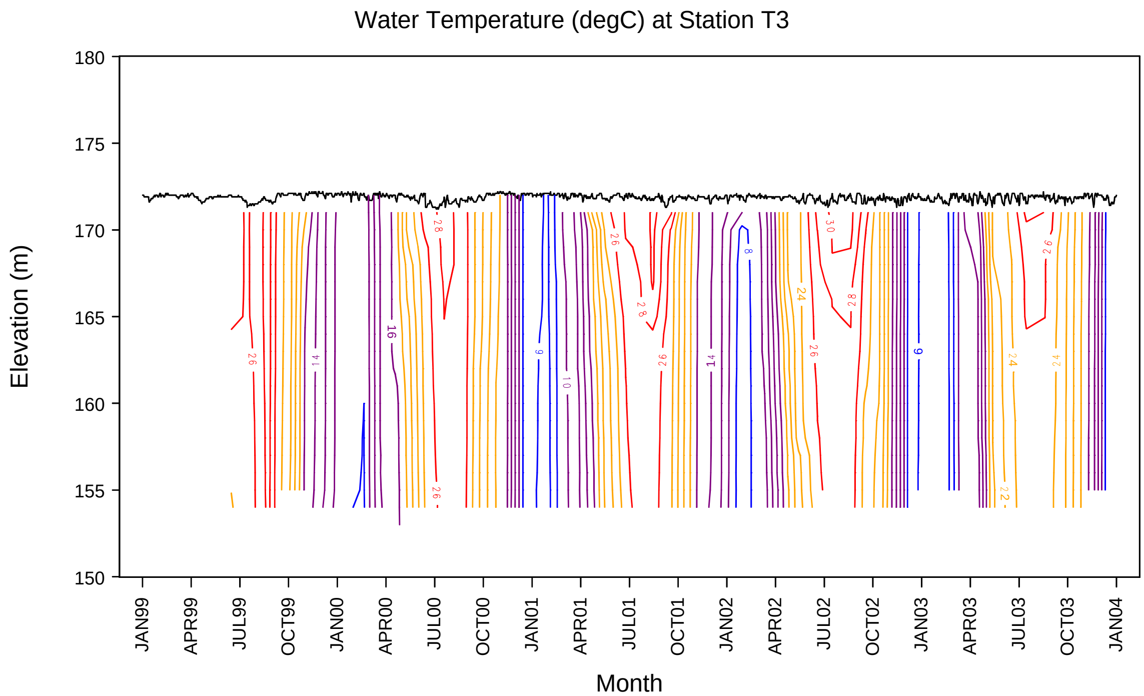
Dissolved oxygen depletion in deeper water typically extends from May through October or November, but anoxic conditions are usually limited to the summer months and to depths below five meters. Dissolved oxygen in the upper five meters of the water column varies considerably among the sampling years. Low dissolved oxygen concentrations (<5 mg/l) at the surface were observed from July to September 1999, August to October 2000, July to August 2001 and briefly in October 2002. In 2003, low dissolved oxygen concentrations were not observed in the upper five meters and bottom dissolved oxygen levels remained above 3 mg/l throughout the year. During the low flow period of 2002 (when the pool elevation of High Rock Reservoir was extremely low), dissolved oxygen concentrations in the top four meters of Tuckertown Reservoir were greater than 7 mg/l, but there was rapid depletion to anoxic conditions below four meters. Both surface and bottom dissolved oxygen concentrations were higher than typical in 2003, the high flow year. The effects of hydroelectric facility operations on dissolved oxygen are discussed in Section 3.4.

Lick Creek and Upper Tuckertown Reservoir

Additional sampling began in the Lick Creek Arm and upper mainstem of the Tuckertown Reservoir in July 2003 in response to comments from the North Carolina Division of Water Quality. The sampling consisted of a series of temperature and dissolved oxygen profiles in the mainstem below the High Rock Dam tailrace and two additional stations in the Lick Creek Arm. Temperature and dissolved oxygen profiles along with water sampling for nutrients and solids was conducted at an additional station in the free-flowing portion of Lick Creek upstream of the confluence with Tuckertown Reservoir. The sampling plan was designed to determine if Lick Creek influenced water quality in Tuckertown Reservoir.

Table 2.3-3. Median values of water quality parameters from June 1999 to December 2003 at each station in Tuckertown, Narrows and Falss Reservoirs

		Alkalinity (mg/l)	Biological Oxygen Demand (mg/l)	Chlorophyll *a* (Fg/l)	Ammonia (mg/l)	Nitrate (mg/l)	Secchi Depth (m)	Total Kjeldahl Nitrogen (mg/l)	Total Nitrogen (mg/l)	Total Organic Carbon (mg/l)	Total Phosphorus (mg/l)	Total Dissolved Solids (mg/l)	Total Solids (mg/l)	Total Suspended Solids (mg/l)	Turbidity (NTU)
Tuckertown	T2	25	2	17.2	0.08	0.47	0.73	0.68	1.15	3.75	0.08	82	96	11.05	17.05
	T3	26	2	16.4	0.10	0.45	0.90	0.68	1.10	3.70	0.08	80	92	9.00	15.10
Narrows	N2	25	<2	14.0	0.06	0.42	1.18	0.60	0.88	3.60	0.06	77	80	5.60	7.45
	N3	25	<2	6.8	0.05	0.43	1.68	0.57	0.87	3.50	0.04	70	75	<5	4.85
	N4	27	<2	8.4	0.08	0.42	1.43	0.61	1.13	3.65	0.05	76	78	<5	5.00
Falls	F2	25	<2	5.6	0.06	0.46	1.60	0.54	0.76	3.45	0.04	74	74	<5	4.50



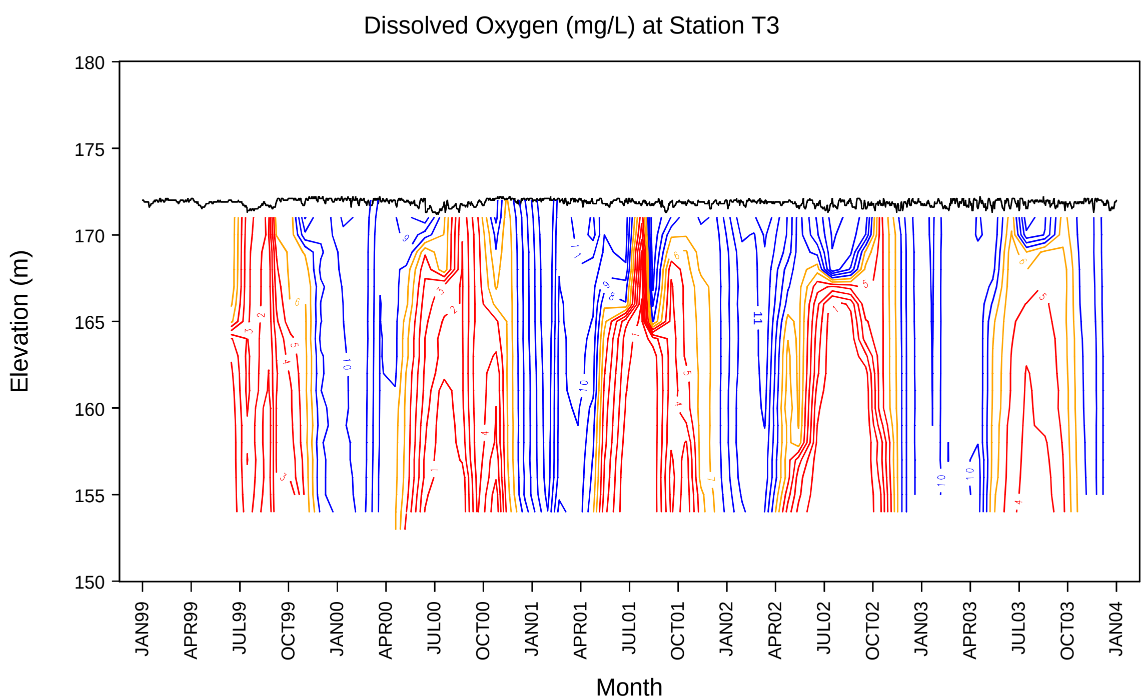


Figure 2.3-2. Temperature and dissolved oxygen profiles in Tuckertown Reservoir near the dam from 1999 to 2003.

The profiles in the mainstem below the High Rock Dam tailrace and in the Lick Creek Arm were measured in a relatively brief period (about 10 minutes apart) which almost provides a snapshot of the area. This sampling was usually conducted in the late afternoon which is probably near the daily maximum for both temperature and dissolved oxygen. Thermal stratification was not observed in the mainstem below the High Rock Dam tailrace on any sampling date (Table 2.3-4). In contrast, intense warming of the surface water occurred in the Lick Creek Arm. The difference between the surface and the bottom (at 2 meters) was as great as 7.3°C, but was more typically in the 2-3°C range. Thermal stratification occurred every month except for October and December. Temperatures in the Lick Creek Arm and the mainstem were generally similar on each sampling date.

Dissolved oxygen concentrations below the High Rock Dam tailrace were greater than 5 mg/l in every month, except for August and a few bottom readings in July (Table 2.3-5). In August, dissolved oxygen concentrations ranged from 3.79 to 4.73 mg/l. Oxygen depletion in the bottom waters was generally limited to a few tenths of a mg/l. In the Lick Creek Arm, surface dissolved oxygen concentrations were always greater than 5 mg/l. Low dissolved oxygen (<5 mg/l) occurred only near the bottom at both stations in July and at the upstream station in August. Dissolved oxygen concentrations varied widely in the Lick Creek Arm. Extremely high values at the surface in July suggest intense algal productivity and concentrations at supersaturation levels. The temperature and dissolved oxygen profiles suggest that the Lick Creek Arm does not mix to any great extent with the mainstem and has very little effect on the mainstem.

Lick Creek was also sampled for nutrients, solids and other water quality parameters in the free-flowing section upstream of its confluence with Tuckertown Reservoir (Table 2.3-6). Chlorophyll *a* concentrations were low despite high nutrient levels as is expected in a stream environment. Most of the nitrogen was organic, although nitrates contributed a large percentage as well. The supersaturated levels of dissolved oxygen in the Lick Creek Arm indicates that the nutrients being supplied by Lick Creek are being exploited as the creek water enters the reservoir. Concentrations of total organic carbon were rather high in Lick Creek. Low algal biomass and low biological oxygen demand suggest that a significant portion of the total organic carbon may be detrital. Turbidity was relatively low for a stream environment. Suspended solids were at levels below the detection limit except for July. Streams are influenced by recent storm events that may produce runoff. The monthly variation in water quality in Lick Creek was considerable and probably related to storm events around the sampling dates. The main differences between Lick Creek water quality and the receiving waterbody, Tuckertown Reservoir, is that Lick Creek has higher alkalinity, lower algal biomass and greater concentrations of total phosphorus, total organic carbon and dissolved solids. Lick Creek is small and although the concentration of total phosphorus may be double in the creek, the load to Tuckertown Reservoir is probably negligible.

2.3.3 Narrows

Narrows Reservoir is the second largest reservoir in the project area covering 5355 acres at full pool. The reservoir has a somewhat dendritic pattern and can be divided into two large basins. Narrows Reservoir receives most of its flow from Tuckertown Reservoir. The mainstem of the Yadkin River forms one of the major basins, the other basin created by the Gladys Fork Arm. The shoreline is mostly residential with some undeveloped areas and the lake is popular as a recreation area. Average residence time in the reservoir is estimated at 2 days. Narrows Reservoir is the deepest of the reservoirs with maximum depth near the dam at 175 feet. Average depth is 45 feet, which is more than double that of the other three reservoirs.

Table 2.3-4. Temperature profiles in Lick Creek, Lick Creek Arm and upper Tuckertown Reservoir from July to December 2003.

		Lick Creek	Lick Creek Arm		Upper Tuckertown Reservoir (distance from T1 in miles)						
		T4	TP8	TP7	TP1	TP2	TP3	TP4	TP5	TP6	TP9
			Upstream	Near Mouth	0.19	0.27	0.44	0.82	1.32	1.74	1.91
Date	Depth	ºC	ºC	ºC	ºC	ºC	ºC	ºC	ºC	ºC	ºC
07/15/03	0	25.4	31.46	28.71	25.9	25.91	25.92	25.98	25.97	25.96	25.88
	1		24.9	26.77	25.9	25.88	25.91	25.98	25.95	25.95	25.86
	2		24.18	25.59	25.89			25.98	25.95	25.95	25.88
	3								25.95	25.96	25.89
	4										25.89
08/19/03	0	24.51	25.99	26.87	25.67	25.72	25.86	25.93	28.81	26.03	26.27
	1		24.27	26.73	25.66	25.72	25.83	25.74	25.75	25.83	25.93
	2		24.16	25.26	25.67			25.67	25.69	25.73	25.83
	3									25.69	25.76
	4										25.73
09/22/03	0	20.98	22.57	22.81	22.08	22.08	22.11	22.14	22.15	22.23	22.2
	1		20.36	22.46	22.07	22.09	22.11	22.14	22.15	22.21	22.2
	2		20.13	20.44				22.13	22.15	22.22	22.2
	3								22.15	22.21	22.2
	4									22.21	22.2
10/27/03	0	15.62	15.46	16.31	16.98	17.01	16.92	16.93	16.85	16.74	16.69
	1		15.47	16.41	17.01	17.02	16.93	16.93	16.85	16.74	16.68
	2		15.47	16.33	17.01			16.93	16.85	16.74	16.69
	3									16.73	16.69
	4										16.69
11/18/03	0	14.14	14.06	15.17	13.7	13.7	13.7	13.72	13.67	13.81	13.81
	1		12.77	14.64	13.69	13.7	13.7	13.72	13.67	13.79	13.8
	2		12.67	13.76	13.68			13.72	13.67	13.79	13.81
	3									13.79	13.81
	4									13.79	
12/16/03	0	6.13	5.38	5.87	6.53	6.53	6.52	6.55	6.58	6.63	6.66
	1		5.24	5.73	6.53	6.53	6.52	6.54	6.57	6.63	6.65
	2		5.22	5.61				6.54	6.57	6.62	6.65
	3								6.57	6.62	6.65
	4									6.63	6.65

Table 2.3-5. Dissolved oxygen profiles in Lick Creek, Lick Creek Arm and upper Tuckertown Reservoir from July to December 2003.

		Lick Creek	Lick Creek Arm		Upper Tuckertown Reservoir (distance from T1 in miles)						
		T4	TP8	TP7	TP1	TP2	TP3	TP4	TP5	TP6	TP9
			Upstream	Near mouth	0.19	0.27	0.44	0.82	1.32	1.74	1.91
Date	Depth	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
07/15/03	0	6.75	12.57	8.48	5.41	5.48	5.36	5.99	5.29	5.3	5.25
	1		7.13	6.48	5.23	5.18	5.27	5.38	5.13	4.97	5
	2		4.89	2.87	5.2			5.3	5.11	4.94	4.91
	3								5.1	4.91	4.89
	4										4.87
08/19/03	0	6.72	5.51	8.02	4.73	4.49	4.49	4.59	4.29	4.47	4.66
	1		5.12	8.27	4.33	4.31	4.09	4.18	4.09	4.28	4.32
	2		4.93	6.09	4.32			3.92	3.93	4.01	4.1
	3									3.86	3.92
	4										3.79
09/22/03	0	7.43	7.15	7.67	6.28	6.09	6.25	6.24	6.21	6.4	6.49
	1		6.93	6.88	6.04	5.99	6.06	6.06	6.05	6.21	6.33
	2		6.46	5.76				6.02	6.01	6.14	6.26
	3								6	6.12	6.23
	4									6.11	6.21
10/27/03	0	6.52	6.44	6.98	8.43	8.12	8	7.93	8.44	8.63	8.19
	1		6.01	7.06	8.21	8.04	7.94	7.92	8.45	8.58	8.06
	2		5.89	6.91	8.12			7.94	8.47	8.55	8
	3									8.55	7.94
	4										7.92
11/18/03	0	8.07	7	9.2	8.93	8.78	8.91	8.9	8.98	8.93	9.3
	1		6.51	8.69	8.83	8.77	8.81	8.8	8.86	8.83	8.93
	2		5.99	7.78	8.8			8.76	8.82	7.77	8.8
	3									8.74	8.77
	4									8.72	
12/16/03	0	11.34	11.47	11.01	10.95	10.95	10.94	11.04	11.03	10.98	11.28
	1		11.17	10.67	10.82	10.82	10.83	10.89	10.92	10.9	11.03
	2		11.04	10.54				10.82	10.88	10.84	10.95
	3								10.83	10.82	10.9
	4									10.8	10.88

Table 2.3-6. Monthly water quality in Lick Creek and the median from Lick Creek and Tuckertown Reservoir from July to December 2003.

Parameter	Date						Median	
	7/15/2003	8/19/2003	9/22/2003	10/27/2003	11/18/2003	12/16/2003	Lick Creek	Tuckertown Reservoir
Alkalinity (mg/l)	33	37	24	39	37	12	35	21
Chlorophyll *a* (Fg/l)	0.8	2.0	2.8	2.0	3.2	1.6	2.0	8.8
Total phosphorus (mg/l)	0.21	0.11	0.14	0.28	0.09	0.05	0.13	0.06
Turbidity (NTU)	13	16	11	11	8	27	12	16
Nitrate (mg/l)	0.80	0.45	0.57	0.19	0.17	0.60	0.51	0.47
Ammonia (mg/l)	<0.05	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	0.06
Total Kjeldahl nitrogen (mg/l)	0.95	0.74	1.71	<0.5	0.68	<0.5	0.71	0.68
Total nitrogen (mg/l)	1.75	1.19	2.28	<0.5	0.85	0.60	1.02	1.13
Total organic carbon (mg/l)	6.4	9.2	6.1	6.3	4.6	6.8	6.35	3.25
Biological oxygen demand (mg/l)	3	<2	<2	<2	<2	<2	<2	<2
Chemical oxygen demand (mg/l)	<20	<20	36	<20	29	<20	<20	<20
Total solids (mg/l)	94	110	84	118	90	82	92	66
Total dissolved solids (mg/l)	38	58	88	118	100	88	88	67
Total suspended solids (mg/l)	33	<5	<5	<5	<5	<5	<5	7

Table 2.3-7. The number of sampling dates when concentrations of nitrite, chemical oxygen demand and toxic substances were above the detection limit in either the surface or bottom samples at each station from June 1999 to December 2003.

	Parameter (detection limit)	Nitrite[a] (<0.1 mg/l)	COD[b] (<20 mg/l)	Cadmium (<0.5Fg/l)	Cyanide (<0.005 mg/l)	Copper (<10 Fg/l)	Lead (<2 Fg/l)	Mercury[c] (<0.2 Fg/l)
Reservoir	**Station**							
High Rock Arms	H2		24	2	3	4	28	4
	H4	1	26	1	6	12	35	2
	H5	1	27	2	5	7	28	1
	H6		16	1	3	7	22	2
	H8		17	1	3	3	20	1
	H9		8	2	1	4	8	
High Rock Mainstem	H1		10	2	1	7	27	6
	H3		10	1	3	6	28	1
	H7	2	9		3	6	20	
	H10	1	9	2	2	6	17	1
Tuckertown	T1		9		2	2	10	
	T2		6	1	2	6	15	
	T3		7		1	5	10	
Narrows	N1	1	3		2	4	4	
	N2		8		2	1	6	
	N3		2		1	1	5	
	N4		12		2		7	23
Falls	F1	1	5		1		4	1
	F2		2	1	7	3	5	1
	F3		1		1		7	1

[a] Nitrite concentrations above the detection limit were observed on four dates: 8/23/99, 9/7/99, 8/22/00, 8/21/02
[b] COD = Chemical Oxygen Demand
[c] Only 8 of the 24 observations of mercury concentrations above the detection limit in High Rock Reservoir occurred on 12/20/00

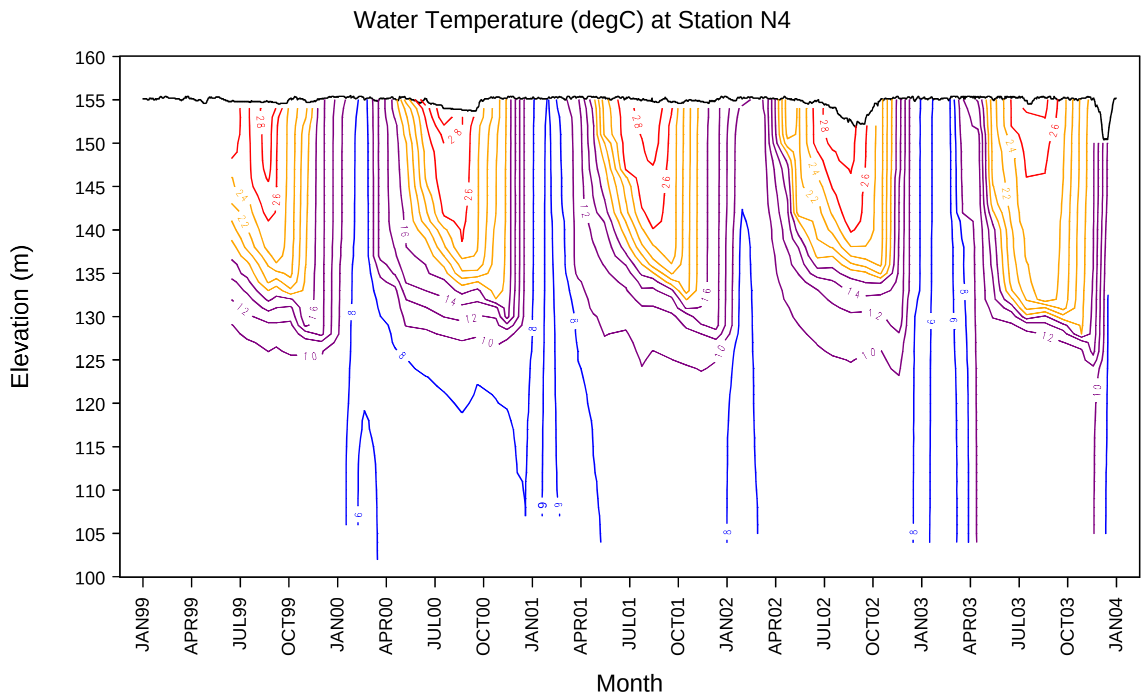
Narrows has greater water clarity and lower concentrations of suspended solids, nutrients and algal biomass than the two upstream reservoirs (Table 2.3-3) and better surface dissolved oxygen conditions than Falls Reservoir which lies downstream (Section 2.3.4). The surface waters are less turbid than the upstream reservoirs, but the photic zone is still relatively shallow, with averages ranging from about 2.4 to 3.4 meters. Average suspended solids concentrations at Narrows are near the detection limit. Nutrient concentrations are lower than in High Rock and Tuckertown Reservoirs, but they are still at levels that can produce nuisance algal blooms, althoughsuch blooms are likely to occur at a lower frequency in Narrows than in the upper reservoirs. Narrows, with its deeper water, is the only reservoir where a true hypolimnion develops (>4°C difference between surface and bottom temperatures).

Water quality conditions across the reservoir are homogeneous and differences among the stations are very small. Slightly greater chlorophyll *a* and suspended solids concentrations occur at the mainstem station that is closest to the Tuckertown Dam tailrace. The Gladys Fork Arm of the reservoir has slightly lower algal biomass, suspended and dissolved solids and total phosphorus than the two stations along the mainstem, but the differences are very small. Total nitrogen concentrations are greatest near the dam.

A strong and persistent thermocline develops near the dam in Narrows Reservoir. Thermal stratification typically begins to develop in May and persists, in some years, into December (Figure 2.3-3). By mid-summer, a well developed epilimnion (warm upper layer) extends from the surface to a depth of about 15 to 20 meters and a well defined metalimnion (transitional layer) separates the epilimnion from the hypolimnion (cool lower layer). Epilimnetic waters reach a maximum of about 30°C in summer. Hypolimnetic waters average 8 to 10°C throughout the spring summer and fall. The upper limit of the hypolimnion is typically at about a depth of 27 meters (pool elevation 128 m). Throughout the fall, the metalimnion thins as the epilimnion cools and deepens. Turnover occurs in late summer or early fall.

Dissolved oxygen concentrations in the upper four or five meters are usually greater than 5 mg/l. Below five meters, low dissolved oxygen concentrations (<5 mg/l) persist from June through September. Oxygen depletion is independent of thermal stratification, occurring in the deeper portions of the epilimnion as well as the metalimnion and hypolimnion. There is a step-wise retreat of the low dissolved oxygen water in the fall. This is probably due to periodic storm events that cause mixing of the epilimnion along with the gradual destruction of the metalimnion. Complete mixing of the reservoir usually occurs in December or January and dissolved oxygen concentrations are similar throughout the water column until stratification returns in late spring.

There are slight differences among years in development of the thermocline. The epilimnion was a little shallower in 2001 and 2002. The epilimnion developed to greater depth earlier during the high flow year of 2003. Dissolved oxygen concentrations were much greater during 2003 and anoxia was not observed in the upper 20 meters of water. A persistent layer of oxygenated water was wedged between two anoxic layers at a reservoir elevation of 120 to 130 meters (80-110 feet below normal full pool). This phenomenon was observed to a lesser extent in 1999 and 2000. This corresponds to the upper portion of the hypolimnion. This is usually caused by a faster rate of oxygen depletion in the metalimnion. Particles tend to concentrate in the metalimnion as they encounter a density gradient caused by the temperature change. With a more concentrated source of nutrition and slightly warmer temperature to increase metabolism, decomposers tend to deplete the dissolved oxygen in the metalimnion faster than in the underlying hypolimnion. This phenomenon occurred in years where



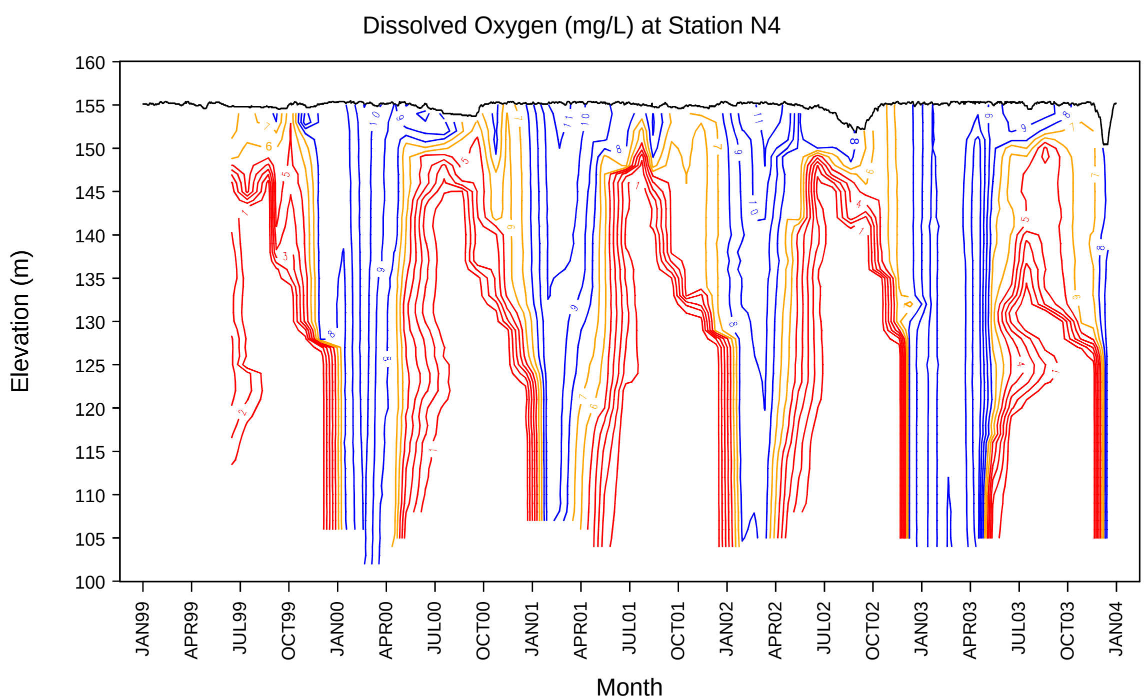


Figure 2.3-3 Temperature and dissolved oxygen profiles in Narrows Reservoir near the dam from 1999 to 2003.

the epilimnion was deeper and developed earlier, thereby creating a deeper, but more pronounced metalimnion.

The station near the Narrows Dam is unique because it is the only station in any of the reservoirs where a hypolimnion develops. The other two stations in Narrows Reservoir are shallower and the warming of the surface waters extends to the bottom (Appendix E). Some thermal stratification is observed at the other two stations, with differences between the surface and bottom being as great 10 or 12°C in the late spring and early summer. By late summer, the epilimnion extends to near the bottom and differencesbetween surface and bottom temperature decreases to about 4 to 6°C. Oxygen depletion occurs during the period of thermal stratification at depths below 3 or 4 meters. Complete turnover of the water column occurs earlier at Stations N2 and N3 when compared to the dam station (N4). Turnover usually occurs in late September or early October, at which point, oxygen levels throughout the water column exceed 5 mg/l.

2.3.4 Falls

Falls Reservoir is the lower-most of the Alcoa reservoirs on the Yadkin River. It has no tributaries of any size and receives almost all of its water from Narrows Reservoir. It is a small reservoir of 204 acres with a predominantly forested shoreline. Falls Reservoir is linear in shape, amounting to little more than a deepening and slight widening of the original river channel. The average residence time is estimated at 2 hours.

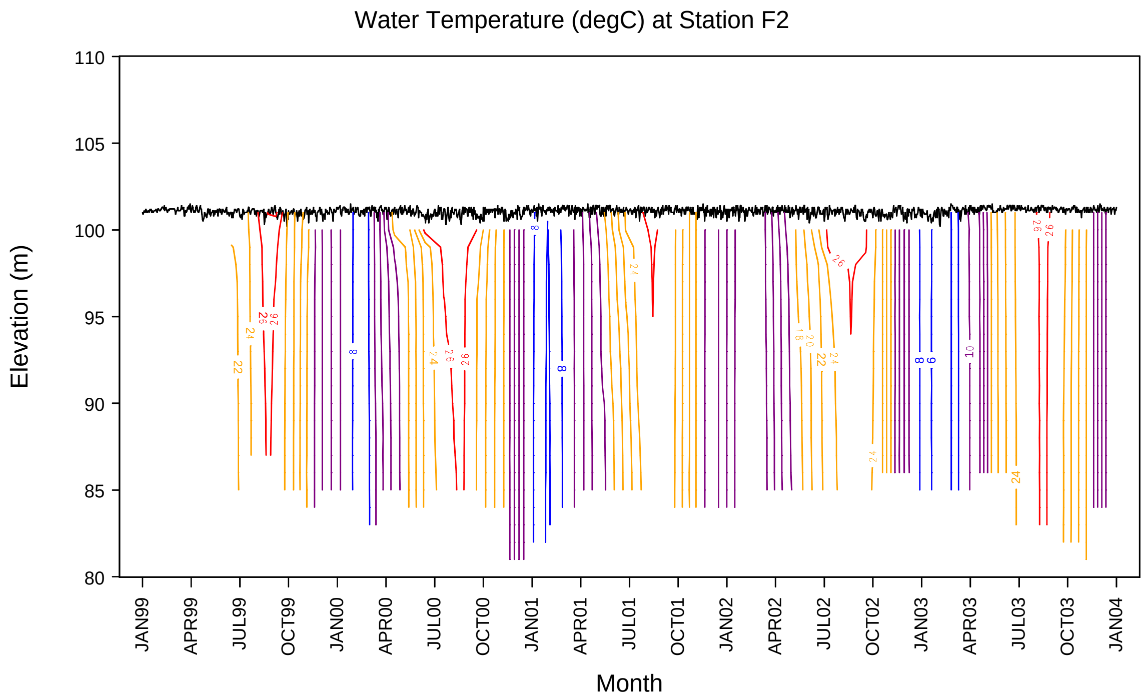
Falls Reservoir has the lowest concentrations of solids, nutrients and algal biomass of all the reservoirs. The levels are generally similar to the concentrations observed in Narrows Reservoir near the dam (Table 2.3-3). Due to the short residence time, limnetic processes do not have sufficient time to alter the water quality. Nutrient concentrations are still at levels that could promote algal blooms. However, algal biomass is low because Falls Reservoir receives as a portion of the discharge, deep epilimnetic water that is assumed to have low algal biomass and the residence time in the reservoir is not sufficient for algal populations to develop. Average Secchi depth is 1.6 meters indicating a photic zone of about 3 meters. Suspended solids concentrations are below detection level.

The PCA-ordination (Section 2.2; Figure 2.2-1) groups the Falls Reservoir station (F2) in close proximity to the Narrows and Falls tailraces. In a sense, the entire Falls Reservoir can be considered as the tailrace of Narrows Dam. The mid-water discharge from Narrows Reservoir includes cooler anoxic water that lowers temperature, pH and dissolved oxygen levels throughout Falls Reservoir.

Thermal stratification does not occur in Falls Reservoir (Figure 2.3-4). Temperatures range from about 8 to 28 °C. Dissolved oxygen concentrations observed at the surface range from 3 to 11 mg/l. In a typical year, low dissolved oxygen concentrations extend from the bottom to within a meter or two of the surface from June to October, but anoxic conditions have not been observed. Low dissolved oxygen water (<5 mg/l) is occasionally observed at the surface. Low dissolved oxygen concentrations did not occur during the high flow year of 2003.

2.3.5 Toxic Substances, Chemical Oxygen Demand and Nitrite

Several parameters are treated separately because they typically occur at concentrations that are below the detection level of the test method. This includes all five of the toxic substances that were tested along with chemical oxygen demand and nitrite-nitrogen. These parameters are evaluated by the frequency of detectable levels at each station by sampling date (Table 2.3.7). The overall median



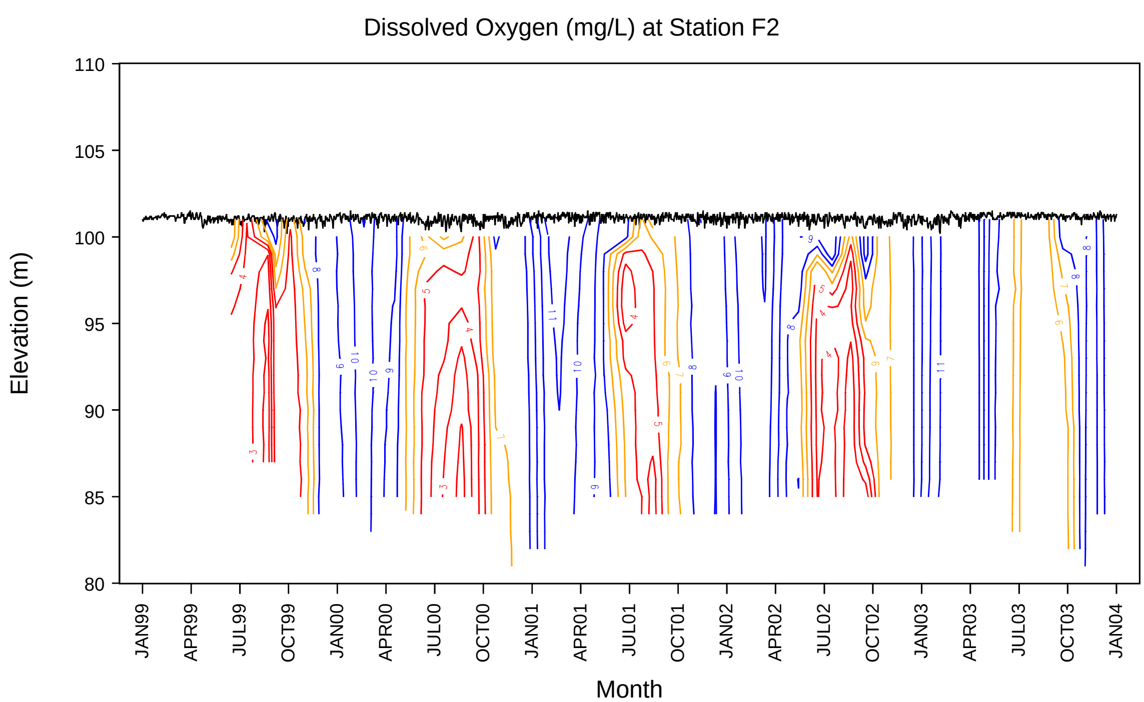


Figure 2.3-4. Temperature and dissolved oxygen profiles in Falls Reservoir near the dam from 1999 to 2003.

values of all seven of these test parameters was below the detection level, although not necessarily at every station**.**

Nitrite-nitrogen was rarely observed at concentrations above the detection level. Detectable levels were observed in the Crane Creek Arm (H4) and upper portion of Abbotts Creek Arm (H5) and the two lower mainstem stations of High Rock Reservoir. Nitrite concentrations were also detected in the tailraces of Tuckertown and Narrows Dams. It was detected on only four sampling dates, all in late August or early September. In natural waters, nitrite concentrations are usually determined by an equilibrium with nitrate where nitrite concentrations are typically about 10 percent of the nitrate levels and nitrate concentrations in the project area were usually below 1 mg/l. Detectable levels of chemical oxygen demand (COD) were observed at every station. COD at concentrations above the detection limit occurred most frequently in the arms of High Rock Reservoir, with the exception of Flat Swamp Creek. In the upper arms of High Rock Reservoir, which is an area prone to low surface dissolved oxygen concentrations, detectable levels of COD occurred on about half of the collection dates and levels were often high. COD levels were also greater near the Narrows Dam (Station N4). These occurrences were mostly in the hypolimnion at Station N4 where a persistent hypolimnion creates anoxic conditions for most of the year allowing the accumulation of oxidizable compounds. There is a general upstream to downstream decrease in the occurrence of detectable levels of COD through the system of reservoirs. The less frequent occurrence of detectable levels of COD is similar to the reduction of suspended solids and algal biomass as water passes through the system of reservoirs.

Cadmium concentrations were rarely above the detection limit. Most observations were in High Rock Reservoir, but detectable levels were also observed at stations in Tuckertown and Falls Reservoirs. Cadmium was not detected in any of the tailraces or in Narrows Reservoir. The greater occurrence of cadmium at detectable levels in High Rock Reservoir and its relative scarcity in the other reservoirs suggests that High Rock is trapping most of the cadmium in its sediments.

Cyanide was detected at every station. However, differences among stations were small in terms of the frequency of detectable cyanide. Cyanide was most likely to be detected in Crane Creek and the upper portion of Abbotts Creek Arms in High Rock Reservoir, the stations in Tuckertown and Falls Reservoirs and in the tailrace below Tuckertown Dam. Detectable levels of cyanide occurred most frequently in the arms of High Rock Reservoir where large standing crops of algae are found. Although algae is not likely to generate cyanide, the large standing crops and high dissolved oxygen concentrations indicate that these are very productive areas and that the cyanide may be generated by other micro-organisms in these areas. There seems to be an unusually high frequency of detectable cyanide concentration in Falls Reservoir.

Copper was most likely to occur at detectable levels in High Rock and Tuckertown Reservoirs. Occurrences downstream from the Tuckertown tailrace were sporadic. The occurrences of copper in High Rock and Tuckertown Reservoirs was relatively evenly spread among the stations, except for the Crane Creek Arm (H4) where 12 of 54 collection dates (22%) had detectable levels of copper. The overall trend suggests a slight decrease in copper concentrations as water moves through the four reservoirs.

Lead was the most commonly occurring toxic substance that was tested. The greatest frequency and highest concentrations were observed in the upper portions of High Rock Reservoir. Both the mainstem stations and the arm stations in the upper portion of High Rock Reservoir had detectable levels of lead on over half of the sampling dates. Lead levels were low in the Flat Swamp Creek Arm of High Rock Reservoir, however. The frequency of detectable levels of lead decreases in the downstream reservoirs and is lowest in Narrows and Falls.

Mercury most frequently occurred at detectable levels in High Rock Reservoir and in the hypolimnion of Narrows Reservoir. In High Rock Reservoir, mercury was most likely to be observed near the mouth of the Yadkin River (6 of 55 samples over 4.5 years) or in Swearing Creek Arm (4 of 55 samples) in the upper portion of the reservoir. Mercury was observed above the detection limit in Abbotts Creek Arm (3 of 55 samples), the recipient of historical mercury discharges from the Duracell battery plant in Lexington. The occurrence of mercury was generally sporadic in High Rock Reservoir, except for December 20, 2000 when detectable levels of mercury occurred at 7 of the 10 stations. Mercury was not detected in Tuckertown Reservoir and most of Narrows Reservoir, which suggests that mercury entering High Rock Reservoir from the Yadkin River and Swearing Creek is retained within High Rock Reservoir. Detectable levels of mercury occurred on almost half of the sampling dates at Station N4 near the Dam in Narrows Reservoir, the only station with a hypolimnion. The anoxic hypolimnion persists for most of the year during which time the hypolimnion is isolated from the surface waters allowing the accumulation of dissolved mercury compounds. The hypolimnion of Narrows Reservoir is probably a source of dissolved forms of mercury. Detectable levels of mercury occurred on one sampling date in each of the Narrows and Falls tailraces and Falls Reservoir. The mercury in the hypolimnion of Narrows Reservoir is either being retained in this reservoir and converted back to insoluble forms of mercury during turnover, or it is being diluted to levels below the detection limit as hypolimnetic water is mixed with surface water in the passage through Narrows Dam.

The metals, lead, copper, mercury and cadmium were more likely to occur at detectable levels in High Rock Reservoir, particularly the upper portions. High Rock is the reservoir that is most affected by runoff. Metals are much more likely to be detected in Crane Creek Arm which has the greatest suspended solids concentrations and the Yadkin River appears to be a significant contributor of lead and mercury. High Rock Reservoir is probably trapping many of these metals since detectable occurrences are less frequent in Tuckertown Reservoir. It appears that almost all the mercury and cadmium is being retained in High Rock Reservoir. The frequency of detectable levels of both lead and copper decrease in the downstream reservoirs.

2.3.6 Seasonal and Annual Variability

Seasonal patterns in water quality are affected by differences among the years. In this study, 2002 was an usually dry year, flows and water levels in High Rock Reservoir reached “historic” lows. Conversely, 2003 was an extremely wet year and flow and lake levels were near record highs. The effects of extreme low flow and high flow years caused alterations in the typical seasonal trends in those years. Seasonal trends are influenced by a number of factors, mostly related to climate and biological activity. Land use practices and other human activities in the watershed that may affect water quality may also vary both annually and seasonally.

The annual minimum and maximum surface temperatures are relatively consistent among the reservoirs and among the years. Surface temperatures increase from winter lows of about 8°C to summer highs of about 30°C (sections 2.3.1 to 2.3.4). Except for Narrows Reservoir, bottom temperatures show a seasonal pattern that is similar to the surface. However, the summer maximum is a little lower, with summer bottom temperatures reaching about 27°C. In High Rock, Tuckertown and Falls reservoirs, weak thermal stratification of up to 4°C occurs in the summer, generally from July to September. In Narrows Reservoir, a hypolimnion develops below a depth of 25 meters. The hypolimnion in Narrows Reservoir develops in spring and persists until December or January. Epilimnetic temperatures in Narrows are similar to the other reservoirs during the summer.

Two distinct seasonal patterns were observed for dissolved oxygen concentrations in the photic zone. In High Rock, Tuckertown and Narrows reservoirs in 2002, 2003 and to lesser extent, 2000, there were two periods of high dissolved oxygen concentrations. In these years, dissolved oxygen concentrations decreased from winter highs to moderate levels in late spring, returned to high levels during the summer, decreased to moderate levels once again in early fall before returning to winter levels in December. In contrast, dissolved oxygen concentrations in 1999 and 2001 decreased from winter highs to late summer and early fall lows. Surface dissolved oxygen was generally lower in 1999 and 2001 with concentrations below 5 mg/l occurring occasionally in the late summer. The summer increases in dissolved oxygen concentrations in 2000, 2002 and 2003 can be attributed to algal production as oxygen is produced during photosynthesis.

Bottom dissolved oxygen concentrations in High Rock, Tuckertown and Narrows reservoirs were relatively consistent among years. Concentrations decreased from winter highs to summer lows. Low dissolved oxygen concentrations (<5 mg/l) typically occurred from May to October in High Rock Reservoir, from May to November in Tuckertown and from April to December/January in Narrows. Anoxia was generally limited to the summer months in High Rock and Tuckertown reservoirs. The volume of the anoxic zone in High Rock and Narrows was reduced in 2002 during the drawdown of the reservoirs as the surface oxygenated layer moved down with the water level and the volume of hypolimnion was reduced.

The dissolved oxygen characteristics of Falls Reservoir are considerably different from the upstream reservoirs. Anoxia is absent and differences between the surface and bottom waters are much more limited than in the other reservoirs. Seasonally, dissolved oxygen concentrations decrease from winter highs to summer lows in both the surface and bottom waters. Oxygen depletion below the photic zone is limited to the summer months.

Suspended solid concentrations do not follow a seasonal pattern. There are large fluctuations, especially in High Rock Reservoir, but the occurrence of the peak periods varies among the years (Figure 2.3-5). The upper mainstem of High Rock Reservoir is strongly influenced by runoff from the Yadkin River where suspended solids concentrations would be affected by precipitation and land use in the upstream watershed. Increases of suspended solids in 2000, 2001 and 2002 in late spring and early summer suggest the possibility of a weak seasonal trend in the lower mainstem and arms of High Rock Reservoir. This trend was not observed in 1999 or 2003 however, suggesting that if seasonal effects exist, they have less influence on suspended solid concentrations than other factors. Suspended solid concentrations in the lower portion and arms of High Rock Reservoir were generally independent of concentrations in the upper mainstem. There were no seasonal trends in Tuckertown or Narrows Reservoirs. Suspended solid concentrations in Tuckertown Reservoir were generally slightly greater when concentrations were higher in the lower portion of High Rock Reservoir. Suspended solids are discussed further in Section 3.5.

Dissolved solids concentrations from 1999 to 2002 were generally greater in the late summer and fall in High Rock and Tuckertown reservoirs (Figure 2.3-6). Peak concentrations in Narrows Reservoir occurred in late fall or early winter suggesting a slight lag that may be related to the time required for surface waters to travel through the system. There was also a slight lag at Tuckertown Reservoir when compared to High Rock. In the low flow year of 2002, there was a two month lag between High Rock and Tuckertown reservoirs and the increase in total dissolved solids concentrations that

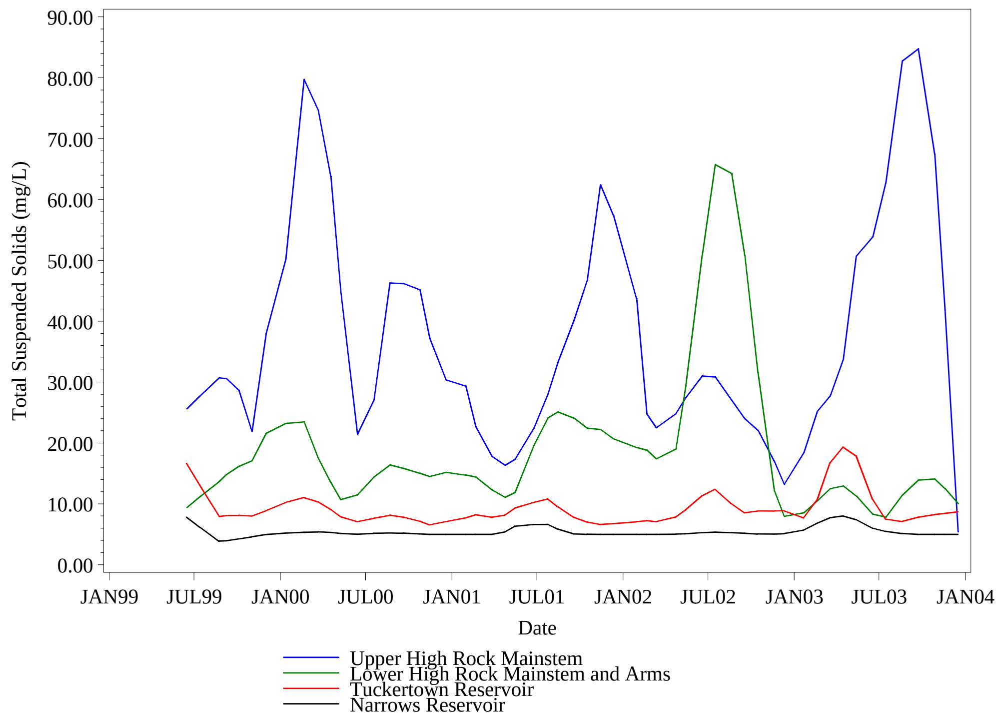


Figure 2.3-5. Locally weighted estimates (LOWESS) of Total Suspended Solids concentrations (mg/l) in the upper mainstem of High Rock, the lower mainstem and arms of High Rock, Tuckertown and Narrows Reservoirs from June 1999 to December 2003.

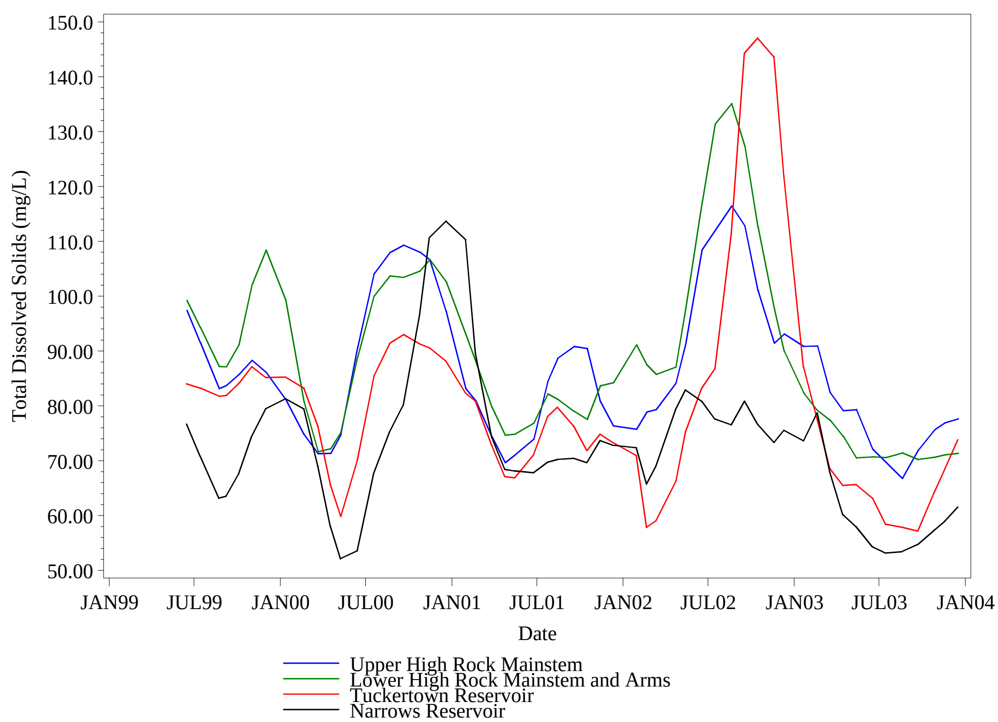


Figure 2.3-6. Locally weighted estimates (LOWESS) of Total Dissolved Solids concentrations (mg/l) in the upper mainstem of High Rock, the lower mainstem and arms of High Rock, Tuckertown and Narrows Reservoirs from June 1999 to December 2003.

typically occurs in Narrows Reservoir was not observed. The seasonal pattern was disrupted during 2003 when high flows occurred and total dissolved solids concentrations remained low throughout the year.

Chlorophyll *a* concentrations, the surrogate measure for algal biomass, has a strong seasonal pattern in the lower mainstem and arms of High Rock, Tuckertown and Narrows Reservoirs. Concentrations are lowest in the early winter and increase to annual maxima in mid-summer (Figure 2.3-7). In the upper mainstem of High Rock Reservoir, chlorophyll *a* concentrations are considerably more variable and a strong seasonal pattern is not seen, although summer levels tend to be higher than late winter and early spring. The greatest concentrations of chlorophyll *a* occurred in 2002, the low flow year, but higher levels were only seen in High Rock and Tuckertown reservoirs. Peak chlorophyll *a* concentrations in the high flow year, 2003 were about half the previous years. Algal biomass during the summer of 2003 in Narrows was slightly greater than normal. This may have been due to increased loading to Narrows Reservoir by the high flows. The decrease in High Rock and Tuckertown reservoirs may have been caused by the shorter residence time of surface water in High Rock not allowing the algal population to fully develop.

There does not appear to be a seasonal trend for total organic carbon (Figure 2.3-8). There was little change in total organic carbon concentrations in 1999 and 2000, thereafter concentrations tended to vary seasonally with the greatest concentrations occurring in 2002. Total organic carbon concentrations in Tuckertown and Narrows reservoirs were almost identical both in terms of magnitude and timing of peaks, except during the low flow year 2002. Concentrations in High Rock's upper mainstem were much lower than in the lower mainstem and arms where a large algal population develops. Total phosphorus concentrations fluctuate widely, especially in High Rock Reservoir, but the variation is not related to season (Figure 2.3-9). Phosphorus concentration in both the upper mainstem and the lower portion of the reservoir reflect changes in the suspended solid concentrations (Figure 2.3-5). A large portion of the phosphorus entering High Rock Reservoir is probably a constituent of particulate matter. Phosphorus concentrations in Tuckertown do not follow a seasonal pattern and are generally unrelated to concentrations in High Rock Reservoir. Narrows Reservoir phosphorus concentrations follow a trend similar to Tuckertown, but the magnitude is slightly less.

Three of the principal constituents of the nitrogen cycle are ammonia, organic nitrogen and nitrous oxides (generally nitrate). Of these three components, ammonia occurs in the lowest concentrations in the surface waters of High Rock, Tuckertown and Narrows reservoirs. Ammonia concentrations are much higher in bottom water, which are not considered here. There are no seasonal trends in ammonia in any of the reservoirs (Figure 2.3-10). Total Kjeldahl Nitrogen (TKN) can provide a rough estimate of organic nitrogen. Since ammonia levels were relatively low in comparison to TKN, the plot of TKN approximates the organic nitrogen concentrations. There was no seasonal trend in TKN concentrations in the upper mainstem of High Rock Reservoir which is influenced by the Yadkin River, but a fairly consistent seasonal trend occurred in the lower mainstem and arm stations where large algal populations develop (Figure 2.3-11). Low concentrations occurred in late winter and early spring and high concentrations occurred in the summer, similar to the increase in chlorophyll *a* concentrations. Except for 2000, seasonal trends were similar in Tuckertown Reservoir and the lower portion of High Rock Reservoir. There were no apparent trends in Narrows Reservoir. The amount of organic nitrogen entering High Rock in the upper mainstem is much lower than in the lower portion of the reservoir. Organic nitrogen is being generated in the lower portion of High Rock and the source of the nitrogen is nitrate. Nitrate concentrations are consistently high in the upper

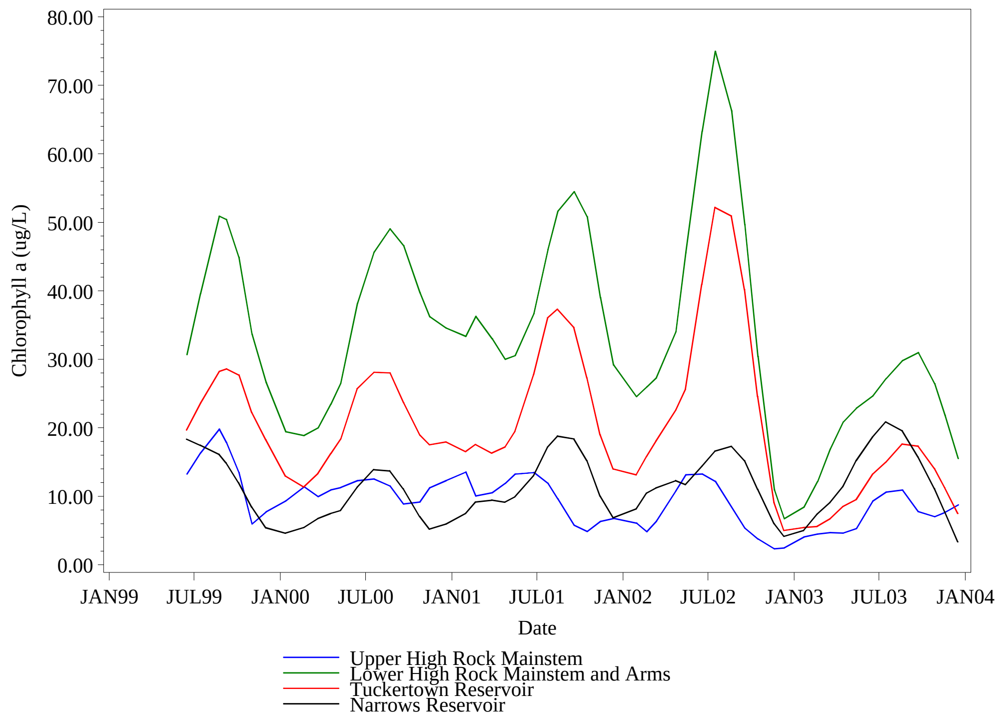


Figure 2.3-7. Locally weighted estimates (LOWESS) of Chlorophyll *a* concentrations (ug/l) in the upper mainstem of High Rock, the lower mainstem and arms of High Rock, Tuckertown and Narrows Reservoirs from June 1999 to December 2003.

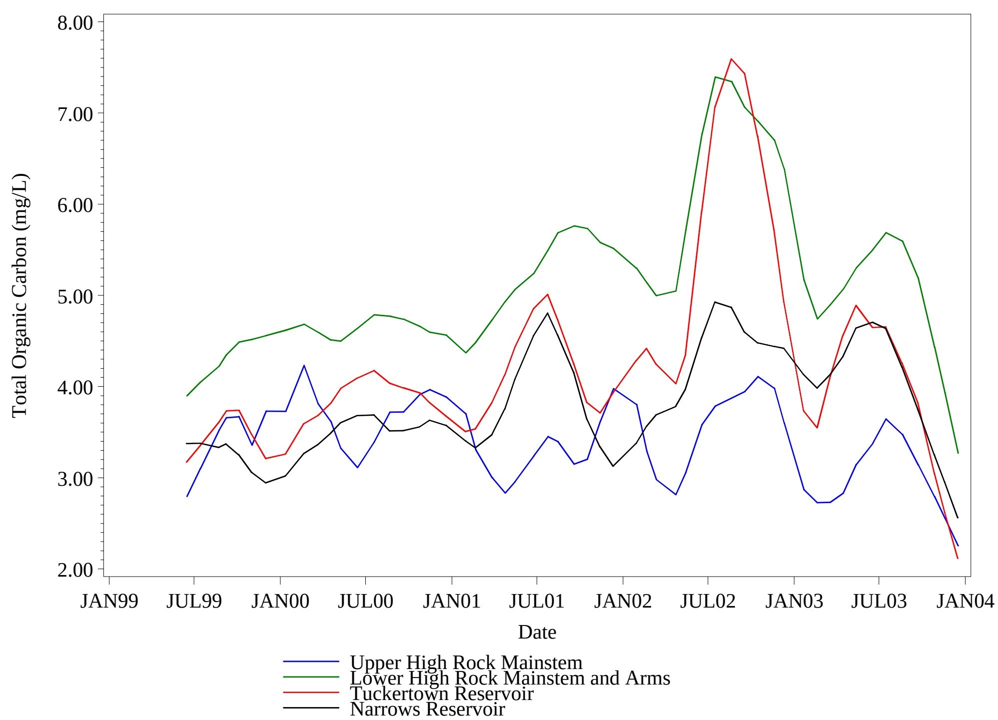


Figure 2.3-8. Locally weighted estimates (LOWESS) of Total Organic Carbon concentrations (mg/l) in the upper mainstem of High Rock, the lower mainstem and arms of High Rock, Tuckertown and Narrows Reservoirs from June 1999. to December 2003.

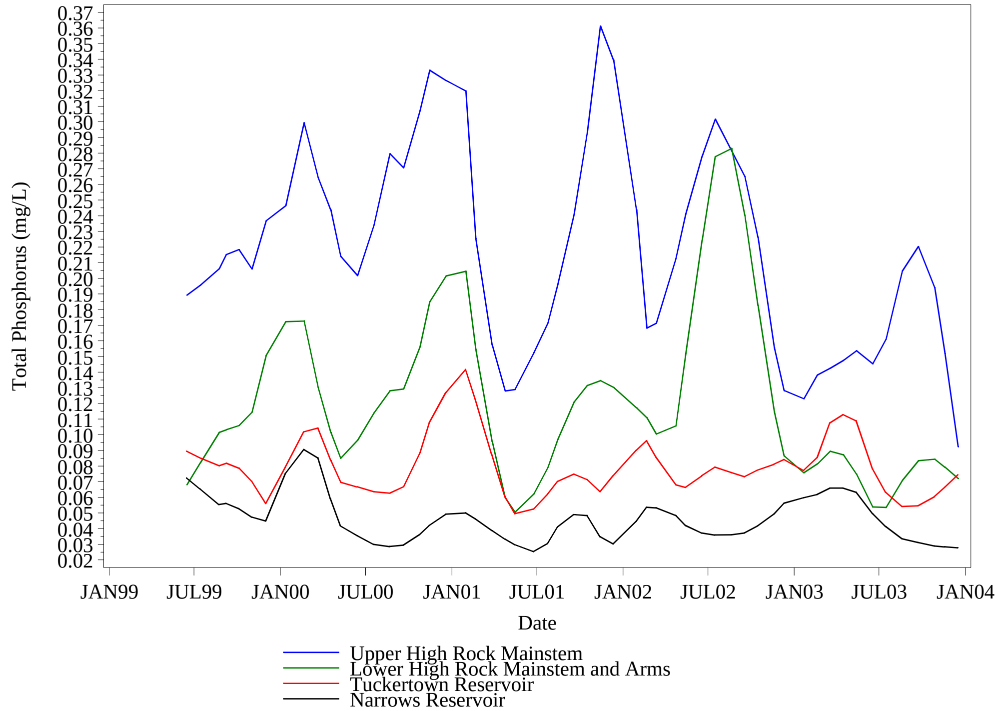


Figure 2.3-9. Locally weighted estimates (LOWESS) of Total Phosphorus concentrations (mg/l) in the upper mainstem of High Rock, the lower mainstem and arms of High Rock, Tuckertown and Narrows Reservoirs from June 1999 to December 2003.

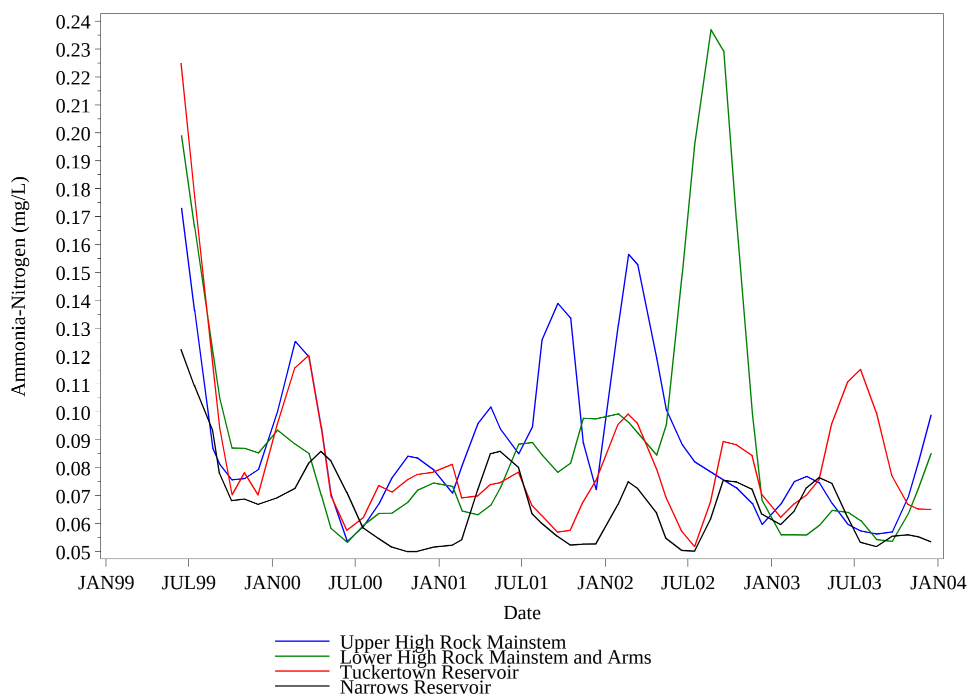


Figure 2.3-10. Locally weighted estimates (LOWESS) of Ammonia-nitrogen concentrations (mg/l) in the upper mainstem of High Rock, the lower mainstem and arms of High Rock, Tuckertown and Narrows Reservoirs from June 1999 to December 2003.

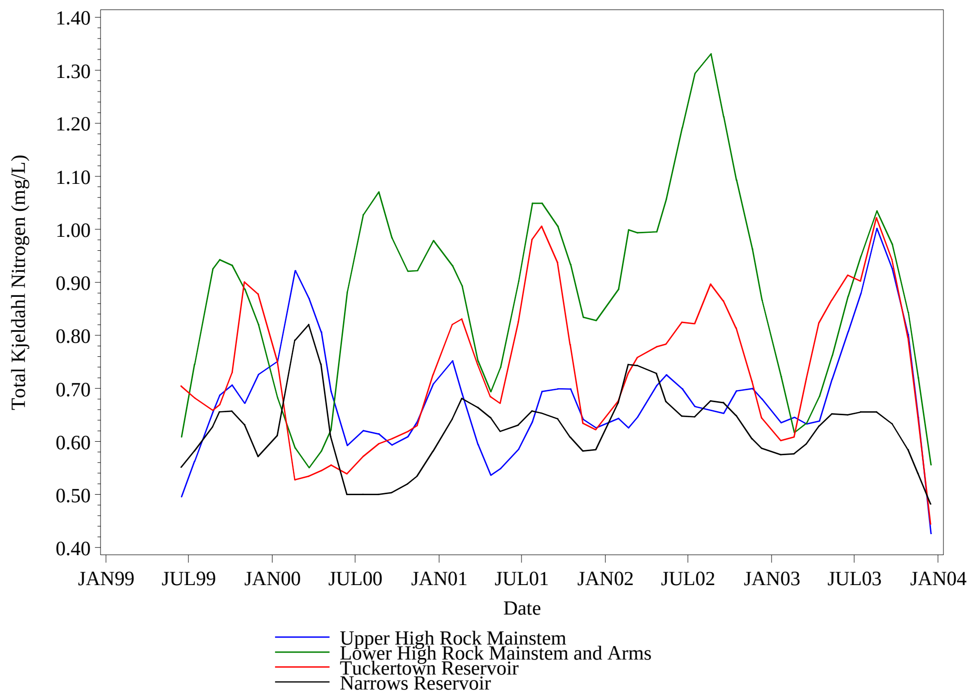


Figure 2.3-11. Locally weighted (LOWESS) estimates of Total Kjeldahl-nitrogen concentrations (mg/l) in the upper mainstem of High Rock, the lower mainstem and arms of High Rock, Tuckertown and Narrows Reservoirs from June 1999 to December 2003.

portion of High Rock Reservoir, but they do not have a seasonal cycle (Figure 2.3-12). A very consistent seasonal cycle with low nitrate concentrations in the summer and high concentrations in the winter occurs in the lower portion of High Rock, and in Tuckertown and Narrows Reservoirs. During the extremely low flow year of 2002, the seasonal nitrate cycle in the lower portion of High Rock was altered and appeared related to the inflowing waters in the upper mainstem, but at much reduced levels. The nitrate seasonal cycle in the lower portion of High Rock is the inverse of the TKN and chlorophyll *a* seasonal cycles. The assimilation by algae and other microbial organisms of nitrate is mostly limited to High Rock Reservoir passage of water through the other reservoirs has little effect on nitrate concentrations.

2.3.7 Water Quality of Bottom Waters

In lake and reservoir environments, bottom waters often have different water quality characteristics than the overlying surface water. A number of factors cause this including stratification caused by temperature or density gradients, chemical reactions of water with the sediment, groundwater inflow, available light and biological activity. Differences between the chemistry of the surface and bottom water varies seasonally due to changes in climate that affect thermal stratification, dissolved oxygen depletion and runoff.

During the summer, bottom collections in the four Yadkin River reservoirs are generally cooler and have lower dissolved oxygen concentrations or are anoxic. In High Rock and Tuckertown reservoirs, summer bottom collections are more turbid with greater concentrations of suspended solids, total phosphorus and ammonia. Ammonia levels are also high in Narrows Reservoir in the bottom collections.

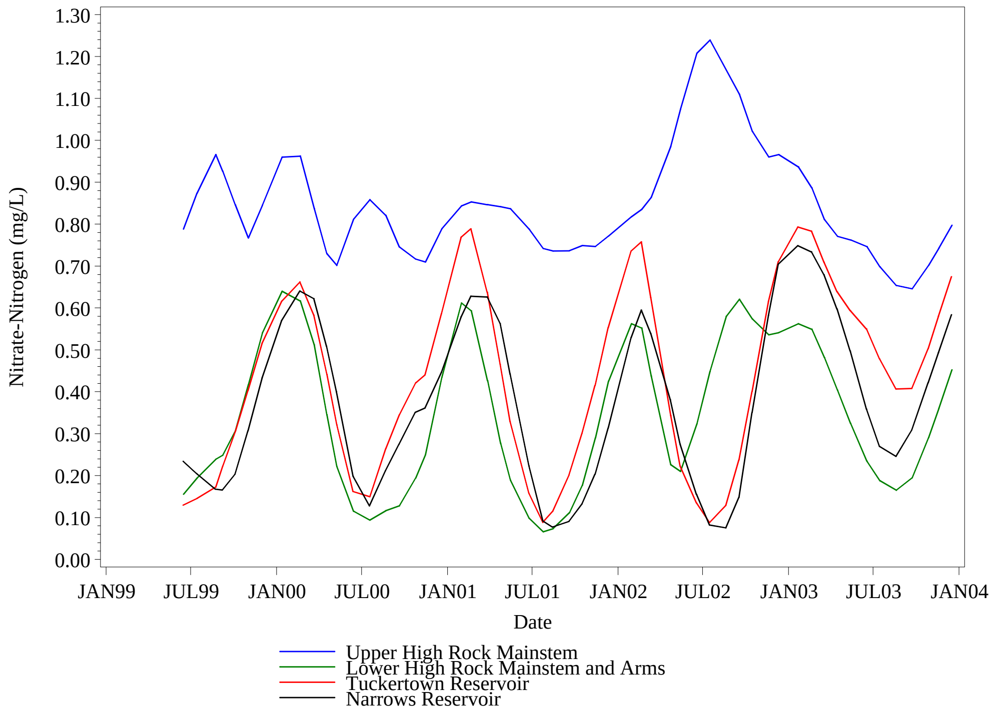


Figure 2.3-12. Locally weighted estimates (LOWESS) of Nitrate-nitrogen concentrations (mg/l) in the upper mainstem of High Rock, the lower mainstem and arms of High Rock, Tuckertown and Narrows Reservoirs from June 1999 to December 2003.

Turbidity and total suspended solids are greater in the bottom waters of High Rock and Tuckertown Reservoirs (Figures 2.3-13 and 2.3-14). By the time waters reach Narrows and Falls Reservoirs, concentrations are near the detection limit and differences between surface and bottom cease to exist. Seasonally, differences between the surface and bottom are greatest in summer in High Rock Reservoir where average bottom concentrations of suspended solids are almost four times greater than the surface concentrations in summer. This can be attributed to lower summer flows which increase retention time in High Rock Reservoir and allows more time for solids to settle. Bottom turbidity and total suspended solids in Tuckertown Reservoir are consistently greater than the surface, but the magnitude is rather small. Since most phosphorus appears to be particulate in origin (Section 2.3.6), it is not surprising that total phosphorus concentrations in the bottom collections (Figure 2.3-15) reflect changes in total suspended solids.

Ammonia concentrations are greater in the summer in all reservoirs except for Falls, where surface and bottom concentrations are similar (Figure 2.3-16). Peak levels occur in July in High Rock and Tuckertown reservoirs. In Narrows Reservoir, concentrations in July are similar to High Rock and Tuckertown, but concentrations increase, rather than decrease, to very high levels in August. Ammonia concentrations are related to anoxic conditions in the bottom waters of the reservoirs. Ammonia is oxidized in the presence of dissolved oxygen and is produced by anaerobic micro-organisms.

Nitrate-nitrogen concentrations were usually slightly greater in the bottom waters, but the differences were small in High Rock, Tuckertown and Narrows Reservoirs. Large differences between surface and bottom concentrations of nitrate were only observed in Narrows Reservoir (Figure 2.3-17).

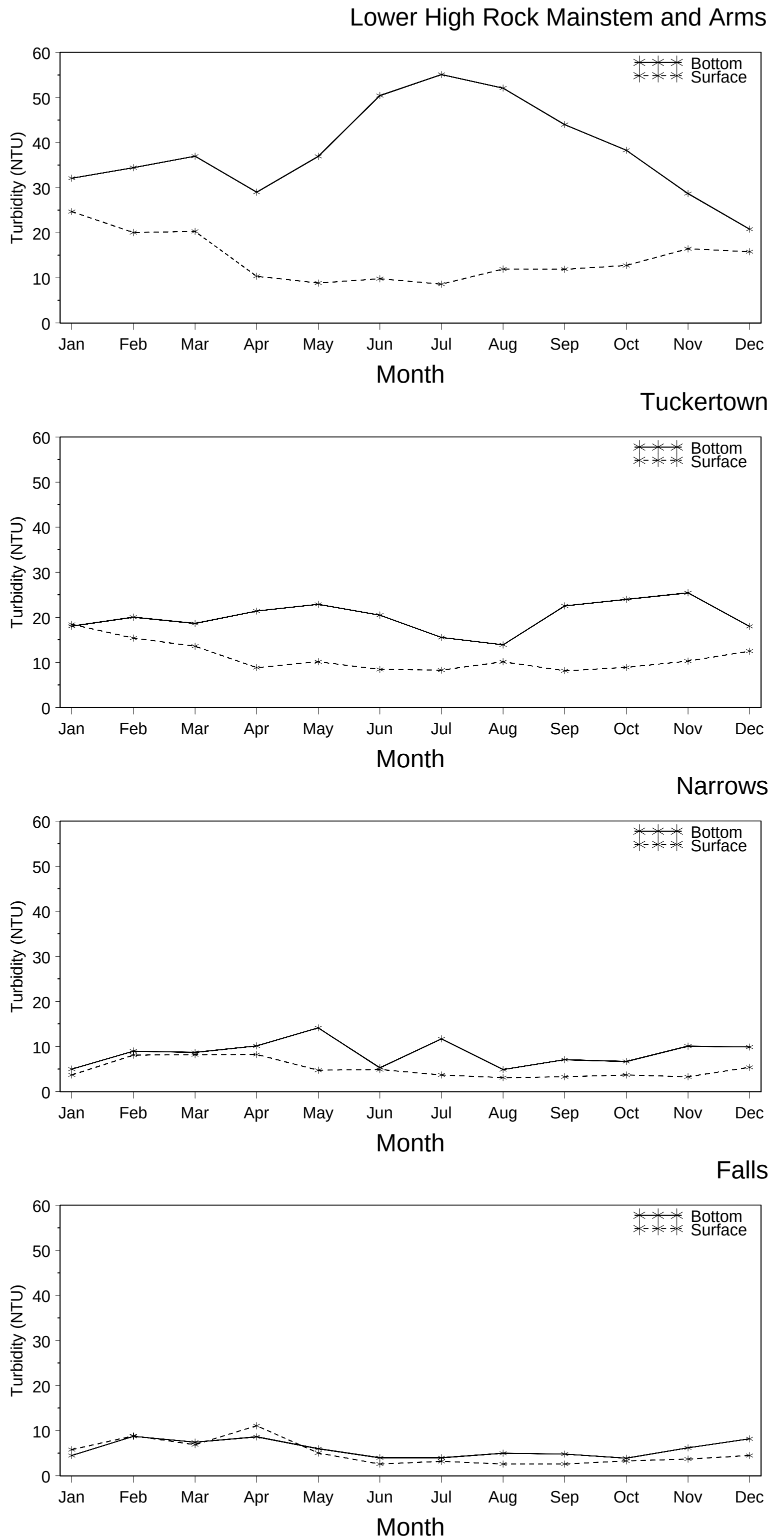


Figure 2.3-13. Monthly surface and bottom median turbidity (NTU) in the lower mainstem and arms of High Rock, Tuckertown, Narrows and Falls Reservoirs. Data are from 1999 through 2003.

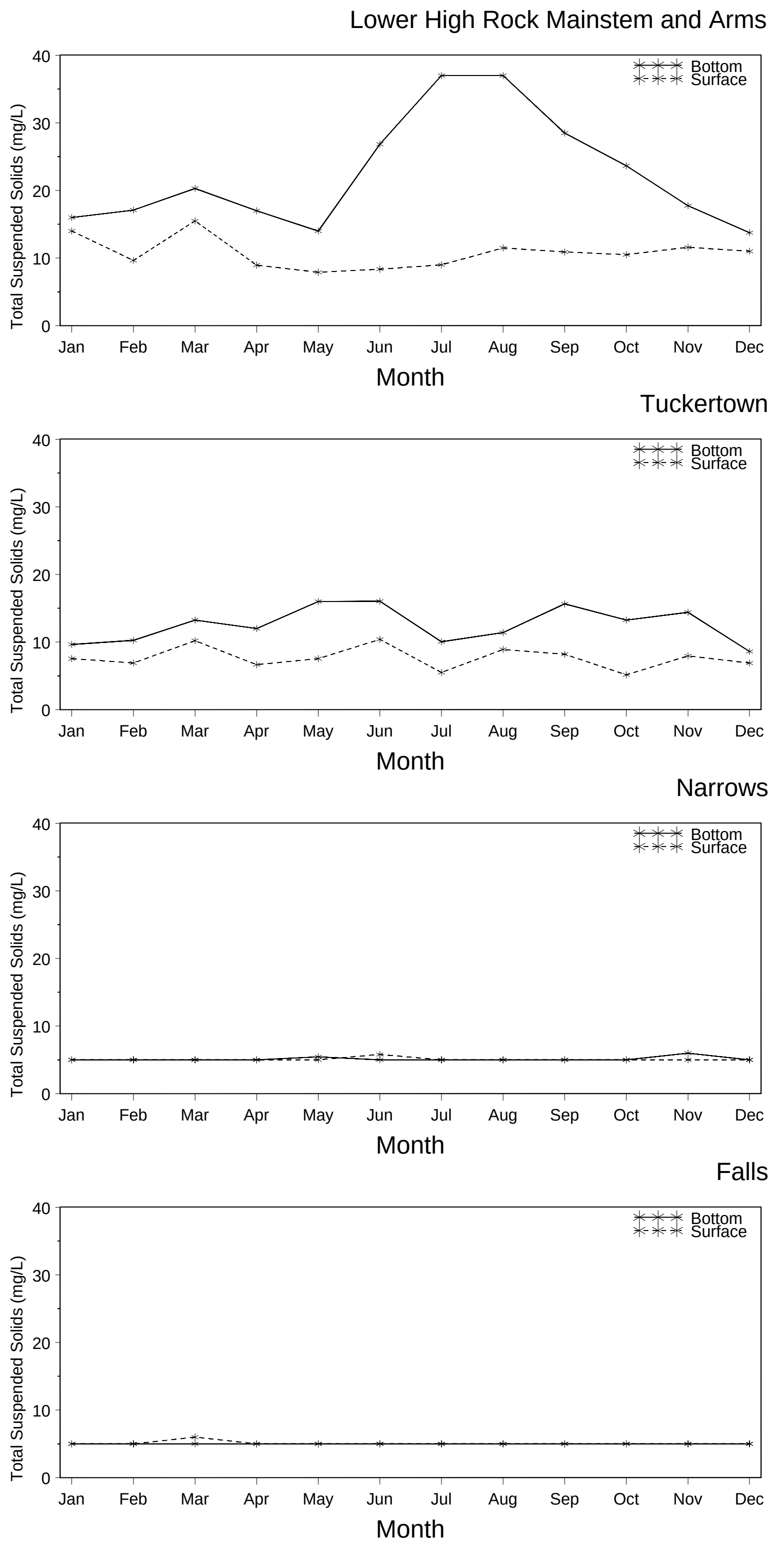


Figure 2.3-14. Monthly surface and bottom median Total Suspended Solids (mg/l) in the lower mainstem and arms of High Rock, Tuckertown, Narrows and Falls Reservoirs. Data are from 1999 through 2003.

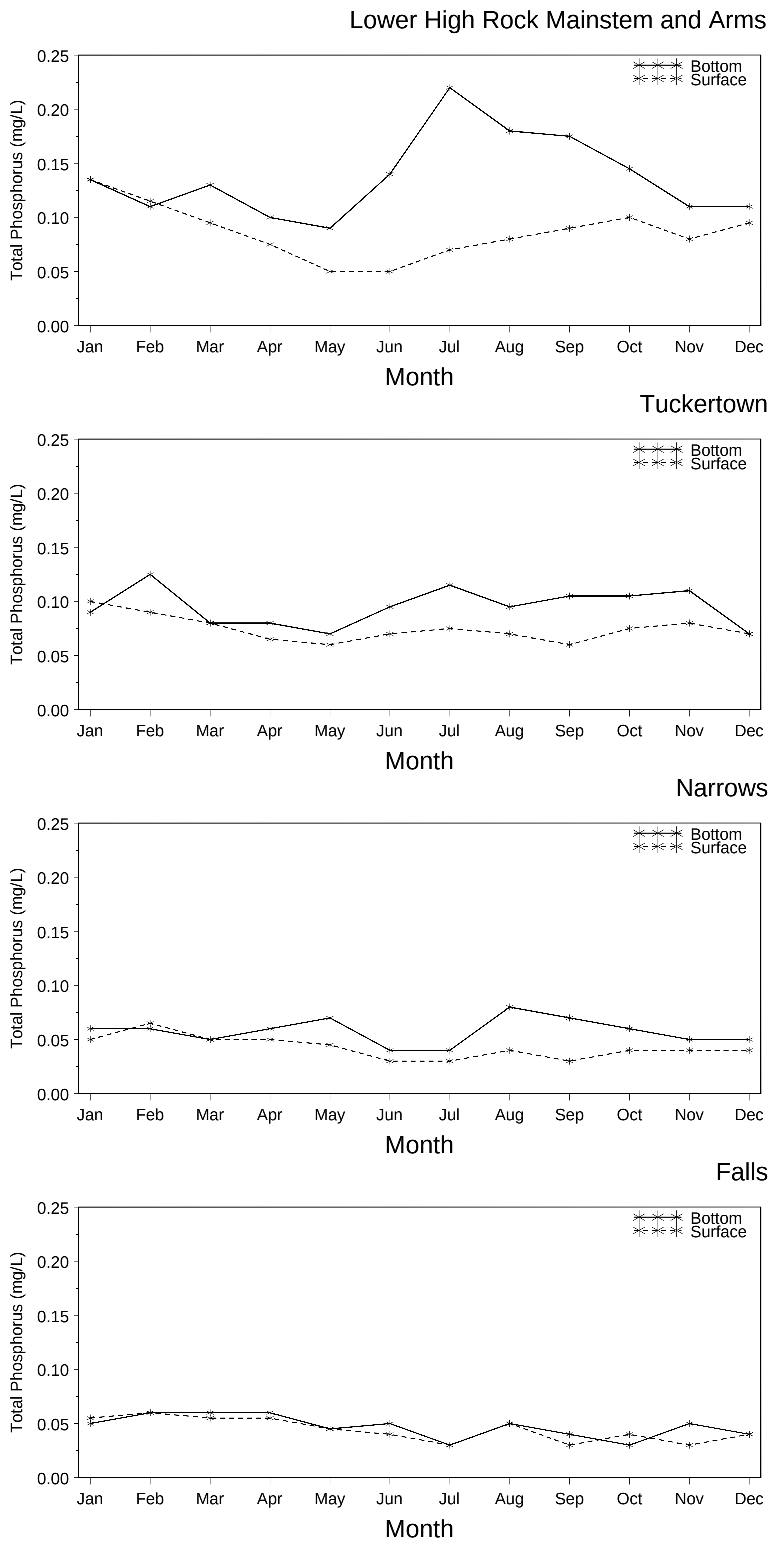


Figure 2.3-15. Monthly surface and bottom median Total Phosphorus (mg/l) in the lower mainstem and arms of High Rock, Tuckertown, Narrows and Falls Reservoirs. Data are from 1999 through 2003.

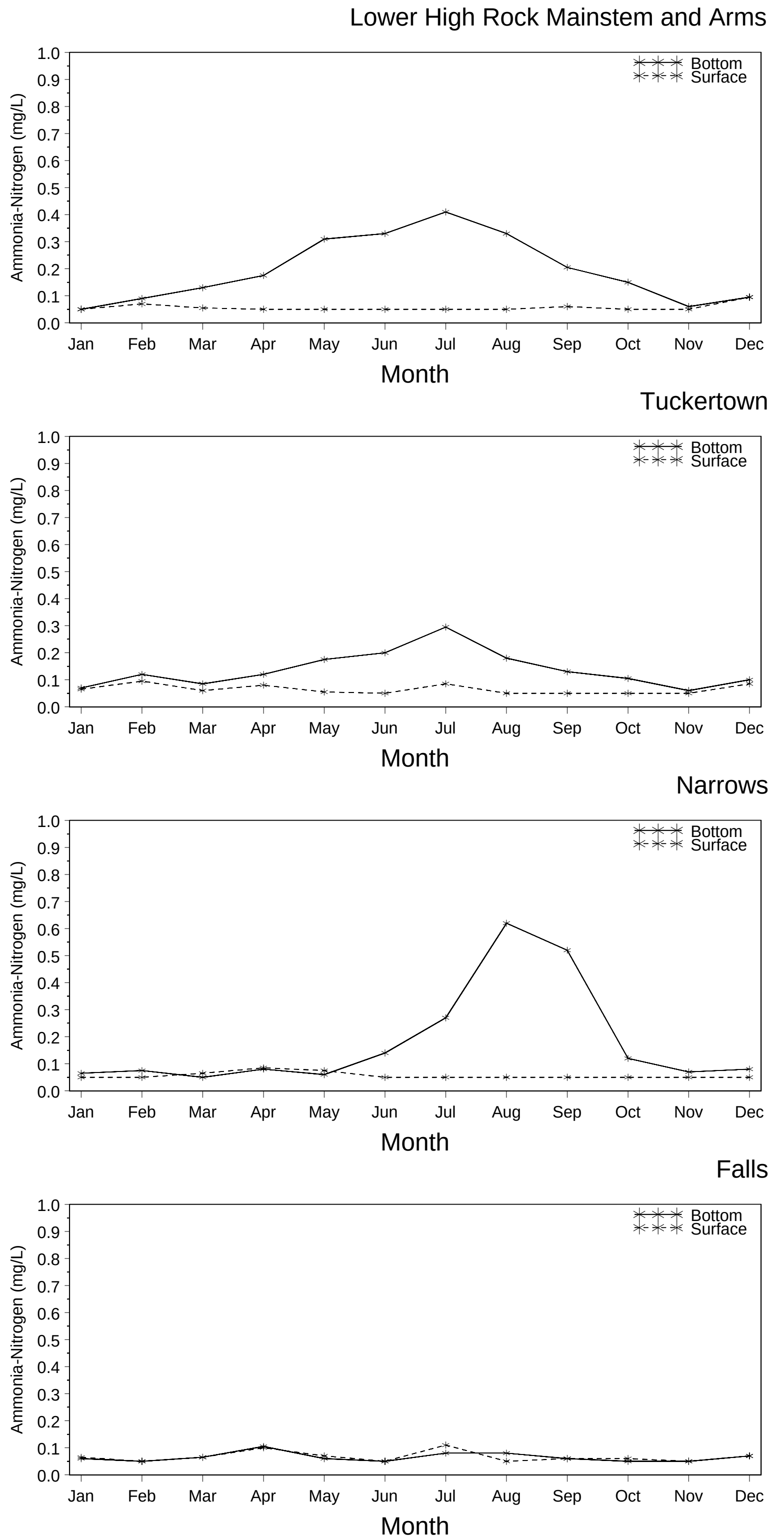


Figure 2.3-16. Monthly surface and bottom median Ammonia-nitrogen (mg/l) in the lower mainstem and arms of High Rock, Tuckertown, Narrows and Falls Reservoirs. Data are from 1999 through 2003.

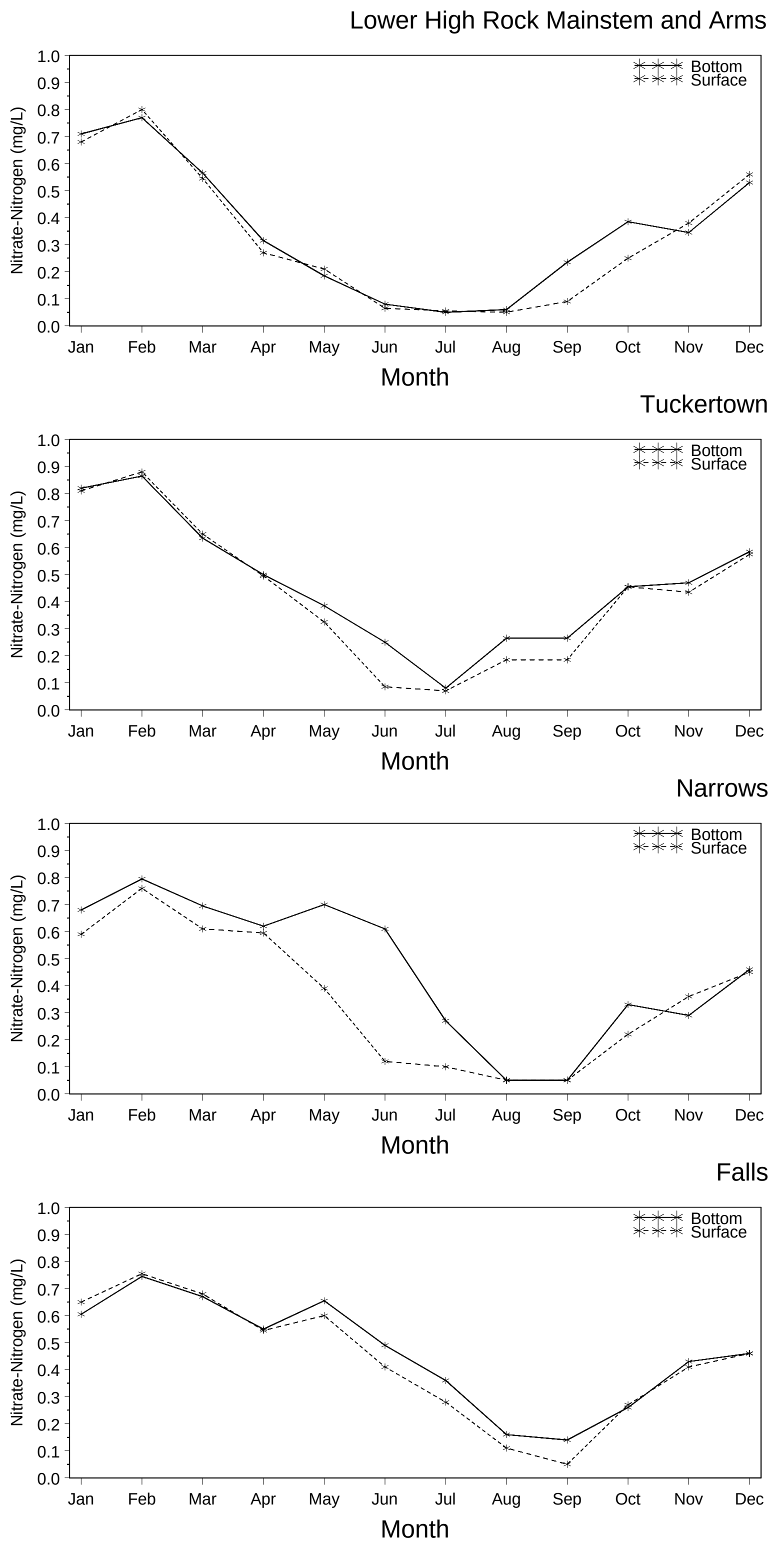


Figure 2.3-17. Median monthly Nitrate-Nitrogen concentrations (mg/l) in surface and bottom collections from the lower mainstem and arms of High Rock and from Tuckertown, Narrows and Falls Reservoirs. Data are from 1999 through 2003.

Differences between surface and bottom occur from May to July coinciding with the development of the thermocline and the isolation of hypolimnetic waters in Narrows Reservoir. Nitrate levels in the hypolimnion remain at about the concentration of nitrate at the initiation of stratification until June. The large decrease in nitrate concentration in July and August coincides with an increase of ammonia that is equal in magnitude. Nitrate concentrations in Falls Reservoir, both surface and bottom, generally follow the seasonal trend seen in the bottom waters of Narrows Reservoir.

Mercury concentrations are often greater under anoxic conditions. Detectable levels of mercury were frequently observed in the hypolimnion of Narrows Reservoir (Section 2.3.5) although mercury was not detected in fish (Section 3.6).

Total dissolved solids and biological oxygen demand concentrations are similar in the surface and bottom collections. Total Kjeldahl nitrogen and total organic carbon are also similar in surface and bottom collections in all reservoirs except for Narrows where small seasonal differences occur (Appendix F).

Differences between the surface and bottom were negligible in the upper mainstem stations of High Rock Reservoir where the depth is shallow and flow is occasionally seen (Appendix D contains dissolved oxygen profiles of the High Rock stations). Stations in the lower mainstem and arms of High Rock Reservoir and the other reservoirs are prone to oxygen depletion below the photic zone and weak thermal stratification in the summer (Sections 2.3.1 through 2.3.4).

2.4 WATER QUALITY OF THE TAILRACES

2.4.1 Monthly Water Quality Monitoring

A downstream trend in median water quality values is apparent through the tailraces. This is mostly due to changes in water quality between Tuckertown and Narrows tailraces (Table 2.4-1). Water quality of High Rock and Tuckertown tailraces is fairly similar. These two tailraces are turbid, nutrient rich and contain moderate amounts of algal biomass. Between Tuckertown and Narrows tailraces there is a moderate reduction of ammonia, chlorophyll *a*, nutrients and solids. Water clarity improves somewhat in the downstream tailraces. The water quality of Narrows and Falls tailraces is almost identical. All four tailraces experience low dissolved oxygen concentrations, although median concentrations are above the state standards. Dissolved oxygen in the tailraces is discussed in much greater detail in Section 2.4.2. Despite the downstream trend, overall water quality does not differ much among the four tailraces, percentiles tend to overlap for most of the parameters.

Water clarity, turbidity and the concentrations of solids and total nutrients in each tailrace are generally similar to the surface water near the dam in the preceding reservoir. Tailraces differ from reservoir stations in temperature, pH, dissolved oxygen, algal biomass, nitrate and ammonia (Section 2.2), which are parameters that exhibit differences between surface and bottom waters. The mixing of water entrained over the wide depth range of the dam intakes alters the water quality of the effluent. As differences between surface and bottom water occur seasonally, the effects of dam passage should also vary seasonally.

Tailrace temperatures have a seasonal cycle that is similar to the cycle seen in the reservoirs (Figure 2.4-1). Temperatures were almost identical in the tailraces in 1999, 2000 and 2003. In the two years with the lowest flow, 2001 and 2002, summer temperatures were slightly cooler in the Narrows and Falls tailraces compared to High Rock and Tuckertown and the other years.

Table 2.4-1. Summary of monthly water quality monitoring data in tailraces (1999-2003).

Parameter	Station											
	High Rock Tailrace			Tuckertown Tailrace			Narrows Tailrace			Falls Tailrace		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
Temperature (deg C)	5.69	18.19	27.87	5.72	18.64	27.92	5.98	17.95	26.48	5.93	18.03	26.49
Dissolved Oxygen (mg/L)	2.66	7.83	11.43	1.03	6.54	11.39	3.64	7.84	11.13	4.47	7.72	11.43
pH (SU)	6.14	7.04	7.55	6.27	7.02	7.45	6.30	6.86	7.23	6.08	6.70	6.99
Conductivity (Fmhos/cm)	54	116	157	53	114	154	55	110	132	54	108	133
Alkalinity (mg/l)	16	27	37	16	27	38	13	26	35	12	24	33
Biological Oxygen Demand (mg/L)	<2	2	6	<2	<2	5	<2	<2	4	<2	<2	3
Chemical Oxygen Demand (mg/L)	<20	<20	23	<20	<20	21	<20	<20	22	<20	<20	<20
Chlorophyll *a* (Fg/L)	3.6	14.0	33.6	4.4	9.2	20.0	2.0	4.8	10.0	2.0	4.0	9.6
Total Organic Carbon (mg/L)	2.4	3.7	6.3	2.6	3.6	6.7	2.6	3.4	5.2	2.7	3.4	5.1
Total Phosphorus (mg/L)	0.04	0.08	0.20	0.03	0.07	0.12	<0.02	0.04	0.15	<0.02	0.04	0.17
Total Nitrogen (mg/L)	<0.5	1.15	1.66	<0.5	0.94	1.65	<0.5	0.75	1.48	<0.5	0.73	1.50
Ammonia-Nitrogen (mg/L)	<0.05	0.12	0.35	<0.05	0.12	0.29	<0.05	0.06	0.15	<0.05	0.06	0.12
Nitrate-Nitrogen (mg/L)	0.07	0.46	0.88	0.09	0.47	0.87	0.05	0.45	0.76	0.09	0.50	0.74
Nitrite-Nitrogen (mg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Kjeldahl Nitrogen (mg/L)	<0.5	0.67	1.11	<0.5	0.63	1.01	<0.5	0.54	0.82	<0.5	0.52	0.81
Turbidity (mg/L)	9	17	43	6	12	39	2	4	19	2	4	18
Secchi Depth (m)	0.43	0.65	1.00	0.38	0.80	1.03	0.67	1.68	2.40	0.62	1.00	1.37
Total Solids (mg/L)	58	92	122	48	88	142	54	76	114	52	74	120
Total Dissolved Solids (mg/L)	48	82	111	30	78	118	46	73	104	48	72	106
Total Suspended Solids (mg/L)	<5	10	17	<5	7	14	<3	<5	8	<3	<5	6
Cadmium (Fg/L)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Copper (Fg/L)	<10	<10	<10	<10	<10	12	<10	<10	<10	<10	<10	<10
Cyanide (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead (Fg/L)	<2	<2	3.3	<2	<2	3.2	<2	<2	3.2	<2	<2	2.8
Mercury (Fg/L)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

The effects of dam operation on dissolved oxygen are covered in detail in Sections 3.3 and 3.4 of this report. Seasonally dissolved oxygen concentrations average about 3 to 5mg/l in the summer in the tailraces, especially High Rock and Tuckertown (Figure 2.4-2). Average dissolved oxygen concentrations were particularly low in Tuckertown tailrace during the extreme low flow year of 2002. Average dissolved oxygen concentrations in daytime collections from the Narrows and Falls tailraces were generally greater than 5 mg/l from 2001 to 2003 which includes the two lowest flow years and the highest flow year. The high flow year, 2003, improved dissolved oxygen concentrations in all the tailraces.

Median chlorophyll *a* concentrations in the tailraces are lower than the preceding reservoir (Table 2.4-1, Figure 2.2-3). Although chlorophyll *a* is not measured from bottom samples, concentrations are assumed to be low because of the lack of solar radiation below the photic zone. In contrast to High Rock and Tuckertown reservoirs, where surface chlorophyll *a* concentrations have a seasonal cycle with a summer peak, tailrace chlorophyll *a* concentrations are relatively constant and generally do not display seasonality (Figure 2.4-3). Chlorophyll *a* concentrations reached nuisance levels (>30 Fg/l) in the High Rock tailrace during the summer of 2002, the extremely low flow year when flow through High Rock and Tuckertown dams was minimal allowing for long retention time and the development of large algal standing crops. Chlorophyll *a* concentrations in the Narrows and Falls tailraces were almost identical.

Median nitrate-nitrogen concentrations are slightly greater in the tailraces than in the surface waters of the preceding reservoir (Tables 2.3-1, 2.3-3 and 2.4-1). Seasonally, a slight lag in nitrate concentrations occurs in Narrows and Falls tailraces when compared to High Rock and Tuckertown (Figure 2.4-4).

Ammonia-nitrogen concentrations are greatest during the summer in the High Rock and Tuckertown tailraces and have a strong seasonality (Figure 2.4-5). Ammonia concentrations in the High Rock and Tuckertown tailraces are similar to concentrations that occur in the bottom water of the preceding reservoir (Figure 2.3-16). In the Narrows and Falls tailraces, ammonia concentrations vary over a much narrower range and lack a seasonal pattern. Despite, very high ammonia concentrations in the hypolimnion near Narrows dam in late summer and early fall, ammonia concentrations in the tailrace remain low. The hypolimnion in Narrows Reservoir develops below the level of the intakes.

2.4.2 Continuous Dissolved Oxygen and Temperature Monitoring in Tailraces

Monitoring Program

Temperature and dissolved oxygen were continuously monitored during the late spring through fall below Narrows and Falls dams from 2000 through 2004 and below Tuckertown and High Rock dams in 2003 and 2004. More limited monitoring occurred below High Rock and Tuckertown prior to 2003 (two 3-day periods). These data were consistent with observations made during the more extensive monitoring effort conducted in 2003 and 2004 in terms of concentrations observed and daily fluctuations in concentrations. These data were discussed in detail in Normandeau (2002).

Tailrace monitoring dates are presented in Table 2.4-2. A summary of meter performance and data quality is presented in Appendix G. Meters were out of service for a total of 73 days out of a cumulative total of nearly 3000 days of deployment. Thirty-seven of the out of service days were attributed to high flow or low water level conditions. The locations of the monitors are provided in Figures 2.4-6 through 2.4-9. The meters were set to record dissolved oxygen concentrations and

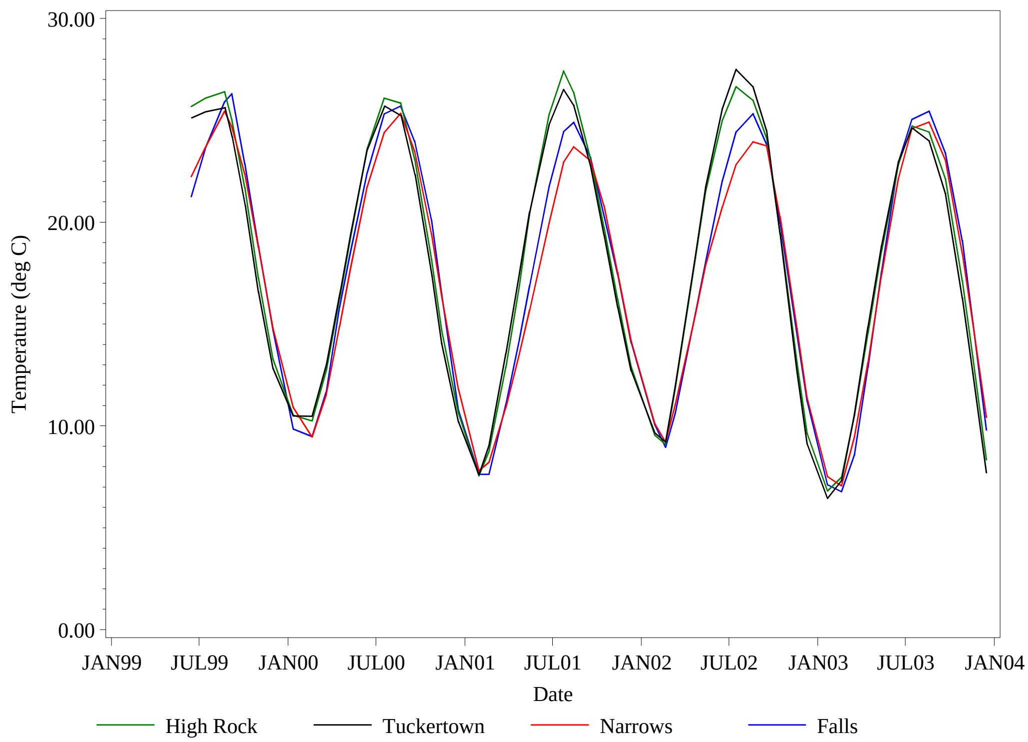


Figure 2.4-1. Locally weighted estimates (LOWESS) of Temperature ºC in High Rock, Tuckertown, Narrows and Falls tailraces from June 1999 to December 2003.

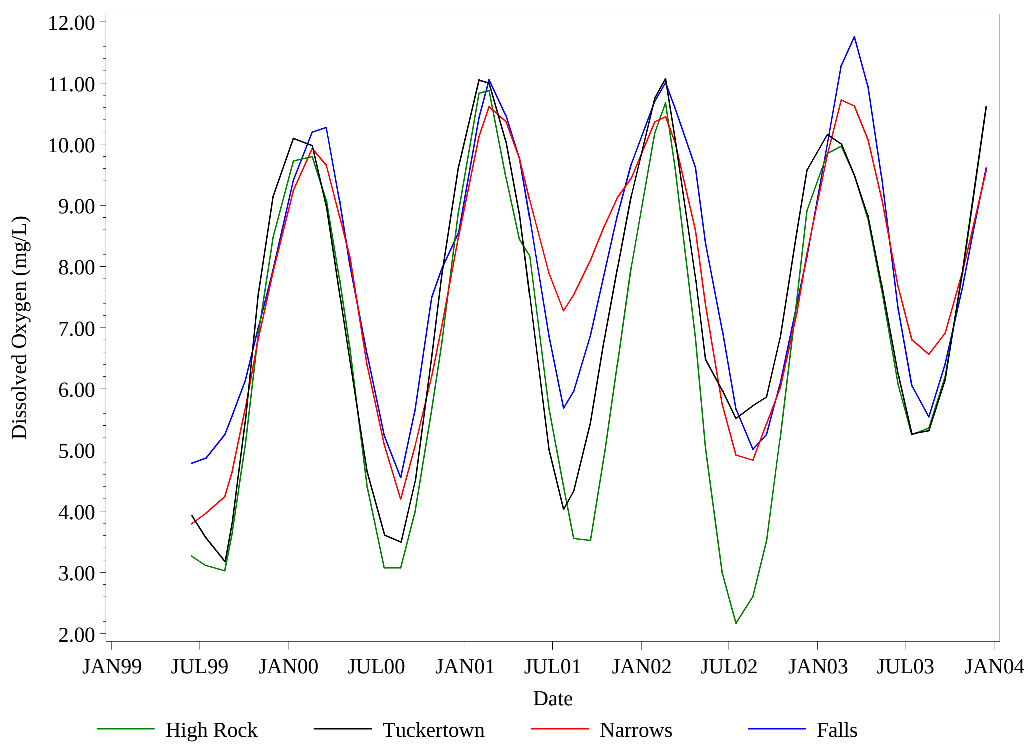


Figure 2.4-2. Locally weighted estimates (LOWESS) of Dissolved Oxygen (mg/l) in High Rock, Tuckertown, Narrows and Falls tailraces from June 1999 to December 2003.

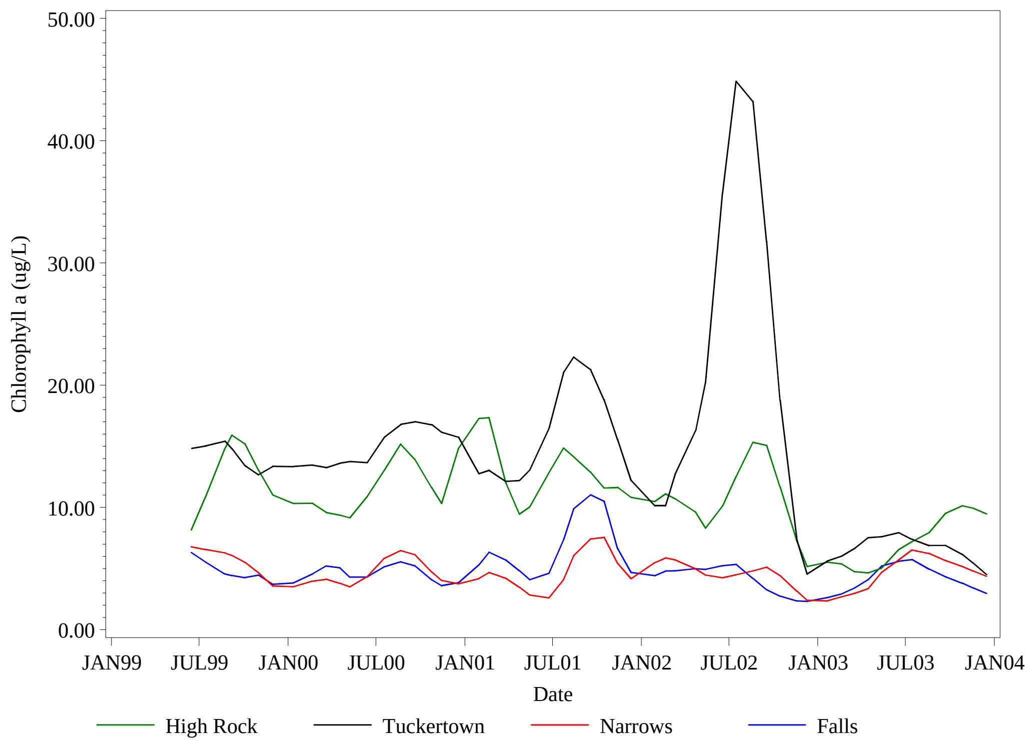


Figure 2.4-3. Locally weighted estimates (LOWESS) of Chlorophyll *a* (µg/l) in High Rock, Tuckertown, Narrows and Falls tailraces from June 1999 to December 2003.

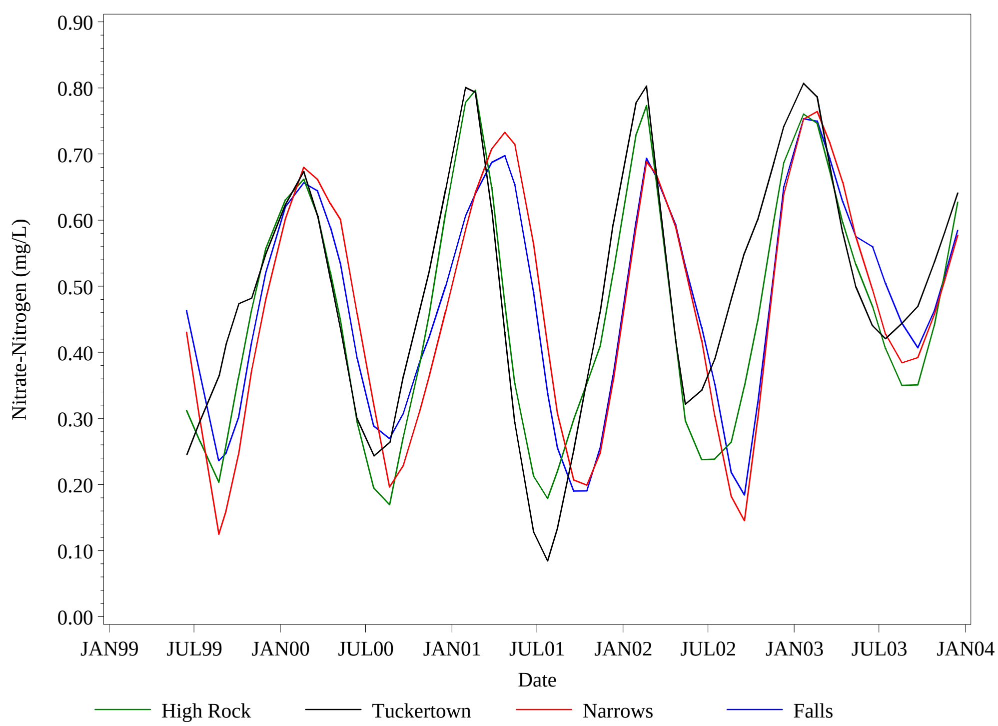


Figure 2.4-4. Locally weighted estimates (LOWESS) of Nitrate-Nitrogen (mg/l) in High Rock, Tuckertown, Narrows and Falls tailraces from June 1999 to December 2003.

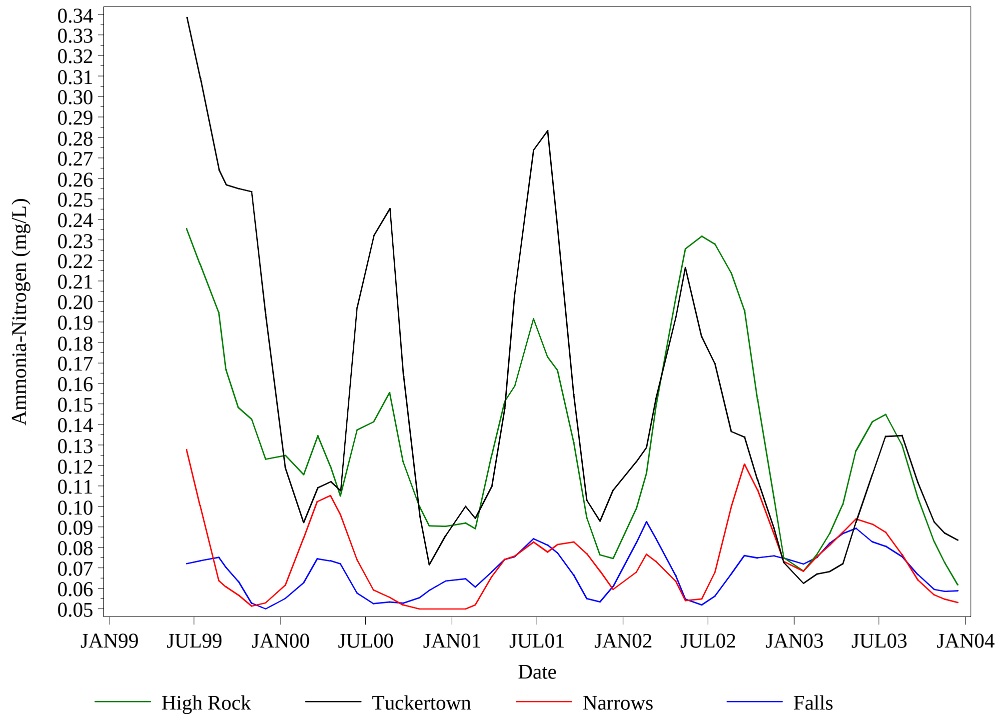


Figure 2.4-5. Locally weighted estimates (LOWESS) of Ammonia-Nitrogen (mg/l) in High Rock, Tuckertown, Narrows and Falls tailraces from June 1999 to December 2003.

Table 2.4-2. Dates of continuous tailrace monitoring in four Yadkin Project tailraces, 2000–2004.

Years	High Rock	Tuckertown	Narrows	Falls
2000			Aug 3-Dec 31	Aug 3-Dec 31
2001			Jan 1-Feb 21	Jan 1-Jan 18
			Apr 26-Dec 4	Apr 26-Dec 4
2002			Apr 27-Dec 9	Apr 27-Dec 9
2003	Apr 24-Dec 17	Apr 24-Nov 20	Apr 24-Dec 1	Apr 24-Dec 18
2004	Apr 22-Dec 2	Jul 1-Dec 2	Apr 22-Dec 2	Apr 22-Dec 2

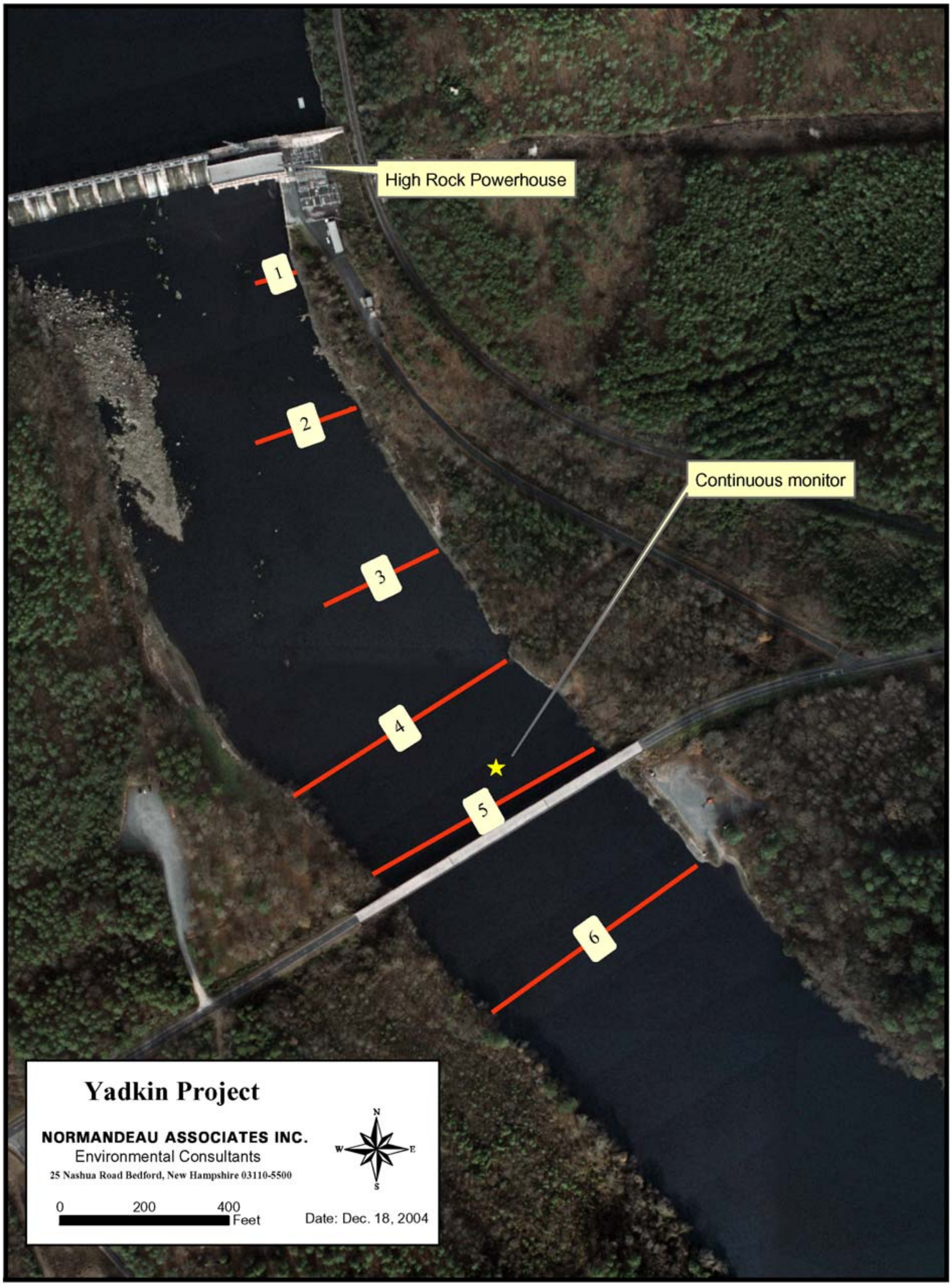


Figure 2.4-6. Transect locations in High Rock tailrace to confirm monitor placement.

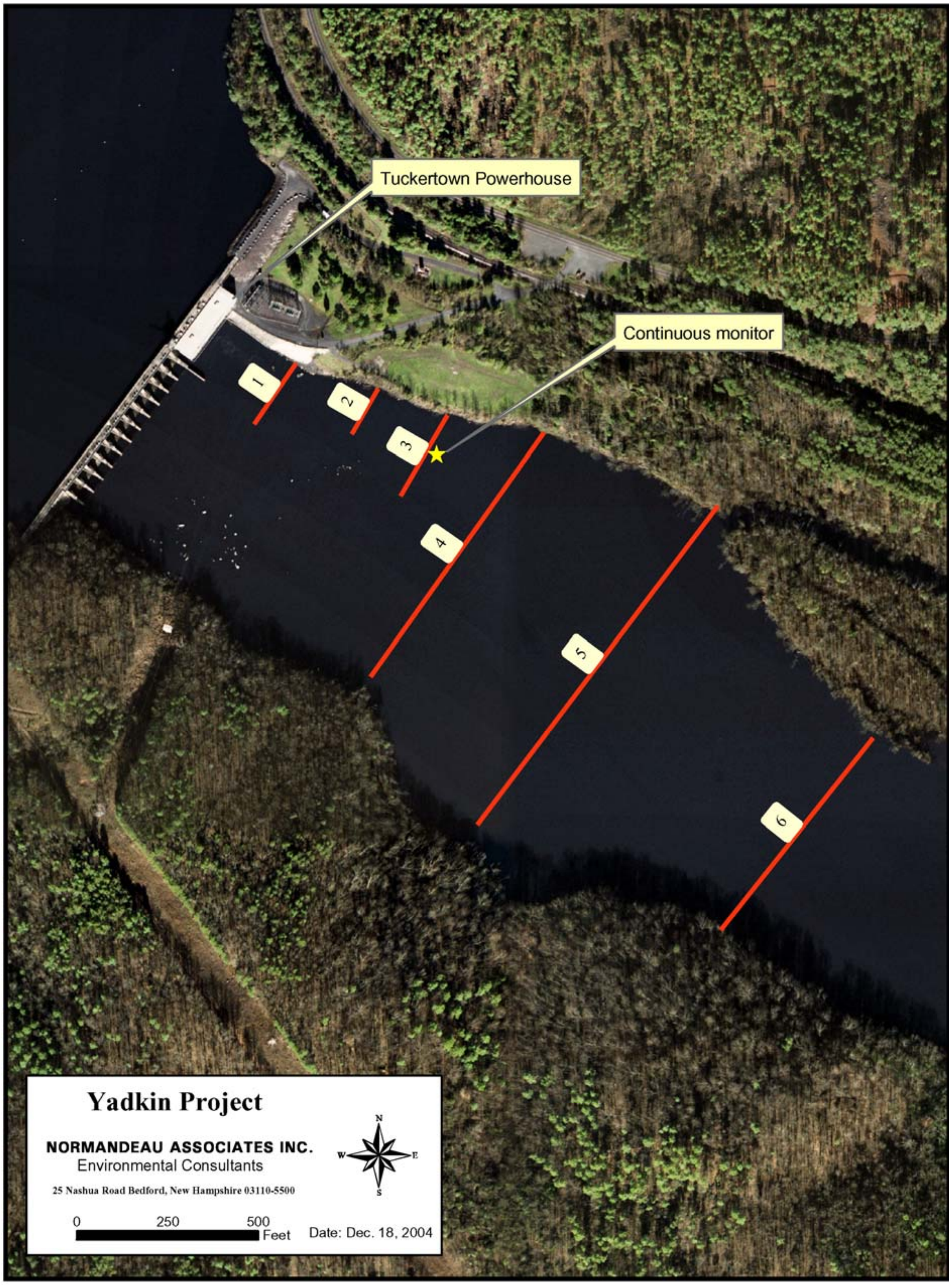


Figure 2.4-7. Transect locations in Tuckertown tailrace to confirm monitor placement.

Figure 2.4-8. Transect locations in Narrows tailrace to confirm monitor placement.

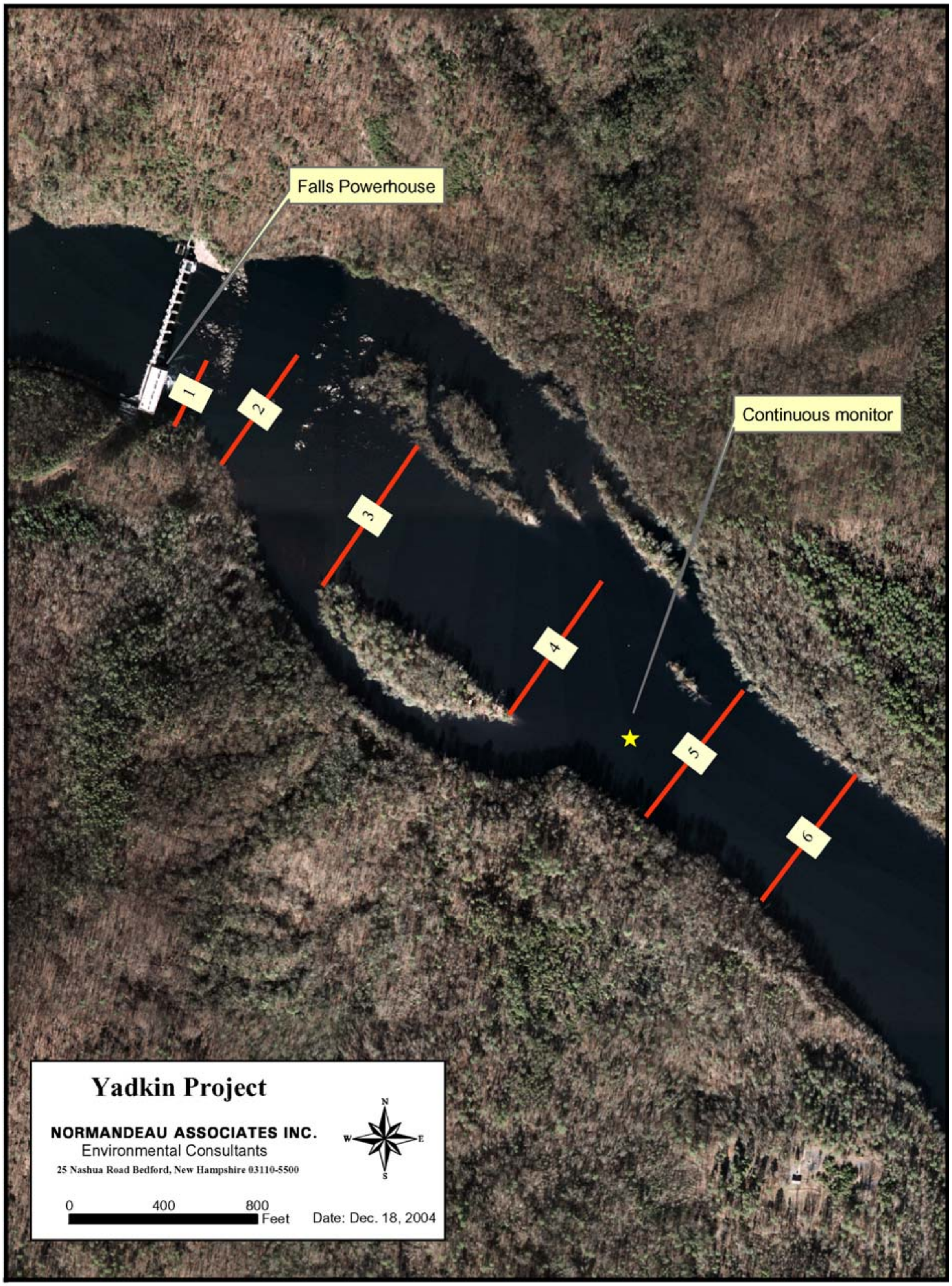


Figure 2.4-9. Transect locations in Falls tailrace to confirm monitor placement.

temperature every 15 minutes. The meters were serviced once every week during the period of deployment. During servicing one or two observations in the time series were deleted corresponding to the time that the meter was out of the water.

Tailrace Mixing

The mixing characteristics of tailrace waters below the Narrows and Falls Dams were evaluated monthly from August through November, 2001. The purpose of this effort was to insure that the placement of the continuous dissolved oxygen and temperature monitors was representative. The transect locations are presented in Figures 2.4-8 and 2.4-9. During each survey dissolved oxygen and temperature profiles were recorded every 50 feet along each transect. Results of the transect surveys are presented in Appendix H.

Temperatures over all transects were within 1.5°C of each other during the August survey and within 1°C of each other on the other three sampling dates in the Narrows tailrace. Temperature changes were even smaller in the Falls tailrace on all dates except October 31, 2001. Water levels in the Falls tailrace on this date were extremely low due to the drawdown in the downstream impoundment on this date.

Dissolved oxygen concentrations generally varied by less than 1 mg/l on each sampling date with a few exceptions. Both Falls (1 sampling date) and Narrows (2 sampling dates) tailraces experienced greater variability at times. The lowest dissolved oxygen readings recorded on these dates were along the transects immediately adjacent to the dams. It is believed that water was stranded between the dam and the powerhouse discharges on these dates (transect 1 in both tailraces), and that water was not representative of the main tailwater flow. On these sampling dates, the distribution of dissolved oxygen concentrations among all other tailrace transects was much less variable.

The mixing characteristics of the tailrace waters below High Rock and Tuckertown dams was evaluated in 2003 in a similar manner as Narrows and Falls. Transect locations are presented in Figures 2.4-6 and 2.4-7. Results of these transect surveys are presented in Appendix H. As in the Narrows and Falls tailraces, the dissolved oxygen concentrations and temperatures observed in the High Rock and Tuckertown tailraces varied little during each of the seven tailrace surveys. At High Rock, dissolved oxygen concentrations varied by less than 1.5 mg/l and temperature by less than 1.25ºC during each of the surveys. The highest dissolved oxygen concentrations were typically close to the dam while the lowest were typically farthest from the dam. At Tuckertown, dissolved oxygen varied by less than 1 mg/l during five of the seven surveys and by slightly over 1 mg/l during the other two. Temperature varied by less than 1.25 ºC during each of the surveys.

The evaluation of tailrace mixing described above suggests that the continuous monitor placement in all four tailraces is appropriate and representative of tailrace water quality.

Monitoring Results

Continuous monitoring data for all five field seasons are presented in Figures 2.4-10 through 2.4-13. These figures present the minimum and maximum temperatures observed for each day and the minimum and average dissolved oxygen concentrations observed. These dissolved oxygen results can be directly compared with the North Carolina Water Quality Standard of 4 mg/l for instantaneous concentrations and 5 mg/l for a daily average. Raw data from the continuous monitoring program are

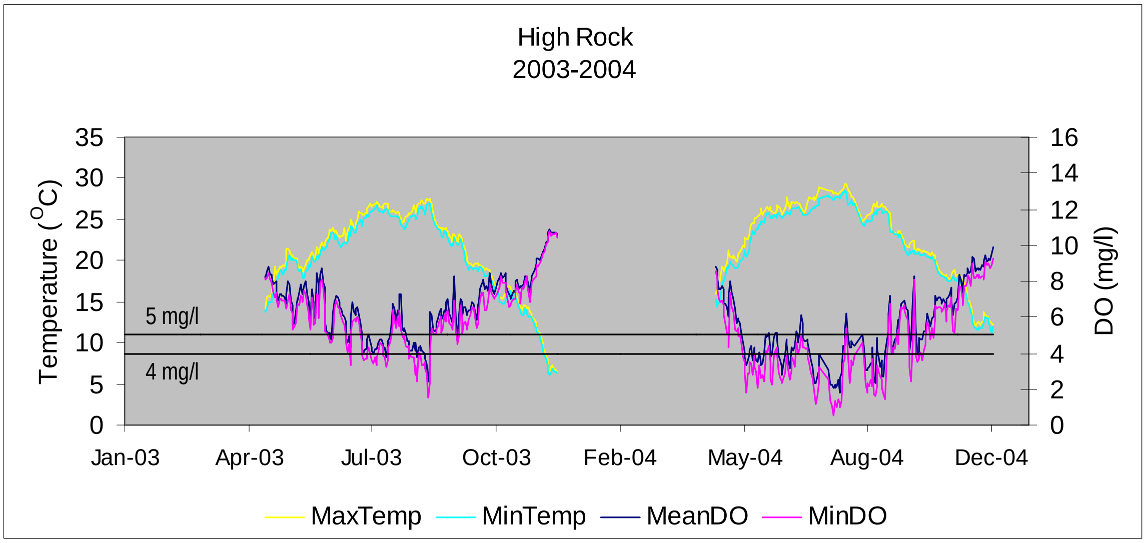


Figure 2.4-10. Continuous dissolved oxygen and temperature data at High Rock Tailrace 2003–2004.

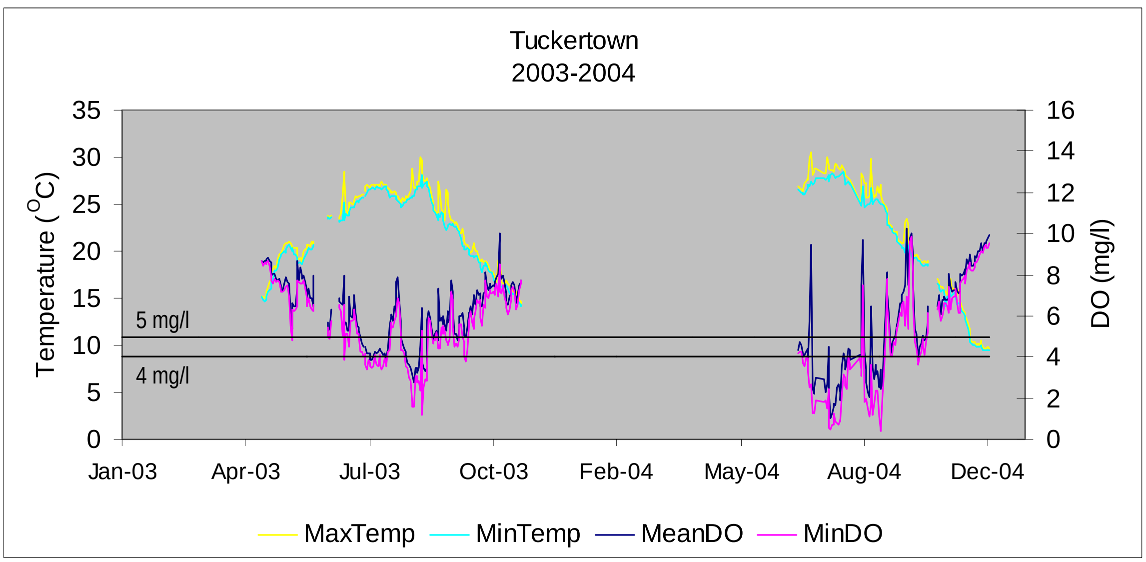
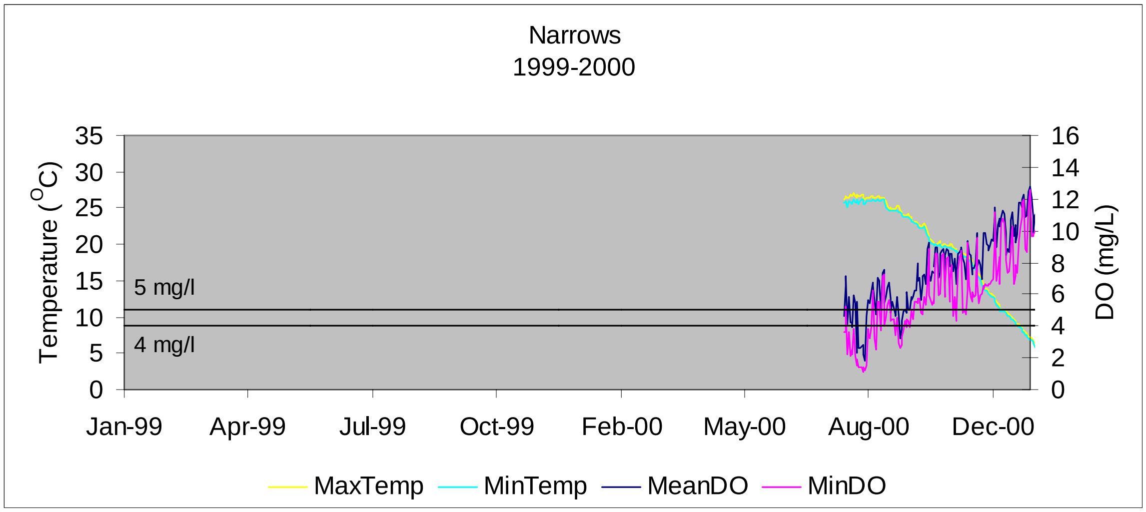
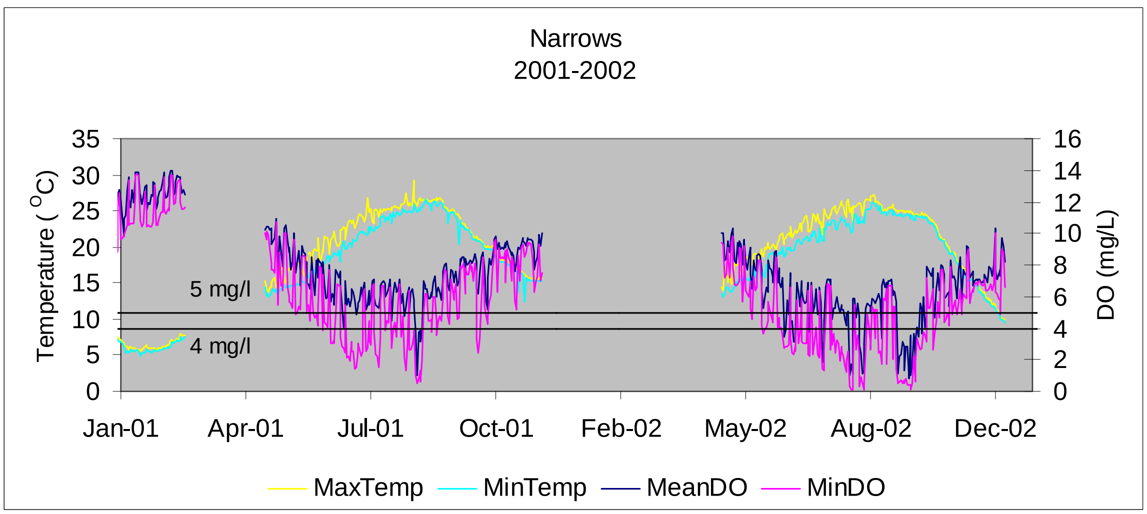


Figure 2.4-11. Continuous dissolved oxygen and temperature data at Tuckertown Tailrace 2003–2004.





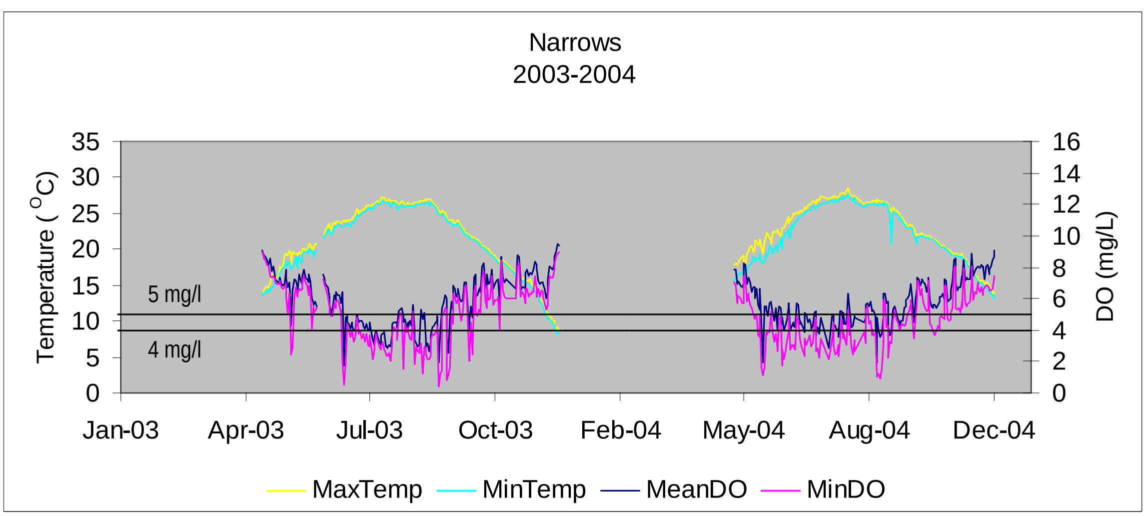
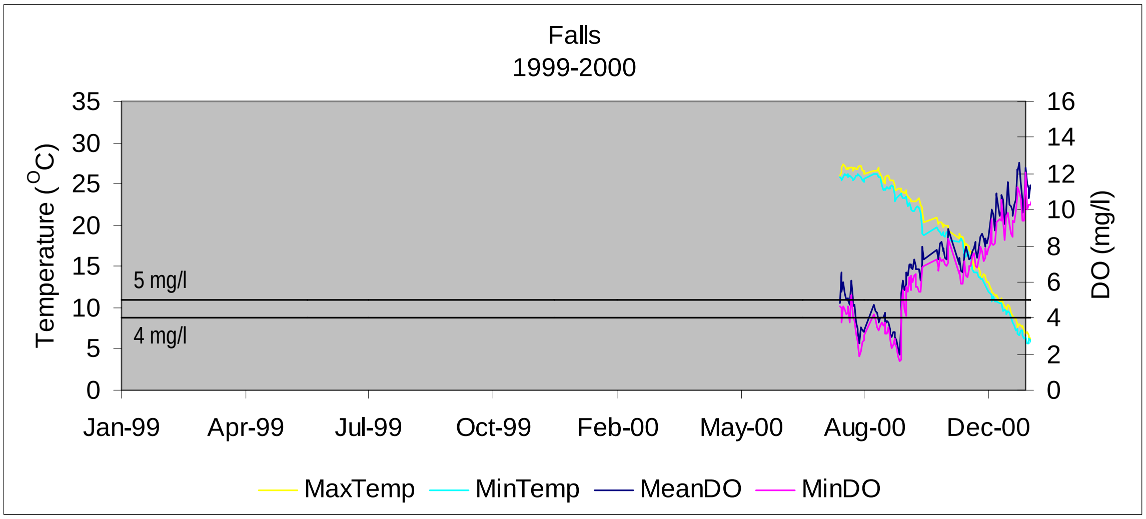
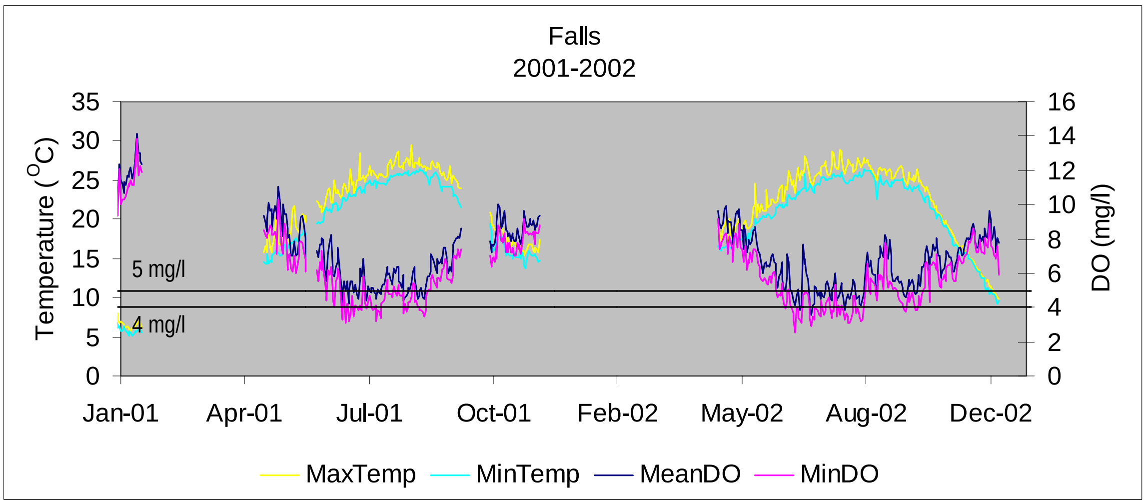


Figure 2.4-12. Continuous dissolved oxygen and temperature data at Narrows Tailrace 2003–2004.





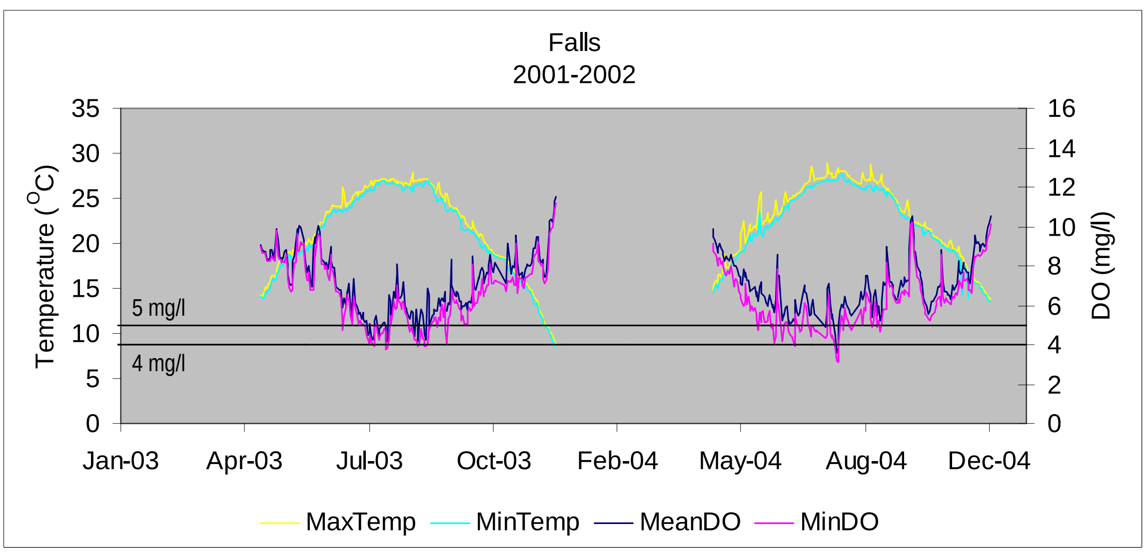


Figure 2.4-13. Continuous dissolved oxygen and temperature data at Falls Tailrace 2003–2004.

presented in Appendix I on the attached CD. These data provide information on the daily variation that occurs in the tailraces below the dams.

Metrics used to evaluate the dissolved oxygen concentration in the four tailraces are presented in Table 2.4-3. This table shows the number of days each year that the observed dissolved oxygen was less than 5 mg/l daily average or the minimum observed dissolved oxygen for the day was below 4 mg/l. 5 mg/l represents the North Carolina Standard for daily average dissolved oxygen concentration while 4 mg/l is the standard for instantaneous dissolved oxygen concentration.

Table 2.4-3. Number of monitored days each project tailrace was below specific dissolved oxygen concentrations.

		2000	2001	2002	2003	2004
High Rock	<5 mg/l[1]	NS[4]	NS	NS	49	107
	<4 mg/l[2]	NS	NS	NS	33	96
Tuckertown	<5 mg/l[1]	NS	NS	NS	48	62
	<4 mg/l[2]	NS	NS	NS	36	55
Narrows	<5 mg/l[1]	23	11	54	79	75
	<4 mg/l[2]	34	57	95	78	91
Falls	<5 mg/l[1]	35	35	48	19	4
	<4 mg/l[2]	32	35	46	9	5

[1] based on daily average concentration.
[2] based on at least one 15 minute reading below 4 mg/l per day.
[3] continous monitoring initiated 08/03/00.
[4] NS – not sampled.

High Rock

The typical pattern at High Rock shows adequate dissolved oxygen resources coupled with lower water temperatures in the spring and fall and depressed dissolved oxygen concentrations through the summer period (Figure 2.4-10). The onset of low dissolved oxygen concentrations in early July of 2003 (a wet year), was later than that observed in 2004 (mid-May), a year with more typical flows. Dissolved oxygen concentrations increased by early September in both years. Daily average temperatures in the High Rock tailrace peaked at approximately 27ºC in 2003 and 28ºC in 2004. Diurnal fluctuation in tailrace dissolved oxygen concentrations was determined to be approximately 3 mg/l during two low river flow, high water temperature surveys in 2001 (Normandeau 2002). These results are consistent with observations from the summers of 2003 and 2004 under similar conditions. Table 2.4-3 summarizes the number of days that individual readings were below 4 mg/l and daily averages were below 5 mg/l over the two field seasons. In 2003, an abnormally wet year, the number of days that dissolved oxygen was below these benchmarks was less than half those observed in 2004, an average year in precipitation and discharge.

Low dissolved oxygen in the High Rock tailrace is a direct reflection of low dissolved oxygen in the upstream impoundment. The low dissolved oxygen concentrations occur in response to the sinking of algal cells out of the photic zone and subsequent aerobic decay in the lower depths of the impoundment. When flows are high, water in the impoundment is exchanged more rapidly, reducing the time that decomposition of algal cells consumes oxygen in the deep layers and diluting poorly oxygenated water in the reservoir with oxygenated inflow water. This translates into relatively higher dissolved oxygen concentrations in the tailrace. In addition, during periods of high flow through the reservoir, floodgates are frequently opened and spill further aerates tailrace waters. The effect of generation on tailrace dissolved oxygen and temperature is discussed further in Sections 3.3 and 3.4.

The 2002 drought related drawdown of High Rock reservoir afforded an opportunity to examine the influence of water level on downstream dissolved oxygen resources. Although continuous tailrace dissolved oxygen data were not collected prior to 2003 in the High Rock tailrace, monthly measurements of dissolved oxygen are available. In a typical flow year, dissolved oxygen is depleted in High Rock reservoir throughout the entire depth of the intakes during the summer and early fall. Oxygenated water is found above the uppermost level of the intakes. This is illustrated in Figure 2.4-14. Water levels in 2001 were near the long term average level throughout the summer season (Figure 1.0-2). Water with low dissolved oxygen concentrations was drawn into the intakes resulting in low dissolved oxygen concentrations in the tailrace. In 2002, water levels in High Rock impoundment in mid-summer were five meters lower than in a typical year (Figure 2.4-15). Surface waters, oxygenated by a combination of surface mixing and photosynthesis, were found at the depth of the turbine intakes during the drawdown. In addition, the volume of water in the impoundment with lower dissolved oxygen concentrations was reduced relative to a typical year. As a result, observed tailrace dissolved oxygen concentrations were higher in 2002 than in a typical year and were generally greater than 5 mg/l.

Tuckertown

Dissolved oxygen concentrations in the Tuckertown tailrace showed a similar pattern to those observed in the High Rock tailrace (Figure 2.4-11). High concentrations observed in the spring and late fall were associated with high flows and low water temperatures and lower concentrations were observed in the summer and early fall. The close association of water quality between the two tailraces is likely a function of the short time of travel of water through Tuckertown Reservoir due to its small size and the coordination of operations between High Rock and Tuckertown dams. Maximum temperatures in the Tuckertown tailrace were 1-2ºC higher than those observed in the High Rock tailrace, peaking at approximately 29ºC in 2003 and 30ºC in 2004. As observed in High Rock tailrace, there were fewer days in 2003 than 2004 when dissolved oxygen concentrations at Tuckertown were less than 4 mg/l for a 15-minute reading or 5 mg/l for a daily average (Table 2.4-3). As in High Rock, this is attributed to high flows through the system during 2003, flushing waters with low dissolved oxygen from the Tuckertown impoundment as well as the frequency of spill events at the High Rock and Tuckertown dams during the summer of 2003. Data are presented in Appendix I.

Narrows

A time series of dissolved oxygen and temperature for the Narrows tailrace is presented in Figure 2.4-12 for the monitoring period of 2000 through 2004. Continuous monitoring data can be found in Appendix I. In Narrows Dam tailrace, summer daily change in dissolved oxygen was usually about 3 mg/l. Dissolved oxygen concentrations less than 4 mg/l were frequently observed from June through October, and periodically in May and November. Peak summer water temperatures were generally between 26 and 27 ºC and varied by only a few degrees each day. The number of days when dissolved oxygen concentrations at Narrows were less than 4 mg/l for one reading or 5 mg/l for a daily average are summarized in Table 2.4-3. Results from 2000 cannot be used for comparison as monitoring did not commence until August 3. During 2001 there were relatively few days (11) when

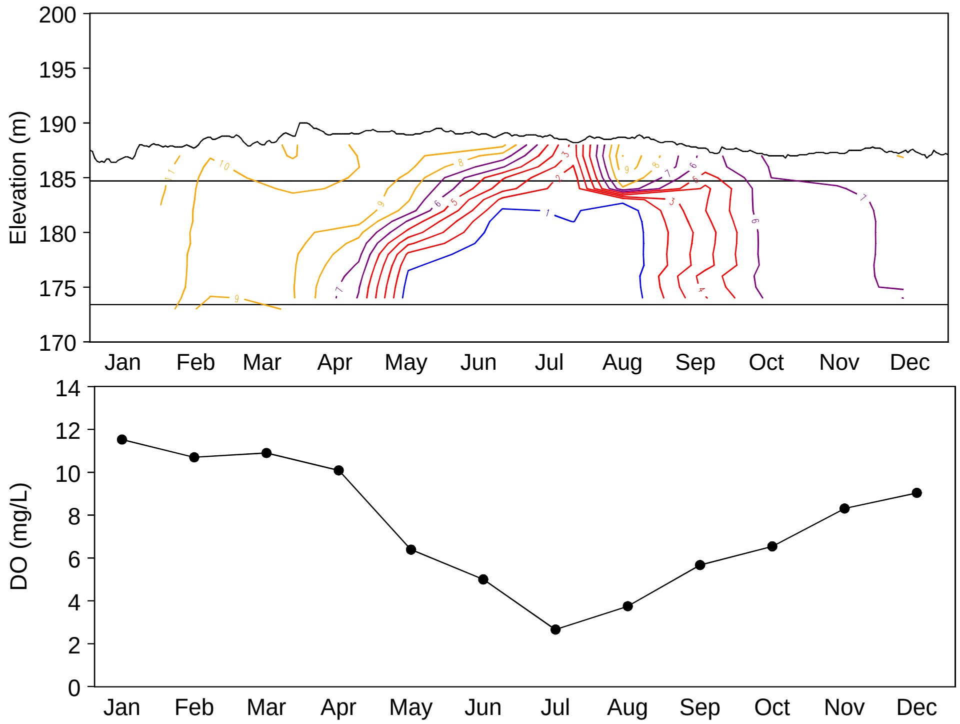


Figure 2.4-14. Dissolved oxygen (mg/l) in High Rock Reservoir and Tailrace 2001 (horizontal lines in top panel represent intake interval).

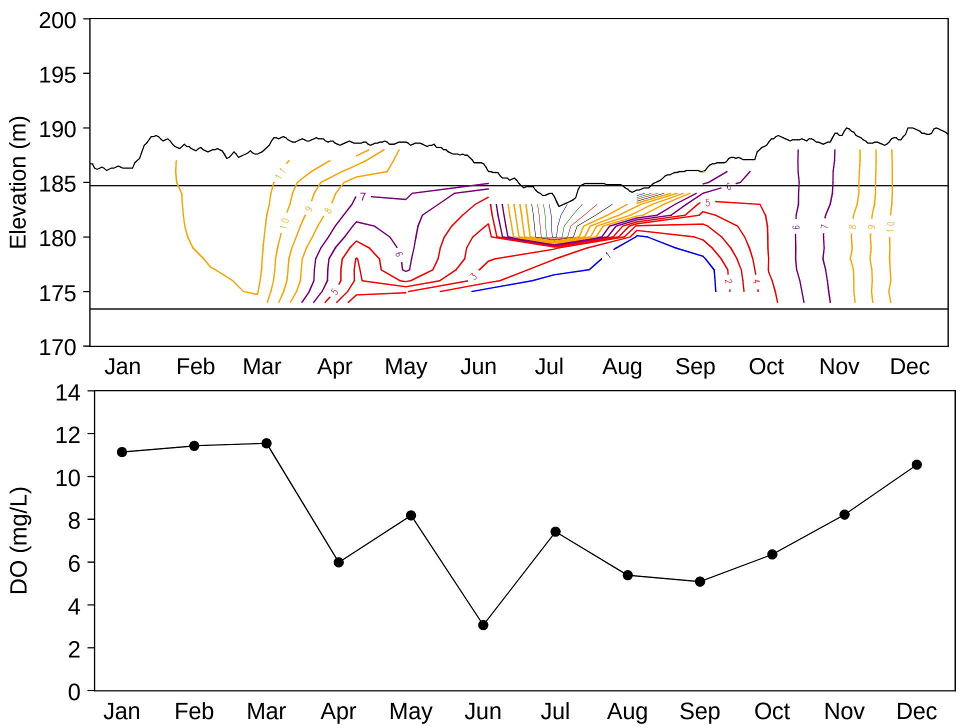


Figure 2.4-15. Dissolved oxygen (mg/l) in High Rock Reservoir and Tailrace 2002 (horizontal lines in top panel represent intake interval).

the daily average dissolved oxygen concentration was below 5 mg/l compared to 2002, 2003 or 2004 (54-79). Likewise, the days when the minimum dissolved oxygen concentration was less than 4 were fewer (57) than observed in 2002, 2003 or 2004 (78-95). Unlike at High Rock or Tuckertown, there does not appear to be any clear relationship between hydrometeorologic conditions and the frequency of low tailrace dissolved oxygen concentrations at Narrows tailrace. Results from 2002, one of the driest on record are similar to those observed for 2003 one of the wettest on record. One potential explanation for this finding is the location of the spillway at Narrows, well downstream of the continuous monitor. During periods of spill, water returning to the mainstem from the side-channel spillway is not represented at the continuous monitor. In addition, the depth of the intakes at Narrows is sufficient to entrain water with low dissolved oxygen even under high flow conditions. The influence of dam operations on tailrace dissolved oxygen concentrations is discussed in Sections 3.3 and 3.4.

Falls

The dissolved oxygen concentrations in Falls are strongly influenced by operations and dissolved oxygen conditions at Narrows (Figure 2.4-13). The Falls impoundment does not stratify and the time of travel through the Falls impoundment is so rapid that water passing the Falls dam is similar to water passing through Narrows dam. Temperatures in the Falls tailrace were similar to those observed in the Narrows tailrace reaching a summer maximum of 26-28ºC (Figure 2.4-13). Dissolved oxygen concentrations were generally higher in the Narrows tailrace than at the other three projects with fewer days with one reading below 4 mg/l and fewer days with an average below 5 mg/l (Table 2.4-3. Beginning in 2002, APGI started operating Narrows Unit 4 exclusively with 2 air valves and is the first unit brought on line and the last taken off line during periods of generation for the period May through November. The influence of air injection at Unit 4 via the air valves is discussed further in Section 3.3. Data are presented in Appendix I.

2.5 STATE STANDARDS AND HISTORICAL DATA

State Standards and the Yadkin APGI Reservoirs

North Carolina has established a set of water quality standards (Administrative Code Section 15A NCAC 2B .0200). The basic standard, designated Class C, applies to all surface waters and states that the waters “shall be suitable for aquatic life propagation and maintenance of biological integrity, wildlife, secondary recreation, and agriculture...” Additional standards apply to specific classes of waters. Among these are water bodies that are used as drinking water supply or are immediately upstream of a drinking water supply (Class WS). Both Class C and Class WS standards apply to all waters in the four Alcoa reservoirs. Each standard lists a variety of water quality parameters along with acceptable ranges. Water quality parameters and their standards that are relevant to the current survey are presented in (Table 2.5-1).

The effects of the four reservoirs on dissolved oxygen concentrations are covered in detail in other sections of this report. Relative to state standards, low dissolved oxygen concentrations in the surface waters are frequently observed in High Rock Reservoir, in particular, the upper arms, and in the tailraces below each dam. Surface dissolved oxygen concentrations are occasionally below standards in Tuckertown and Falls Reservoirs during the warmer months. Surface dissolved oxygen concentrations in Narrows Reservoir exceed state standards. Oxygen depletion occurs below the photic zone in High Rock, Tuckertown and Narrows reservoirs.

Table 2.5-1. Parameters measured in this study that have applicable North Carolina Water Quality Standards.

Parameter	NC Standard Class C Aquatic Life	NC Standard Class WS Drinking Water
Chlorophyll a	<40 µg/l	
Dissolved Oxygen	>5.0 mg/l daily average and	
	>4.0 mg/l instantaneous	
PH	6.0 to 9.0	
Temperature	<32ºC and	
	<2.8ºC above natural temperature	
Turbidity	<25 NTU	
Cadmium	<2.0 µg/l	
Cyanide	<5.0 µg/l	
Lead	<25 µg/l	
Mercury	0.012 µg/l	
Copper	7µg/l Action Level	
Total Dissolved Solids		<500 mg/l
Nitrate Nitrogen		<10.0 mg/l

Summer temperatures in the reservoirs are generally well below the 32°C state standard (Figure 2.2-4 and Section 2.3.1). The operation of the hydroelectric facilities does not produce a heated discharge and tailrace temperatures are similar to reservoir temperatures. There are two instances when temperature exceeded 32°C, (Appendix J). In both cases, it is the surface reading on a hot sunny day in an arm of High Rock Reservoir.

Surface pH at the reservoir stations occasionally exceeds the state standard. The 95th percentile of pH at lake stations exceeds the upper limit of the state standard of nine units (Figure 2.2-4). High pH is most frequently seen during the summer, in High Rock, Tuckertown and Narrows reservoirs and is usually associated with high dissolved oxygen and chlorophyll *a* concentrations. The high pH levels are limited to the photic zone and indicate intense algal productivity. Surface water pH at the upper High Rock mainstem stations and in the tailraces usually exceeds the lower limit of the state pH standard. The 5th percentile is slightly greater than six in these areas, but there are occasional occurrences below the state pH standard at these sites. Low pH is frequently seen in the hypolimnion of Narrows Reservoir.

Turbidity and chlorophyll *a* levels in High Rock and Tuckertown reservoirs frequently exceed the state standards. Average turbidity in High Rock Reservoir is near the state standard (Figure 2.2-2). About 25% of the chlorophyll *a* samples in High Rock Reservoir exceed the state standard (Figure 2.2-3). High Rock Reservoir is the first major impoundment on the Yadkin River and it receives a large suspended solid and nutrient load from surface runoff. The nutrients are exploited by algae in the arms and lower portion of the reservoir where large standing crops of phytoplankton develop. The combination of a large phytoplankton standing crop and large amounts of suspended sediments causes excessively high turbidity. These conditions also occur in Tuckertown Reservoir, but they occur much less frequently and the magnitude is greatly reduced.

Five toxic substances (lead, cadmium, copper, cyanide and mercury) were monitored in this survey. Detectable levels of lead occurred in every reservoir and cadmium was detected in High Rock, Tuckertown and Falls reservoirs (Section 2.3.5). However, most of these measurable concentrations of lead and cadmium were below the state standards. There were five samples, all from High Rock Reservoir, where concentrations exceeded the state standard (Appendix J). There were two samples that contained cadmium concentrations above the state standard, one from High Rock near the mouth of the Yadkin River and the second in Tuckertown Reservoir. The analytical detection limits for the copper, cyanide and mercury are at or are slightly greater than the state standards and these toxic substances are discussed in Section 2.3.5.

In addition to the Class C standards, drinking water standards apply to all waters of the four reservoirs. Nitrate concentrations never occurred at concentrations exceeding the drinking water standard of 10 mg/l. Total dissolved solids usually did not exceed 150 mg/l but there were three samples that contained concentrations that exceeded the state standard of 500 mg/l (Appendix J)

About 2000 samples were analyzed in this survey. State standards for lead, cadmium, nitrate and total dissolved solids were rarely exceeded. Cyanide, copper and mercury were more likely to occur at concentrations that exceed state standards. For most stations, concentrations of cyanide, copper and mercury exceeded state standards on less than 13% of the sampling dates (Table 2.3-7).

Historical data from the four reservoirs and long-term trends

Historical data on the water quality of the four Alcoa reservoirs on the Yadkin River are limited. A survey of the American water willow in Narrows Reservoir was conducted from 1999 to 2001 included some nutrient data collected in the nearshore environment (Touchette, B. W. et al. 2001). The concentrations of nitrate, ammonia, TKN and total phosphorus were similar to results obtained in this survey in the more open water sites.

The State of North Carolina Department of Environment and Natural Resources, Division of Water Quality (DWQ) has conducted water quality sampling in all four reservoirs. The earliest observations obtained from DWQ are from 1981, and the data record is not continuous. It contains periodic water quality measurements in Falls and Tuckertown impoundments and more frequent observations in Narrows and High Rock reservoirs. Data were collected from eight stations in High Rock Reservoir, four stations in Badin Lake (Narrows), and two stations each in Tuckertown Reservoir and Falls Lake. Samples were generally collected once per year from June through September, although limited additional data are available in some years. Parameters include dissolved oxygen, temperature, pH, conductivity, Secchi transparency, nutrients including phosphorus and nitrogen, chlorophyll *a*, solids and turbidity from the surface waters. Recent (1996-2000) chlorophyll *a* data are suspect due to laboratory irregularities (Owen personal communication) and were disregarded.

Although DWQ historic data and the current survey differ in the number of stations and sampling months, an attempt was made to equate the two sets of data as much as possible for comparative purposes. Only stations located in similar areas were used. Since most DWQ sampling was conducted in July and August, the APGI/NAI survey medians were recalculated using only July and August, as well. DWQ sampling was conducted annually from 1981 to 1986, thereafter sampling occurred about every three years and the two periods are presented separately. A Wilcoxon signed-rank test was used to compare the current survey with the DWQ data from 1981 to 1986. The number of samples was insufficient in the other three reservoirs for this test.

Over the 22 year period from 1981 to 2003, the water quality of the four reservoirs has remained relatively similar. Concentrations of nutrients are currently and historically been at levels that can support considerable algal growth (Table 2.5-2). Suspended and dissolved solids concentrations are currently at levels that existed in the early DWQ sampling. Small but significant differences exist between the early sampling (1981 to 1986) and the current sampling. Concentrations of total phosphorus and all forms of nitrogen are slightly greater in recent years. Nitrogen levels are also slightly greater in the other reservoirs as well. In High Rock Reservoir, waters are currently slightly more turbid, have greater conductivity and lower dissolved oxygen and pH when compared to the earlier sampling.

The DWQ station in the upper portion of High Rock Reservoir closest to the mouth of the Yadkin River is somewhat downstream from current survey station (H1) and the number of samples is rather limited so assessment of trends should be made with caution. A large increase in nitrate concentrations entering High Rock Reservoir occurred after 1986 and, this coincided with a large decrease in chlorophyll *a* concentrations during the same period. Water clarity is slightly better during the summer months in the current survey (1999 to 2003). Secchi depth increases while both turbidity and total suspended concentrations decrease from the early DWQ sampling to the current survey.

A review of water quality data for High Rock was recently completed (TetraTech 2004) for the NC DENR in support of Total Maximum Daily Load (TMDL) evaluations for High Rock Lake. Upper High Rock Lake is listed as impaired due to chlorophyll *a*, low dissolved oxygen and turbidity in the North Carolina 2004 draft 303d list. Abbotts Creek is listed as impaired for dissolved oxygen and turbidity and lower High Rock Lake is listed for dissolved oxygen and turbidity. The report suggests that DWQ will be removing the low dissolved oxygen listing for all segments of High Rock Reservoir. The review acknowledges the short residence time of High Rock lake as well as the high inputs of suspended solids, phosphorus and nitrogen. Algal production based on historic chlorophyll *a* data is thought to be controlled by light availability and flushing with a "diminished response to nutrients." The report concludes that High Rock retains both suspended solids and phosphorus but may be a net exporter of nitrogen due to nitrogen fixation by blue-green algae and ammonia release from the sediments under anoxic conditions. It should be noted that the conclusions of this review were based largely on data collected by NCDEWQ. Although the authors review the 2002 interim report prepared for Yadkin APGI (Normandeau 2002), the data analysis apparently did not include the extensive data set collected as a part of the Yadkin APGI relicensing effort. Nonetheless, the conclusions drawn from the TetraTech review are generally consistent with the conclusions drawn for High Rock Reservoir in this report.

Table 2.5-2. Comparison of historical water quality data with current data.

Parameter	High Rock (Stations 3,6,7,10)									
	NCDWQ 1981-86			NCDWQ 1987+			Current Survey			
	5%	Median	95%	5%	Median	95%	5%	Median	95%	Prob > |Z|
Temperature (deg C)	24.0	28.5	32.2	25.0	28.1	30.2	25.3	28.5	30.4	
Dissolved Oxygen (mg/L)	6.9	9.7	11.9	6.0	8.4	11.7	2.5	7.3	12.8	<0.01
pH	6.5	8.7	9.7	7.0	8.5	9.2	6.5	7.9	9.5	<0.01
Conductivity	73.0	102.0	124.0	79.0	115.5	137.0	77	139	206	<0.01
Secchi Depth (m)	0.1	0.6	1.2	0.3	0.7	1.0	0.2	0.7	1.0	
Turbidity (NTU)	3.0	6.9	33.0	4.3	6.4	28.0	5	12	68	0.02
Total Dissolved Solids (mg/L)	81.0	97.0	140.0	72.0	97.5	120.0	46	90	162	
Total Suspended Solids (mg/L)	8.0	12.0	47.0	2.0	9.0	26.0	5	12	44	
Chlorophyll *a* (Fg/l)	4.0	33.0	63.0	10.0	22.0	58.0	12	34	147	
Total Phosphorus (mg/L)	0.1	0.1	0.2	0.0	0.1	0.2	0.02	0.08	0.26	0.01
Total Nitrogen (mg/L)	0.5	0.6	2.2	0.3	0.5	1.3	0.59	1.09	2.35	<0.01
Nitrate-Nitrogen (mg/L)	0.0	0.1	0.8	0.0	0.1	0.5	0.05	0.13	1.08	
Ammonia-Nitrogen (mg/L)	0.0	0.0	0.7	0.0	0.0	0.3	0.05	0.05	0.24	<0.01
Total Kjeldahl Nitrogen (mg/L)	0.4	0.5	1.4	0.3	0.4	0.8	0.50	0.87	1.78	<0.01

Parameter	Tuckertown									
	NCDWQ 1981-86			NCDWQ 1987+			Current Survey			
	5%	Median	95%	5%	Median	95%	5%	Median	95%	
Temperature (deg C)	24.0	28.3	32.0	25.2	27.0	30.0	25.4	28.4	30.7	
Dissolved Oxygen (mg/L)	4.1	9.6	15.2	4.7	8.0	9.2	1.9	6.8	13.3	
pH	6.1	8.3	9.0	6.1	7.8	8.7	6.2	7.8	9.4	
Conductivity	66.0	107.5	123.0	83.0	96.0	119.0	70.0	134.5	171.5	
Secchi Depth (m)	0.1	0.6	1.8	0.5	0.7	1.1	0.5	0.7	1.0	
Turbidity (NTU)	2.2	11.2	20.0	2.5	7.7	19.0	4.2	9.9	32.5	
Total Dissolved Solids (mg/L)	83.0	92.0	134.0	82.0	90.0	110.0	42.0	85.0	101.0	
Total Suspended Solids (mg/L)	1.0	12.0	43.0	6.0	7.0	12.0	4.0	8.6	13.7	
Chlorophyll *a* (Fg/l)	12.0	40.5	61.0	16.0	18.0	20.0	7.8	36.0	84.7	
Total Phosphorus (mg/L)	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	
Total Nitrogen (mg/L)	0.5	0.8	2.4	0.4	0.6	0.8	0.5	1.0	1.6	
Nitrate-Nitrogen (mg/L)	0.0	0.3	1.0	0.0	0.2	0.3	0.1	0.1	0.5	
Ammonia-Nitrogen (mg/L)	0.0	0.1	0.7	0.0	0.1	0.3	0.1	0.1	0.3	
Total Kjeldahl Nitrogen (mg/L)	0.4	0.6	1.4	0.2	0.5	0.7	0.5	0.8	1.4	

(continued)

Table 2.5-2. (Continued)

Parameter	Narrows (Badin)									
	NCDWQ 1981-86			NCDWQ 1987+			Current Survey			
	5%	Median	95%	5%	Median	95%	5%	Median	95%	
Temperature (deg C)	26.0	29.4	33.7	26.7	28.8	30.6	25.6	28.7	30.4	
Dissolved Oxygen (mg/L)	5.5	8.6	12.9	4.2	7.9	10.4	6.1	8.4	11.2	
pH	6.8	8.3	9.0	6.4	7.9	9.1	6.9	8.3	8.9	
Conductivity	68.0	96.0	178.0	74.0	96.5	108.0	75.0	117.5	139.0	
Secchi Depth (m)	0.5	1.0	2.2	0.7	1.2	1.7	0.9	1.3	1.9	
Turbidity (NTU)	1.6	3.3	7.0	1.6	3.1	6.6	1.6	3.4	6.9	
Total Dissolved Solids (mg/L)	60.0	87.0	100.0	64.0	76.5	110.0	38.0	68.0	92.0	
Total Suspended Solids (mg/L)	3.0	7.0	11.0	1.0	4.0	10.0	3.0	5.0	6.5	
Chlorophyll *a* (Fg/l)	0.5	15.5	46.0	6.0	10.0	31.0	8.4	16.6	31.6	
Total Phosphorus (mg/L)	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	
Total Nitrogen (mg/L)	0.2	0.6	2.9	0.4	0.4	0.6	0.5	0.7	1.1	
Nitrate-Nitrogen (mg/L)	0.0	0.2	1.4	0.0	0.1	0.3	0.1	0.1	0.4	
Ammonia-Nitrogen (mg/L)	0.0	0.0	1.1	0.0	0.0	0.2	0.1	0.1	0.2	
Total Kjeldahl Nitrogen (mg/L)	0.2	0.4	1.5	0.2	0.3	0.5	0.5	0.6	0.8	

Parameter	Falls									
	NCDWQ 1981-86			NCDWQ 1987+			Current Survey			
	5%	Median	95%	5%	Median	95%	5%	Median	95%	
Temperature (deg C)	25.8	27.6	28.0	26.2	26.6	26.9	23.7	26.4	28.0	
Dissolved Oxygen (mg/L)	3.0	6.8	7.3	3.8	4.8	5.7	3.9	5.5	9.9	
pH	6.1	6.7	7.7	6.9	7.2	7.5	6.3	6.9	8.2	
Conductivity	69.0	78.0	116.0	77.0	88.0	99.0	68.0	112.0	125.0	
Secchi Depth (m)	0.3	1.2	1.7	1.4	1.5	1.6	1.0	1.6	2.0	
Turbidity (NTU)	2.2	2.9	13.0	2.1	3.2	4.2	2.0	2.9	13.1	
Total Dissolved Solids (mg/L)	68.0	68.5	110.0	83.0	87.0	91.0	42.0	65.0	92.0	
Total Suspended Solids (mg/L)	3.0	5.0	10.0	1.0	3.0	5.0	3.0	5.0	5.0	
Chlorophyll *a* (Fg/l)	5.0	6.0	18.0	4.0	9.0	14.0	5.2	8.0	19.6	
Total Phosphorus (mg/L)	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	
Total Nitrogen (mg/L)	0.4	0.5	0.8	0.5	0.5	0.6	0.5	0.8	1.3	
Nitrate-Nitrogen (mg/L)	0.1	0.3	0.4	0.2	0.2	0.3	0.1	0.2	0.7	
Ammonia-Nitrogen (mg/L)	0.0	0.0	0.3	0.1	0.1	0.1	0.1	0.1	0.4	
Total Kjeldahl Nitrogen (mg/L)	0.2	0.3	0.4	0.3	0.3	0.3	0.5	0.6	0.9	

(continued)

Table 2.5-2. (Continued)

Parameter	High Rock near mouth of Yadkin River									
	NCDWQ 1981-86			NCDWQ 1987+			Current Survey			
	5%	Median	95%	5%	Median	95%	5%	Median	95%	
Temperature (deg C)	23	26.8	32	22.3	28	29.8	21.8	26.7	31	
Dissolved Oxygen (mg/L)	6.9	7.9	11.3	5.7	7	7.7	6.2	6.9	8.1	
pH	6.6	7.4	8.5	6.9	7.5	7.9	6.1	7	7.5	
Conductivity	62	90	115	85	109	189	74	135.5	206	
Secchi Depth (m)	0.1	0.3	0.6	0.2	0.4	0.5	0.3	0.5	0.7	
Turbidity (NTU)	4.6	46	300	18	28	70	16.2	34.3	60.7	
Total Dissolved Solids (mg/L)	99	113	260	98	120	190	64	94.5	780	
Total Suspended Solids (mg/L)	10	30	140	18	24.5	59	14.7	20.5	32.3	
Chlorophyll *a* (Fg/l)	5	35	43	2	4	8	2	5	16	
Total Phosphorus (mg/L)	0.1	0.1	0.3	0.1	0.2	0.3	0.1	0.2	0.3	
Total Nitrogen (mg/L)	0.6	1	1.2	0.8	1.1	1.6	0.8	1.3	2	
Nitrate-Nitrogen (mg/L)	0.1	0.3	0.7	0.6	0.8	1.2	0.6	0.8	1.3	
Ammonia-Nitrogen (mg/L)	0	0.1	0.2	0	0.1	0.3	0.1	0.1	0.1	
Total Kjeldahl Nitrogen (mg/L)	0.3	0.5	0.9	0.1	0.3	0.5	0.5	0.6	0.9	

3.0 IN-DEPTH ANALYSIS OF SPECIFIC WATER QUALITY ISSUES

The following sections address specific issues brought forward through the licensing process. These issues are evaluated primarily through an in-depth analysis of data collected through the monthly and continuous tailrace monitoring program. These data were supplemented with targeted field collecting, where necessary.

3.1 INFLUENCE OF FLOW ON WATER QUALITY

There is the potential for water quality in the Yadkin system to be influenced by flow through the system. Differences in observed water quality in the reservoirs among years and seasons with different hydrometeorologic regimes were discussed in Section 2.3. The timescale of reservoir response to changes in flow is on the order of weeks or months for High Rock and Narrows and days to weeks for Tuckertown and Narrows due to differences in the flushing rates of these impoundments. Water quality in the tailraces is influenced by flow on a much shorter time scale. Water in the tailraces can be exchanged in a matter of minutes if flows through the projects are large. The water exchange in the tailraces is slower when flows are extremely low during the dry periods typical of late summer and early fall.

Kendall's tau correlation coefficients were computed to examine potential relationships between water quality parameters and flow through the dams (Table 3.1-1). Reservoir water quality data from the surface samples were used in the analysis because surface waters are most visible to reservoir users and phytoplankton growth (represented by chlorophyll a) is restricted to the surface waters. Tailrace waters represent a mix of surface and bottom waters due to the intake depths so correlations from tailraces may or may not be similar to results from upstream reservoirs. The average flow for the seven days preceding sample collection was used in the correlation because instantaneous and daily flows can vary considerably and water quality, especially in the reservoirs, is affected by retention time. Because tailraces flush rapidly and may respond to flow on a more rapid timescale, correlations based on a daily average flow were also calculated. These results can be found in Appendix L. Results based on daily averages were similar to correlations calculated using 7 day average flows although in general, correlations were not as strong and the number of significant relationships was lower. Results based on these daily average flows are not discussed further. Reservoir water quality is discussed in more detail in section 2. Dissolved oxygen and temperature are discussed in this section however; the dynamics of dissolved oxygen and temperature in the tailraces are evaluated and discussed in more detail in section 3.4 through discussion of the much more extensive continuous monitoring data set.

Throughout the Yadkin system, higher flows are associated with lower concentrations of alkalinity, pH, algal biomass (chlorophyll a), total dissolved solids (TDS), biological oxygen demand (BOD), and total organic carbon. All of these parameters are influenced to some extent by biological processes. Greater flow reduces retention time in the reservoirs, allowing less time for microbial and phytoplankton populations to develop. The relationships between flow and BOD, chlorophyll a, and total organic carbon are strongest in the lower mainstem and arms of High Rock Reservoir and in Tuckertown Reservoir. Strong relationships between alkalinity, pH and flow exist in all locations. Total phosphorus (TP) and total suspended solids (TSS) show a weak negative relationship with flow in High Rock, especially in the arms and generally positive relationships with flow in the lower reservoirs and tailraces. This may be attributable to a high percentage of inorganic solids and

Table 3.1-1. Kendall's tau correlation coefficients of weekly average flow versus water quality parameters in the reservoirs and tailraces.[1]

Parameter	Reservoirs: Upper High Rock Mainstem	Reservoirs: Lower High Rock Mainstem	Reservoirs: High Rock Arms	Reservoirs: Tuckertown	Reservoirs: Narrows	Reservoirs: Falls	Tailraces: High Rock	Tailraces: Tuckertown	Tailraces: Narrows	Tailraces: Falls
Alkalinity	**-0.4020**	**-0.4095**	**-0.2582**	**-0.4694**	**-0.4574**	**-0.4612**	**-0.3876**	**-0.4573**	**-0.4536**	**-0.5096**
BOD	0.0222	**-0.2517**	**-0.2401**	**-0.2807**	-0.0646	0.0462	**-0.2265**	**-0.3034**	0.0550	-0.0309
Chlorophyll a	-0.0561	**-0.2375**	**-0.2512**	**-0.3919**	-0.0929	**-0.2289**	**-0.3877**	**-0.3884**	-0.1123	-0.0791
Secchi Depth	-0.0244	0.0468	**0.2250**	-0.1226	**-0.1697**	**-0.4319**	-0.1576	-0.1691	**-0.3645**	NA
Total Organic Carbon	**-0.1565**	**-0.2217**	-0.0535	**-0.1334**	0.0346	0.0454	**-0.1900**	-0.1335	0.1355	0.0434
Ammonia	-0.1071	**-0.2431**	**-0.1391**	0.0993	0.0849	0.0760	-0.1557	-0.1769	0.1033	0.1066
Nitrate	-0.1171	0.1143	**0.1140**	**0.3279**	**0.3634**	**0.4224**	0.1478	**0.2529**	**0.3920**	**0.4121**
Total kjeldahl Nitrogen	-0.0084	**-0.2040**	**-0.2261**	-0.0766	0.0302	-0.0083	**-0.2012**	**-0.1907**	0.0300	-0.1128
Total Nitrogen	-0.0381	-0.0979	**-0.1370**	**0.1413**	**0.2351**	**0.2182**	-0.0840	0.0130	**0.2320**	0.1064
Total Phosphorus	**-0.2410**	**-0.1418**	**-0.2101**	0.0191	**0.2366**	**0.2752**	-0.1065	0.0370	**0.3209**	**0.2242**
Total Dissolved Solids	**-0.1902**	**-0.2958**	**-0.2267**	**-0.1987**	**-0.2448**	**-0.2312**	**-0.2572**	**-0.2884**	**-0.2059**	**-0.2551**
Total Suspended Solids	-0.0139	-0.0736	**-0.2454**	0.0812	**0.1459**	**0.2115**	0.0258	0.0267	**0.2292**	**0.2298**
Turbidity	0.0446	0.0635	**-0.1429**	**0.2982**	**0.2804**	**0.5188**	**0.2806**	**0.3903**	**0.4852**	**0.5554**
Temperature	**-0.1294**	**-0.1325**	**-0.0941**	**-0.2151**	**-0.1851**	**-0.2337**	**-0.1819**	**-0.2175**	**-0.2103**	**-0.2098**
Dissolved Oxygen	0.0894	0.0817	0.0190	-0.0528	**0.2337**	0.1368	0.0849	**0.2560**	**0.2169**	**0.2221**
pH	**-0.4097**	**-0.2471**	**-0.2419**	**-0.3971**	**-0.1666**	**-0.3546**	**-0.3833**	**-0.2253**	**-0.2510**	**-0.3459**

[1] Significant correlations at 95% level ($p \leq .05$) are noted in bold type.

phosphorus represented in High Rock total suspended solids concentrations. Many of these inorganic solids and associated phosphorus settle in High Rock (discussed further in Section 3.5) increasing the relative importance of organic solids and phosphorus associated with algae lower in the system. Algae often reach high concentrations during low flow periods throughout the system, but reperesent a larger percentage of total suspended solids lower in the system.

In general, nitrogen concentrations are poorly correlated with flow. With the exception of nitrate, the correlation coefficients are very low and significant correlations do not reveal any consistent trends. Nitrate concentrations tend to increase with greater flows, probably the outcome of reduced time for microbial populations to exploit the nutrient. Also, nitrate concentrations are lowest during the summer, when flows tend to be lower. Nitrate concentrations in the upper mainstem of High Rock Reservoir, where algal biomass is typically low, are negatively correlated with flow which suggests that dilution during high flow periods has a greater effect than algal assimilation. Greater flows are associated with greater turbidity, especially downstream of High Rock Dam. Temperature is also slightly cooler during high flow periods.

Significant correlations (14 of 16 parameters) were most frequently observed in the arms and lower mainstem of High Rock Reservoir. High Rock Reservoir is the largest reservoir and has the longest retention time. It is also the location of intense biological activity as the environment transitions from a river to a reservoir environment. There were somewhat fewer significant correlations (9-11 of 16 parameters) at all other stations except Upper High Rock (6 of 16 parameters). Upper High Rock water quality may be more closely related to inflow from the Yadkin and South Yadkin rivers than flow through High Rock Dam.

Flow through High Rock Reservoir and the entire system is primarily controlled by precipitation and climate particularly during periods of normal to high precipitation in the watershed however daily flow through each of the dams is controlled by scheduled releases during periods of low flow. During the five years of this study, drought conditions were extreme in 2002 resulting in near-record low flows in the Yadkin River basin. The drought year was followed by an extremely wet year and flow was at high levels throughout 2003. This provides the opportunity to examine the effects of extreme flow conditions on water quality in the reservoirs. Flows differed by about an order of magnitude between 2002 and 2003 (Figure 1.0-1) with flows in the other years at intermediate levels.

During the drought year, High Rock and Tuckertown dams were essentially shut down during the summer and the water pooled behind the dams dropped to record low levels. Surface temperatures were slightly warmer in the summer of 2002 and dissolved oxygen levels in High Rock were extremely high indicating intense algal photosynthesis. Concentrations of chlorophyll *a*, total dissolved solids, total organic carbon and total Kjeldahl nitrogen were greater than normal in High Rock reservoir, suggesting that intense algal productivity was occurring in the pooled slightly warmer waters impounded above High Rock Reservoir. Higher levels of chlorophyll *a*, total dissolved solids and total organic carbon occurred in the downstream reservoirs as well. Nitrate concentrations in High Rock reservoir were lower than normal during the drought year of 2002, probably due to the greater retention time allowing algae more time to exploit the nutrients.

Concentrations of most parameters were lower during 2003, the high flow year. Chlorophyll *a* and total dissolved solids concentrations were much lower in 2003. The high flows result in much shorter retention time in the reservoirs and algal populations likely did not have time to develop to the concentrations observed in the other years. Nitrate concentrations were greater in 2003 because of the lower concentrations of algae. The increase in precipitation appears to have had a diluting effect in the reservoirs. Total dissolved solids concentrations were much lower during the high flow year. To a lesser extent, concentrations of most of the other parameters were also lower in 2003. The high flow rates of 2003 had great effects on dissolved oxygen concentrations. In all four reservoirs, well-oxygenated waters extended to greater depths and persisted longer than the previous years. Oxygen depletion in the bottom was limited to July and August and anoxia was much more limited than observed in previous years.

3.2 INFLUENCE OF RESERVOIR WATER LEVELS ON WATER QUALITY

Water levels in the Yadkin system vary seasonally. During periods of normal precipitation and flows, High Rock is operated as a seasonal storage facility. Typically, this means that High Rock is drawn down to its lowest levels during the fall and winter in anticipation of late winter and spring storms and high flow events. During periods of extreme drought however, High Rock and Narrows reservoirs can experience substantial drawdown in the summer, as occurred in 2002. Tuckertown and Falls reservoirs maintain relatively stable pools most of the time. Water levels in the four impoundments over the water quality monitoring study period are presented in Figures 1.0-2 through 1.0-5. Differences in water quality in the reservoirs among years and seasons with different hydrometeorologic regimes were discussed in Section 2.3. The influence of water level changes on tailrace dissolved oxygen and temperature resources is discussed further in Section 3.4.

The effect of the reservoir water level on surface water quality in each respective reservoir was evaluated using the monthly surface water quality data collected from 1999 through 2003 and reservoir water level data obtained from Yadkin APGI. The influence of reservoir water level on water quality was evaluated by Kendall Tau correlation analysis. Tailrace water quality was correlated with the water level in the upstream reservoir. Correlation coefficients ($p<0.05$, 95% significance level) of water level versus 10 water quality parameters are presented in Table 3.2-1. Dissolved oxygen and temperature are discussed in this section and the dynamics of dissolved oxygen and temperature in the tailraces are evaluated and discussed in more detail in Section 2.4 using the much more extensive continuous monitoring data set. The influence of water level on oxygen distribution and thermal stratification was discussed in more detail in Section 2.3.

Surface water quality is poorly correlated with lake level. Most correlation coefficients are low indicating that poor, if any, relationships exist between lake level and water quality. Significant correlations are absent in Falls Reservoir and rare in Tuckertown, the two reservoirs where lake level remains constant. Significant correlations are not observed for total organic carbon or ammonia in any of the reservoirs. Correlations of the other parameters with lake level, even if significant, are generally poor in High Rock and Narrows reservoirs. The strongest associations are for total phosphorus and total dissolved solids in High Rock Reservoir and for nitrate and temperature in Narrows Reservoir. In general, coefficients were negative indicating that as lake levels drop, concentrations tend to increase, but the increase is likely an effect caused by seasonality as the extreme low lake levels occurred in summer in High Rock Reservoir and in summer and fall in Narrows Reservoir.

The correlation of water quality of the tailraces with the lake level of the upstream reservoir is also poor. In High Rock Reservoir, low lake levels were associated with greater levels of biological

Table 3.2-1. Correlation coefficients ($p < 0.05$, 95% significance) of water level versus surface water quality parameters throughout the Yadkin system. Significant correlations are noted in bold type.

	Reservoirs						Tailraces			
Parameter	**Lower HR Mainstem**	**Upper HR Mainstem**	**HR Arms**	**Tuckertown**	**Narrows**	**Falls**	**High Rock**	**Tuckertown**	**Narrows**	**Falls**
Biochemical Oxygen Demand	-0.1776	0.1001	**-0.2677**	-0.0138	-0.0097	-0.0820	**-0.3005**	0.0117	0.1420	0.0844
Chlorophyll a	**-0.1886**	0.0682	**-0.2563**	-0.0182	**-0.2519**	-0.1250	**-0.3728**	0.0690	**-0.2388**	0.0028
Ammonia	-0.0872	-0.0280	-0.1734	0.0244	0.1032	0.0760	0.0083	-0.1561	0.0077	**0.2101**
Nitrate	0.0088	**-0.2250**	0.0655	0.0974	**0.5391**	0.0915	-0.0108	**0.2014**	**0.4900**	0.0862
Total Dissolved Solids	**-0.3652**	**-0.2980**	**-0.4329**	0.0615	-0.0485	-0.1795	**-0.3199**	0.0707	-0.0482	**-0.2714**
Total Organic Carbon	-0.0665	-0.0170	-0.0703	-0.0584	0.0144	0.0950	-0.1476	-0.0294	0.1402	0.0929
Total Phosphorus	**-0.3079**	**-0.3131**	**-0.3817**	0.1374	**0.2437**	0.1256	-0.1508	-0.0284	**0.1957**	0.0893
Total Suspended Solids	-0.1649	-0.0520	**-0.3939**	0.1199	0.1732	0.0900	-0.0773	0.0432	**0.3660**	0.0530
Dissolved Oxygen	0.0217	-0.0147	0.0070	**0.2014**	**0.3099**	0.0788	-0.0148	0.1698	**0.4274**	0.0653
Temperature	0.0276	0.0222	0.0627	-0.1731	**-0.3948**	-0.0492	-0.0270	**-0.1838**	**-0.4532**	-0.0254

oxygen demand, chlorophyll *a* and total dissolved solids; parameters that reached high concentrations during the extreme low lake levels experienced during the drought year 2002. At Narrows tailrace, most parameters are correlated with the level of Narrows Reservoir. The strongest correlations occurred between lake level and temperature, dissolved oxygen and nitrate, which are all highly seasonal parameters. Since low lake levels ocuur in the summer and fall, temperature are greater during periods of low lake level. Conversely, both dissolved oxygen and nitrate are seasonally at low levels in summer and are positively correlated with lake level. Correlation coefficients in Tuckertown and Falls Reservoirs were all low indicating no effects of lake level on water quality.

In general, reservoir water levels probably have little or no direct effect on water quality. Under normal operations in typical hydrologic years, reservoir levels are lowest in the late fall and winter. During periods of drought, such as that experienced in 2002, reservoir levels were at their lowest in the summer in High Rock and Narrows reservoirs. In this year, changes in water quality that appear related to reservoir level are more likely related to seasonal effects caused by climate and biological activity or flow through the reservoirs as discussed in Section 3.1.

3.3 INFLUENCE OF OPERATIONS ON DISSOLVED OXYGEN IN TAILWATERS

Continuous dissolved oxygen and temperature data from all four tailwaters have been discussed in detail in Section 2.4. This section presents a detailed look at tailrace conditions under specific controlled operating conditions.

Modifications to Narrows Unit 4 turbine, including the addition of two air injection valves, were completed in early 2001. Operation of these valves was intended to introduce air into the flow during Unit 4 generation to increase dissolved oxygen concentrations downstream. In August 2001, following the installation of the air valves, a series of tests were performed to understand the effect on downstream dissolved oxygen of operation of the new air valves under various generation regimes. A second round of operational testing was performed in 2004 to supplement the data gathered in 2001.

3.3.1 August 2001 Operations Testing

The 2001 testing focused on the Narrows tailwater and took place over a two-day period in August, 2001 recording dissolved oxygen concentrations under various operating regimes, with and without Unit 4 air valve operation. Results of this survey were reported on in detail in an earlier study report submitted to FERC (NAI, 2002). A summary description of the various operating regimes and the observations recorded during each survey are presented in Table 3.3-1. The actual dissolved oxygen readings taken at 15-minute intervals in the Narrows tailwater are presented in Figure 3.3-1 and the Narrows station flow and generation data are presented in Figures 3.3-2 and 3.3-3, respectively. In addition, to provide an indication of the conditions upstream of Narrows during that same time frame, dissolved oxygen concentrations at selected locations in the Yadkin River on August 14 and 15, 2001 are presented in Table 3.3-2.

A review of the field test data indicate that operational changes, including use of the air valves, do affect dissolved oxygen in the Narrows tailwater. Figure 3.3-1 illustrates the effect that both level of operation and aeration have on the dissolved oxygen concentration in the tailwater and reveals the following trends:

Table 3.3-1. Summaries of Dissolved Oxygen Observations During August, 2001 Testing

Survey	Operating Regime	Observations
1	Unit 4 at 22 MW (1700 cfs), and no air injection	With the start up of Unit 4 at full load , dissolved oxygen drops sharply about 5 mg/l
2	Unit 4 at 28 MW (2300 cfs) and 1 air valve open	With the opening of one air valve, dissolved oxygen increases 3 mg/l
3	Unit 4 at 22 MW (1700 cfs) and 2 air valves open	With the opening of a second air valve, dissolved oxygen increases an additional 0.5 mg/l.
4	4 units at 0 MW (0 cfs) and no aeration	With the shutdown of all units, dissolved oxygen decreases 2 mg/l over the course of 2 hours.
5	4 units at 89 MW (7000 cfs) and no aeration	With the startup of 4 units at full load, the dissolved oxygen drops sharply about 2 mg/l. During the one hour following the sharp drop the dissolved oxygen levels stabilize and there is little further change.
6	4 units at 0 MW and no aeration – units wheeling, no indication of flow rate (see Note)	The effect of the Survey 6 operating regime is masked by the antecedent operating regime. With flow release from all units and no generation the dissolved oxygen appears to rise from 1.5 to 7.5 mg/l over a two hour period. However, two hours prior to Survey 6, the plant was running Units 1 and 2 at full load, causing a sharp reduction in dissolved oxygen to 1.5 mg/l. Then, one hour before Survey 6, Units 1 and 2 are shut down, causing a sharp rise in dissolved oxygen such that the dissolved oxygen has increased to almost 5 mg/l by the start of Survey 6.
7	4 units at 86 MW (6865 cfs) and 2 air valves open	When the 2 air valves are opened during generation at full load, the dissolved oxygen rises 1.5 mg/l.

Note: The reported operating condition during Survey 6, occurring from 1130 through 1230 –that is, flow released through all four turbines with no generation– does not appear to correspond with either the power generation data or the flow data recorded in the Yadkin Flow Extractor. As seen in Figures 6 and 7, both flow and generation are recorded during hour 1100 on Aug 17. However, the non-zero values are an indication that generation and corresponding flow occurred for a short time at the beginning of the hour. Shortly after the hour, the generator was tripped and the turbine turned or “wheeled”, releasing water without generating electricity. During hour 1200, the continuation of Survey 6, neither flow nor generation are recorded. Because Yadkin determines turbine discharge by measuring generation and converting to flow, the Flow Extractor would record zero turbine flow under this operating condition.

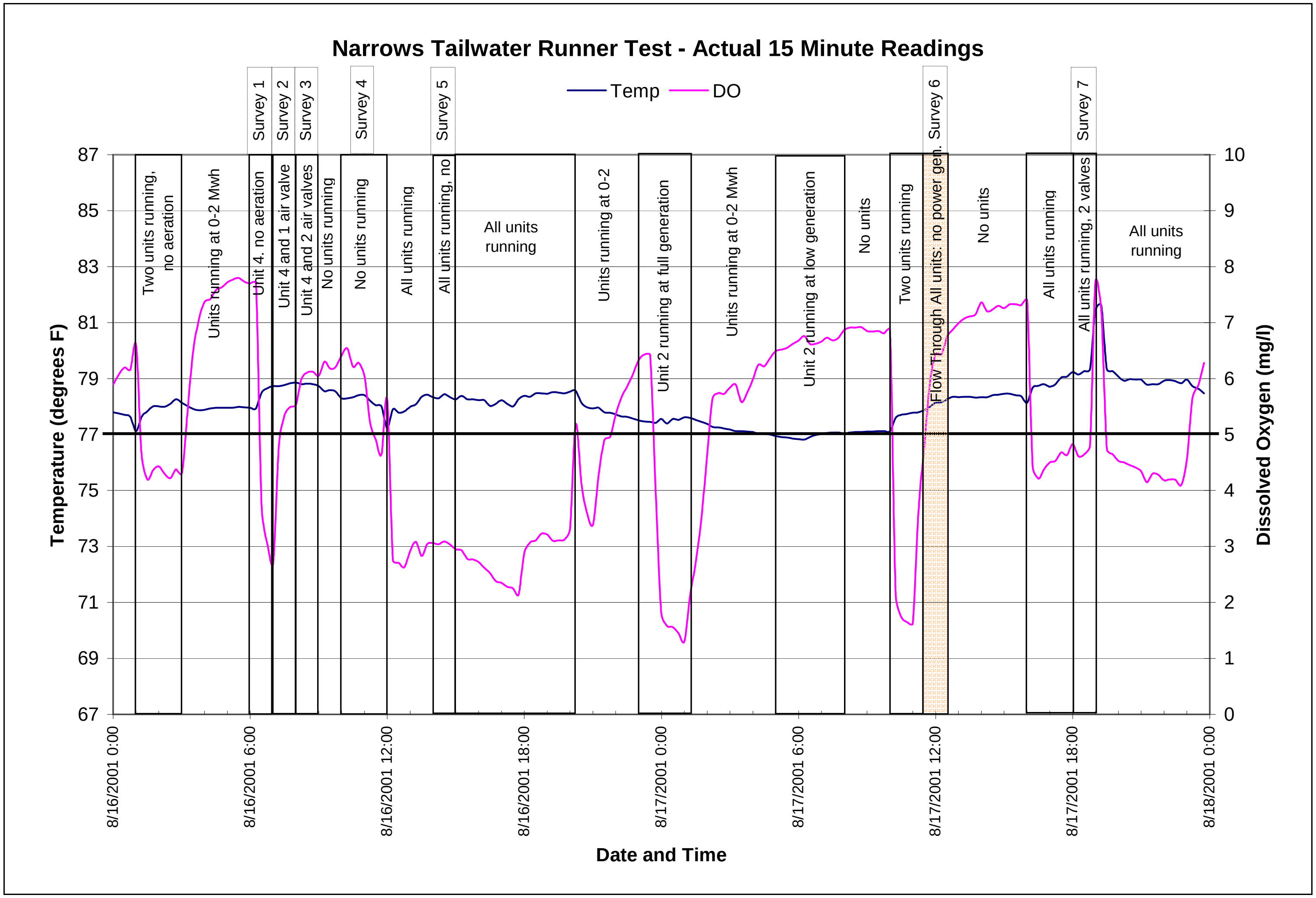


Figure 3.3-1. Narrows 2001 Runner Test - Actual 15 Minute Readings

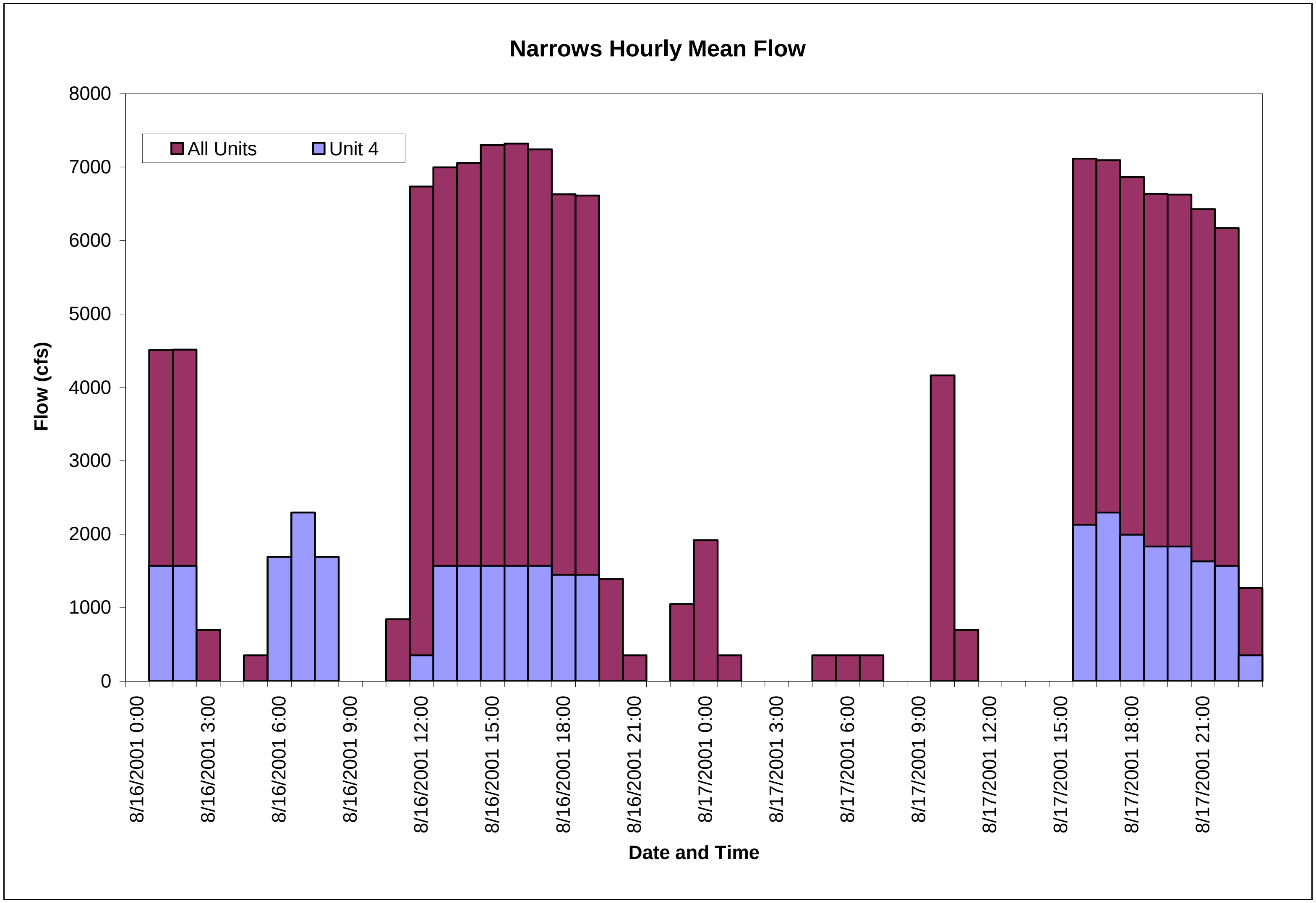


Figure 3.3-2. Narrows 2001 Runner Test – Average Hourly Flow.

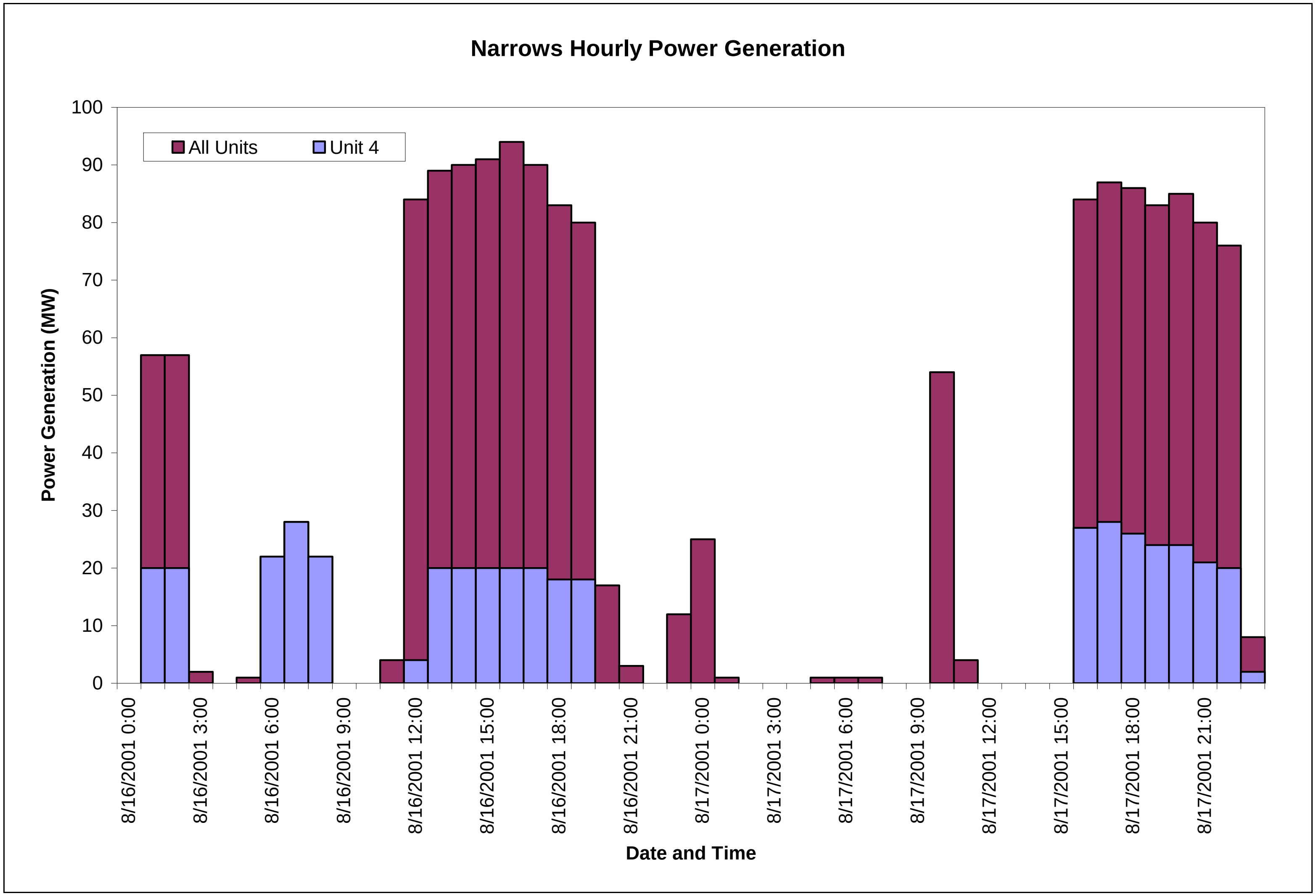


Figure 3.3-3. Narrows 2001 Runner Test – Average Hourly Generation.

Table 3.3-2. Dissolved Oxygen Concentrations at Selected Locations Upstream of Narrows During the Time Frame of the August 2001 Testing

Dissolved Oxygen Station	Date	Location	Depth	Dissolved Oxygen Concentration
H1	8/15/2001	Yadkin River at the upstream end of High Rock Reservoir	3 m	6.3 mg/l
N4	8/14/2001	Narrows Reservoir upstream of Dam	15 m	0.2 mg/l
F1	8/14/2001	Narrows Dam Tailwater	3 m	6.0 mg/l

- ***When one of any of the four units is operating at very low levels (1 to 10 MW***; <1000 cfs), ***dissolved oxygen levels increase significantly.***
  This trend is apparent at 0200 on Aug 17 when the units are running at 2 MW, and the dissolved oxygen increases about 4 mg/l from 1.5 mg/l to 5.5 mg/l over a 2-hr period. A discussion with Ken Hunsucker, APGI Operations staff, indicated that each Narrows turbine includes the provision of air valves on the head cover to admit air into the turbine on startup and shutdown to protect the turbine from transient pressures. These air valves, separate from the new air injection valves on Unit 4, are mechanically linked to the wicket gate operating ring and are designed to open at 20% gate and close at 35% gate. At low loads the Narrows turbines are likely operating in this range of wicket gate opening and the additional air is reflected in the dissolved oxygen downstream. The introduction of air causes a substantial loss in unit efficiency. Moreover, the units are not designed to operate at this load on a continuous basis, and to do so would significantly damage the units.

- ***When power generation is at high levels (20 to 90 MW, approx. 1500-7000 cfs), dissolved oxygen levels fall sharply.***
  A comparison of dissolved oxygen under various operating regimes shows that when any number of units from one to four are generating at full power, the dissolved oxygen concentrations decrease significantly. For example, upon running all units at 80 to 85 MW from hours1200 to 2000 on Aug 16, the dissolved oxygen drops 2 mg/l from 4.7 to 2.7 mg/l.

- ***When air valves are opened at high generation levels, the dissolved oxygen concentration increases 2-3 mg/l.***
  The effect of operation of the air valves is illustrated during Survey 1 through Survey 3. When only Unit 4 is operating ,(approx. 2000 cfs) dissolved oxygen concentrations drop sharply about 5 mg/l with no aeration, increase 3 mg/l upon opening a single air valve and increase an additional 0.5 mg/l for a total improvement of 3.5 mg/l with both air valves open. The majority of the total dissolved oxygen increase is provided upon opening the first air valve, with a lesser benefit provided by opening the second air valve.

- ***After making an operational change, there is a time lag before dissolved oxygen changes are observed in the tailwater.***
  This time lag is illustrated during Survey 1, where Unit 4 is started (at 22 MW and 1700 cfs) at 0600 on August 16 and the initial effect on dissolved oxygen is not observed until about 0630, indicating a time lag of about 30 minutes. Similarly, just after the

completion of Survey 4, all units are started up (at 84 MW and 6700 cfs) and the initial effect on dissolved oxygen is not observed until about 15 minutes later. Time lag appears to be a function of total flow rate, with a shorter lag as flow increases.

- ***In addition to this time lag, the total time required for the downstream dissolved oxygen to reach a new equilibrium following each operational change appears to be longer than one hour. The one-hour duration for these tests was too short to clearly show the effects of the operating configurations on tailwater dissolved oxygen.***
  Referring again to Figure 3.3-1, an example of this trend is seen when, after starting Unit 4 at 0600 on Aug 16, the dissolved oxygen drops sharply and does not have time to level out before one air valve is opened at 0700, opening one air valve. While the general direction of the response to each operational change was evident, none of the seven surveys performed allowed sufficient time for dissolved oxygen to reach a new equilibrium, and the total effect of the various operations was not clearly observed.

Based upon the results of the August 2001 testing, the normal operating policy at Narrows in 2002, 2003, and 2004 was revised to operate with both air valves open whenever Unit 4 is operated between May and November in an attempt to increase dissolved oxygen downstream.

3.3.2 August 2004 Operations Testing

Based on the data from the 2001 testing at Narrows and discussions with the Water Quality IAG, there were several areas in which further investigation was warranted, and some of these areas were the subject of the additional operations testing performed in 2004. First, at the May 4, 2004 meeting, the WQ IAG suggested some additional investigation of the aeration capability provided by the Unit 4 air injection valves to better understand the effect of air injection through Unit 4 on Narrows tailwater dissolved oxygen concentrations, particularly under various unit operating configurations. Second, through discussions with the IAG, it became clear that it would be useful to understand the effect on dissolved oxygen concentrations in the Falls tailwater given an increase in dissolved oxygen concentrations in the Narrows tailwater. Similarly, the relationship between dissolved oxygen in the High Rock tailwater and dissolved oxygen in the Tuckertown tailwater were also deemed to be worth investigating.

The objectives of the additional operations testing were:

- To further evaluate the effectiveness of the air injection valves at Narrows Unit 4 to increase tailwater dissolved oxygen levels;
- To determine how increases in dissolved oxygen concentrations in the Narrows tailwater impacts the dissolved oxygen concentrations in the Falls tailwater; and
- To determine if an increase in dissolved oxygen concentrations in the High Rock tailwater impacts the dissolved oxygen concentrations in the Tuckertown tailwater.

The target timing for the 2004 testing was during a period of low river flow coupled with high water temperatures, conditions that have historically resulted in low tailwater dissolved oxygen concentrations. In the Yadkin system, these conditions are typically encountered between August 1 and September 30. Preliminary testing to confirm travel times from High Rock to Tuckertown and from Narrows to Falls was scheduled for August 5 through 8, 2004; and the final testing was scheduled to be completed on September 8, 9 and 10, 2004. The preliminary testing was completed as scheduled, with dissolved oxygen conditions and water availability allowing Yadkin to perform the desired testing. The occurrence of high inflows due to hurricanes in the region, however, delayed the final testing. When the inflows finally receded enough to safely perform the tests, the reservoir dissolved oxygen had increased thereby increasing the tailrace concentrations and the second test was cancelled. As a result, the data presented in this report are those collected during the August preliminary tests.

3.3.2.1 Methodology for 2004 Survey

The continuous monitors placed in each of the tailwaters was the primary point of measurement of tailwater conditions. The locations of these monitors are presented in Figures 2.4-6 through 2.4-9. During each test, dissolved oxygen and temperature readings were continuously logged and reviewed in the field in "real time". Dissolved oxygen concentrations were recorded throughout the test period or until equilibrium in dissolved oxygen concentrations was reached. Equilibrium was considered to have been reached when the dissolved oxygen concentrations of three successive readings were within 0.5 mg/l of each other. Each reading for this test was a 15-minute average concentration. Short term variations of less than 0.5 mg/l are typical in the tailwaters due to water turbulence. Once equilibrium was reached in the tailwater under each operating scenario, real time monitoring continued for at least 2 hours. At the end of each day's testing, all data were downloaded and evaluated to help guide the following day's testing and shed light on the persistence of changes in tailwater dissolved oxygen concentrations downstream. The meters were serviced and calibrated prior to and after testing and were checked for calibration with an independent meter at the beginning and end of each test scenario and each time the data were downloaded.

Similar data were required for all dissolved oxygen testing. The data type and source are as follows:

- Dissolved Oxygen and Temperature - The existing continuous dissolved oxygen/temperature monitors in the High Rock, Tuckertown, Narrows and Falls tailwaters were used to measure dissolved oxygen and water temperature.
- Turbine Power Output - The turbine power output for all powerhouses was measured using existing metering equipment and recorded in the APGI Operating Center.
- Turbine Discharge - Water flow through all turbines was calculated from power output.

Narrows

At Narrows, a follow-up to the 2001 dissolved oxygen testing was performed to meet the first and second study objectives outlined above. The testing was designed to use existing equipment to temporarily increase Narrows tailwater dissolved oxygen to the extent possible, and to investigate how and to what degree this translated into dissolved oxygen increases downstream through the Falls tailwater. To do this, the turbines at Narrows powerhouse were used to introduce air into the water stream in the draft tubes through two sources. The first source is the aeration system installed on the draft tube at Narrows Unit 4 as part of the turbine refurbishment and upgrade. In addition, the Narrows Units 1 through 3 naturally aspirate air through the water wheel cone in the range of 20 to 35 percent wicket gate opening (approximately 1000 cfs per unit). Valves open while the turbine is operating at this small wicket gate setting to allow air to enter the draft tube to stabilize the turbulence that is inherent in this operating range.[2]

[2] This air serves to reduce vibration and damage to the equipment during loading and unloading of the generating unit. While this mode of operation allowed Yadkin to conduct a test on a short-term basis, it is not suitable for continuous operation due to the very low efficiency and the potential for damage to the turbines.

The Narrows turbines were started individually beginning with Unit 4 at best efficiency with both air valves closed. Next, a single air valve was opened, and then the second air valve was opened. The other three turbines were started sequentially and operated at 30% wicket gate to allow air to enter the draft tube. Next, each of Units 1 through 3 were brought from 30% gate to best efficiency one at a time so that the incremental impact of the configuration changes could be observed. To allow the tailwater dissolved oxygen concentrations to reach equilibrium for each operating configuration, the duration of each test was a minimum of 3 hours and the various test sequences were run on successive days.

The operation of the Narrows turbines in each test mode was continued for a sufficient length of time to evaluate the effect of increased dissolved oxygen at Narrows on dissolved oxygen in the Falls tailwater. The expected travel time of the oxygenated water from Narrows to Falls was estimated at about 3 hours based upon discharge volume and reservoir storage prior to the survey and confirmed by observations during the testing. This expected travel time is lower than the annual average (1.7 hours) presented earlier in this report.. The dissolved oxygen in the Falls tailwater was monitored using the currently installed continuous dissolved oxygen monitors throughout the testing at Narrows.

Falls

The turbines at Falls powerhouse were started and operated at power output necessary to pass the flow coming from Narrows powerhouse with a minimum of reservoir fluctuation, mimicking typical operation for Yadkin.

High Rock and Tuckertown

A similar set of information is desired at High Rock and Tuckertown to address the third objective of this study. Though no air injection system is currently installed at High Rock, as part of this study, Yadkin used existing piping and valves on the three High Rock units to inject air through the bearing riser to the top of the runner, on a short term basis, as a way of increasing High Rock tailwater dissolved oxygen concentrations. While this method of injecting air can only be used for short term test purposes due to the low efficiency and potential damage to the turbine, it was used to evaluate on an order-of magnitude basis, whether increasing High Rock dissolved oxygen concentrations results in a measurable improvement in dissolved oxygen concentrations in the Tuckertown tailwater. The testing program below High Rock and Tuckertown was conducted in a manner similar to that proposed for Narrows and Falls as described above.

During this test, the intent was to start Tuckertown turbines and operate at power output necessary to pass the flow coming from High Rock powerhouse with a minimum of reservoir fluctuation. However, power generation needs required that Tuckertown be operated somewhat differently than planned and the units were operated in more of a peaking mode.

3.3.2.2 Results for 2004 Survey

The results of the 2004 testing are presented and discussed for each development. Results are presented in Table 3.3-3 and in Figures 3.3-4 through 3.3-6. The dissolved oxygen and temperature data and the discharge data are presented in separate figures for clarity, and the figures are presented one above the other for comparison.

Narrows

The 2004 Narrows/Falls testing took place over a four-day period in August, recording dissolved oxygen concentrations under various operating regimes, with and without air valve operation. A description of the various operating regimes, from lowest to highest discharge, and the observations recorded during each survey are presented in Table 3.3-3. The actual dissolved oxygen readings taken at 15-minute intervals in the Narrows tailwater are presented in Figure 3.3-4, the Narrows discharge data are presented in Figure 3.3-5 and a profile of the intake dissolved oxygen is presented in Figure 3.3-6. The Narrows data show that:

Table 3.3-3. August 2004 Operations Testing – Narrows Configuration and Results.

Test	Unit Configuration	Total Discharge cfs	Dissolved Oxygen Change mg/l	Dissolved Oxygen mg/l
Baseline	U4 @ 20% gate or 4 MW	350		5.25
Test 6	U4 @ BE or 28 MW no air	2240	-2.00	3.25
Test 7	U4 @ BE or 28 MW 1 air vlv	2240	1.75	5.00
Test 8	U4 @ BE or 28 MW 2 air vlv	2240	0.25	5.25
Test 9	U4 @ BE or 27 MW 2 air vlv U1 @ 30% gate or 5 MW	2580		
Test 4	U4 @ BE or 25 MW 2 air vlv U1, U2 @ 30% gate or 8, 8 MW	3420	0.25	5.50
Test 5	U4 @ BE or 25 MW 2 air vlv U1, U2, U3 @ 30% gate or 8, 8, 7 MW	4625		
Test 1	U4 @ BE or 23 MW 2 air vlv U1 @ BE or 23 MW 333U2, U3 @ 30% gate or 8, 8 MW	4885	-1.50	4.00
Test 2	U4 @ BE or 25 MW 2 air vlv U1, U2 @ BE or 24, 24 MW U3 @ 30% gate or 8 MW	6440	-0.50	3.50
Test 3	U4 @ BE or 29 MW 2 air vlv U1, U2, 26, 28, U3 @ BE or 28 MW	9170	0.00	3.50

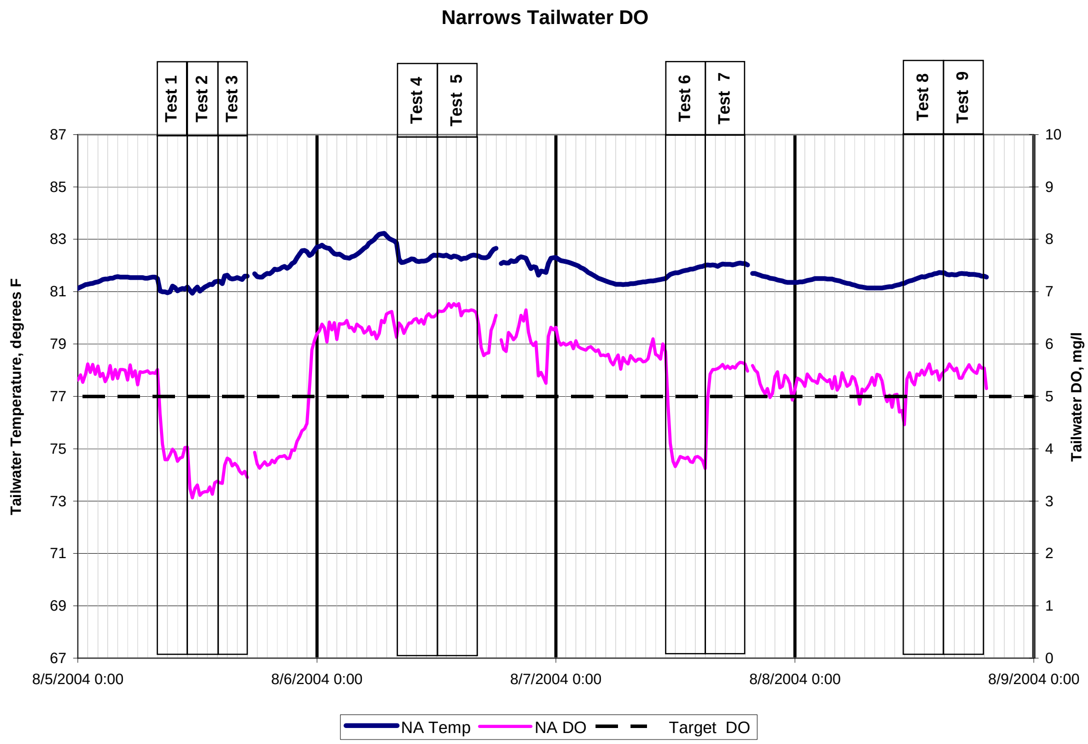


Figure 3.3-4. Narrows 2004 Operations Test – dissolved oxygen and Temperature

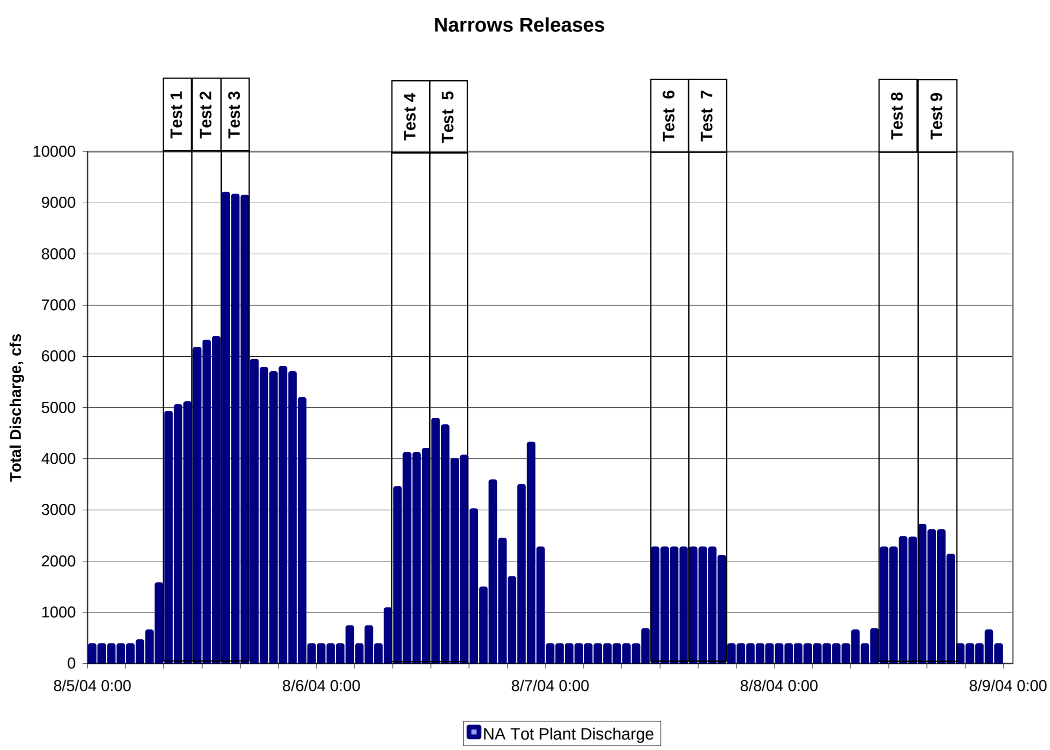


Figure 3.3-5. Narrows 2004 Operations Test – Discharge

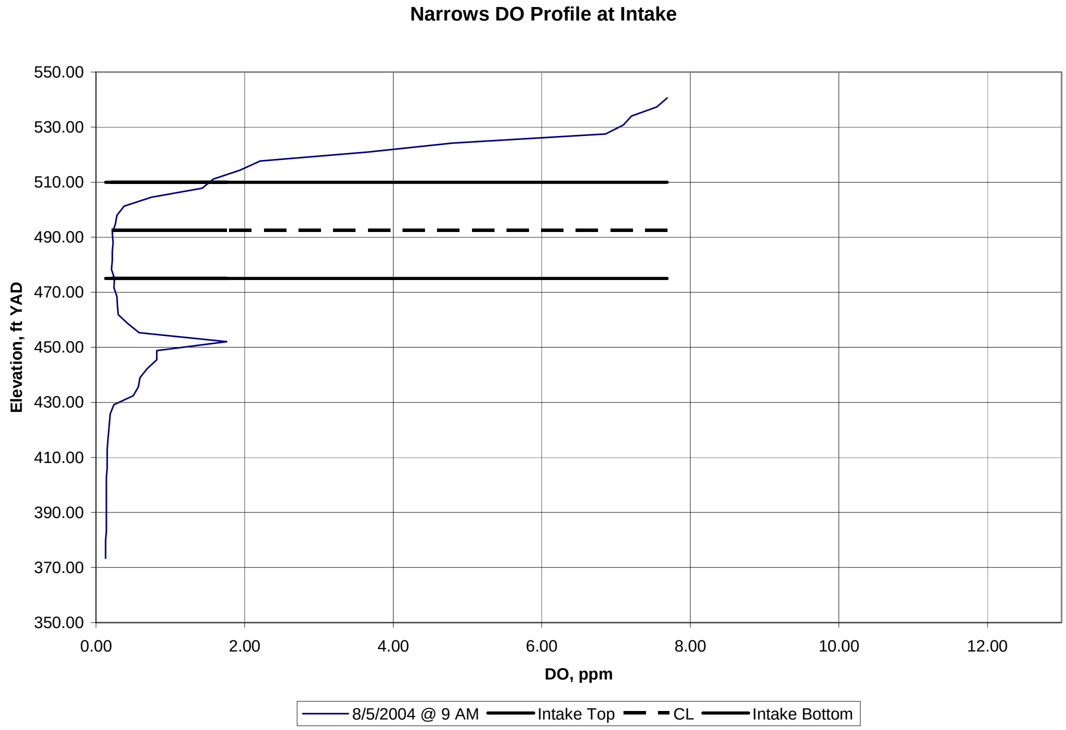


Figure 3.3-6. Narrows 2004 Operations Test – Intake dissolved oxygen Profile

- **Baseline -** At the start of the testing, Unit 4 was running at 3-4 MW, the reservoir dissolved oxygen was about 1 mg/l at the intake, and the tailwater dissolved oxygen was 5 to 6 mg/l. The higher tailwater dissolved oxygen could be because, 1) the volume of low dissolved oxygen water introduced into the tailwater under this operating condition is so small that it has negligible impact on the fully-mixed tailwater dissolved oxygen; 2) the unit is pulling the higher dissolved oxygen surface water into the intake; or 3) running a unit at 3-4 MW adds substantial dissolved oxygen to the discharge. Tests 9, 4 and 5 further investigate the effect on tailwater dissolved oxygen of operation at low loads. The results lead to the conclusion that running a unit at 3-4 MW does not significantly improve the tailwater dissolved oxygen under higher flow configurations.
- **Test 6 -** Starting Unit 4 at best efficiency with no air valves reduces dissolved oxygen by 2 mg/l.
- **Tests 7 and 8 -** With only Unit 4 on-line, opening the two air injection valves increased the dissolved oxygen about 2 mg/l with about 88 percent of the increase provided by the first valve, and an additional 12 percent increase from the second valve.
- **Tests 9, 4 and 5 -** The sequential addition of Units 1, 2 and 3 at 30 percent gate improves the dissolved oxygen only slightly. The operation of Units 1, 2 and 3 at 30 percent gate resulted in a discharge plume white with air bubbles, but the dissolved oxygen measured in the tailwater increased only 0.25 mg/l.
- **Tests 1, 2 and 3 -** The sequential ramp up of Units 1, 2 and 3 from 30 percent gate to best efficiency reduces the dissolved oxygen 2 mg/l.

Falls

The actual dissolved oxygen readings taken at 15-minute intervals in the Falls tailwater are presented in Figure 3.3-7, the Falls discharge data are presented in Figure 3.3-8 and a profile of the intake dissolved oxygen is presented in Figure 3.3-9. In general, the response in the Falls tailwater DO to changes in the Narrows tailwater DO is similar though of lesser magnitude. A low discharge at Narrows, such as that during single unit operation, has a slight effect in the Falls tailwater, and the effect increases as the Narrows discharge increases. The Falls data show that:

- **Baseline -** At the start of the testing, dissolved oxygen at both the Falls reservoir intake and tailwater was 6 to 7 mg/l.
- **Tests 6, 7 and 8 –** Tests 6, 7 and 8 are all single unit operation at Narrows. The 2 mg/l drop in dissolved oxygen in the Narrows tailwater that resulted from starting Unit 4 at best efficiency with no air valves, followed by the 2 mg/l increase upon opening the two air valves has a similar though very small, if any, impact on Falls tailwater dissolved oxygen levels.
- **Test 9 -** The addition of Unit 1 at 30 percent gate at Narrows does not have any measurable effect in either the Narrows or the Falls tailwater.
- **Tests 4 and 5 -** The sequential addition of Units 2 and 3 at 30 percent gate at Narrows does not have a measurable effect at Narrows. However, the Falls tailwater dissolved oxygen drops 1 mg/l from 6 to 5 mg/l during Tests 4 and 5. This 1 mg/l drop in dissolved oxygen at Falls may be due to lower dissolved oxygen water released from Narrows the day before, residing in Falls reservoir during the overnight Falls shutdown, then being released on Falls at the start up for Test 4.
- **Tests 1, 2 and 3 -** Tests 1, 2 and 3 are two-, three- and four-unit operation at Narrows, respectively. Changes in the Narrows tailwater dissolved oxygen under these higher flow releases are more strongly reflected in the Falls tailwater. The 2 mg/l drop in dissolved oxygen at Narrows that results from the sequential ramp up of Units 1, 2 and 3 from 30 percent gate to best efficiency results in a 1 to 2 mg/l drop in the Falls tailwater dissolved oxygen.

High Rock and Tuckertown

The 2004 High Rock/Tuckertown testing took place over a three-day period, recording dissolved oxygen concentrations under a single operating configuration with air injection into all three High Rock units. Valves on all three High Rock units were opened at 1PM on August 4 and the High Rock units were run in this configuration for a period of 44 hrs, the estimated time required for the water to travel to Tuckertown Dam. The units were set at 50% gate, the setting that provided the maximum air intake. The actual dissolved oxygen readings taken at 15-minute intervals in the High Rock tailwater are presented in Figure 3.3-10. The High Rock discharge data are presented in Figure 3.3-11 and a profile of the intake dissolved oxygen is presented in Figure 3.3-12. The High Rock data show that:

- The reservoir dissolved oxygen at the start of the test, as shown in Figure 3.3-12, varies from 1 to 9 mg/l from the bottom to the top of the intake and averages about 4 mg/l. At the end of the test, Figure 3.3-13, the reservoir dissolved oxygen profile at the intake has become a more uniform 5.5 mg/l across the intake.

Because no response is seen upon opening the valves at the beginning of the test, this method of air injection does not result in a measurable increase in the High Rock tailwater dissolved oxygen. Though the dissolved oxygen increases over the three-day test period, it is apparently the result of improved reservoir dissolved oxygen and diurnal cycles in the dissolved oxygen and temperature rather than air introduced by the unit valves.

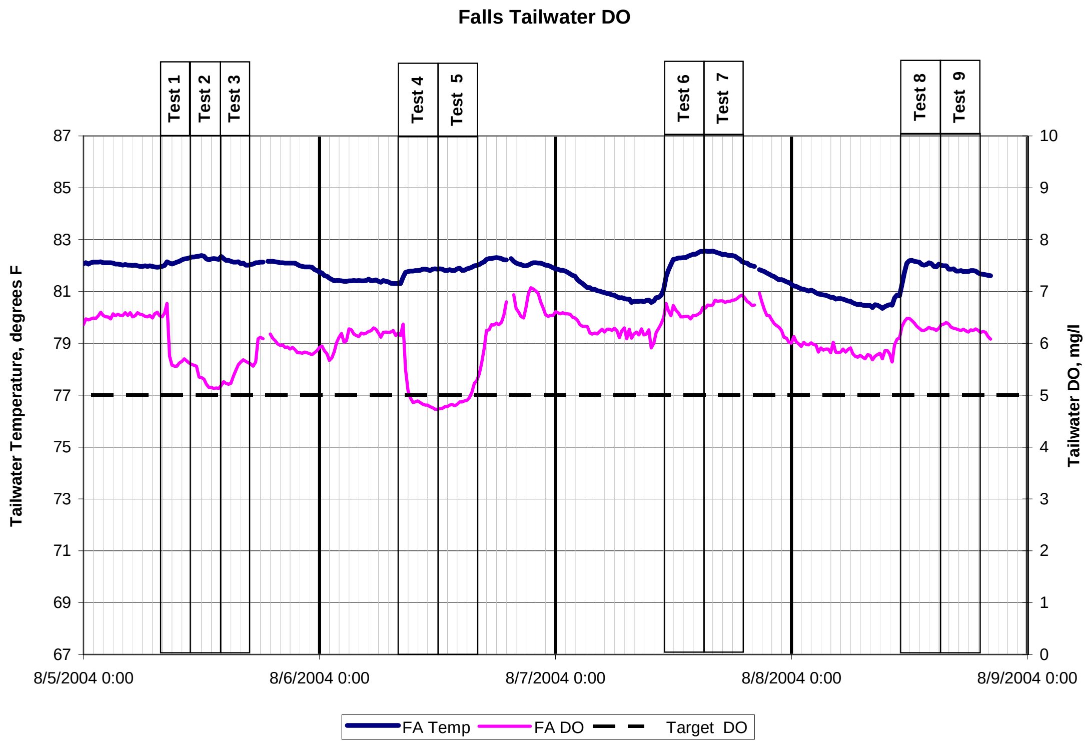


Figure 3.3-7. Falls 2004 Operations Test – Dissolved Oxygen and Temperature

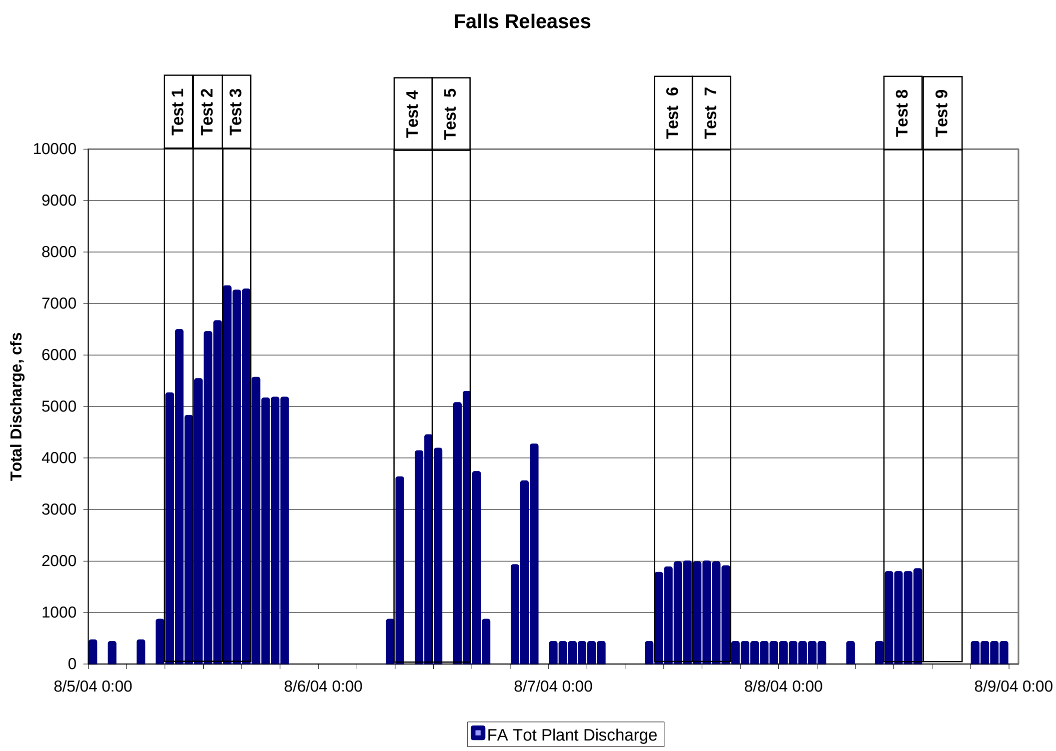


Figure 3.3-8 Falls 2004 Operations Test – Discharge

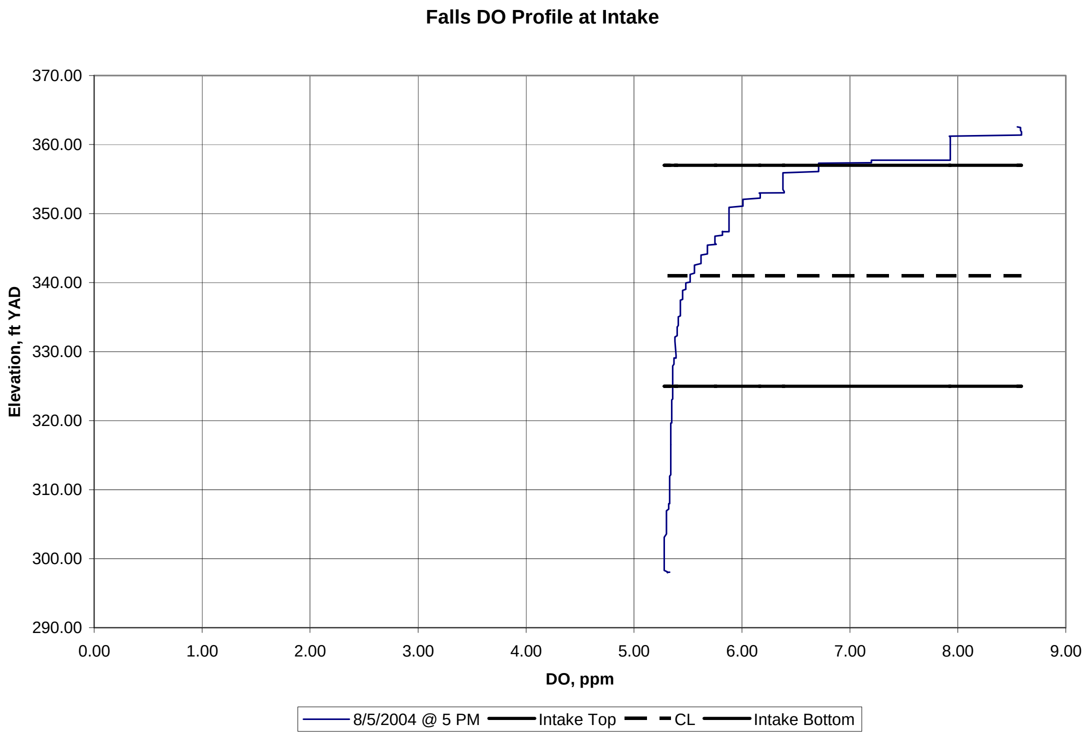


Figure 3.3-9. Falls 2004 Operations Test – Intake Dissolved Oxygen Profile

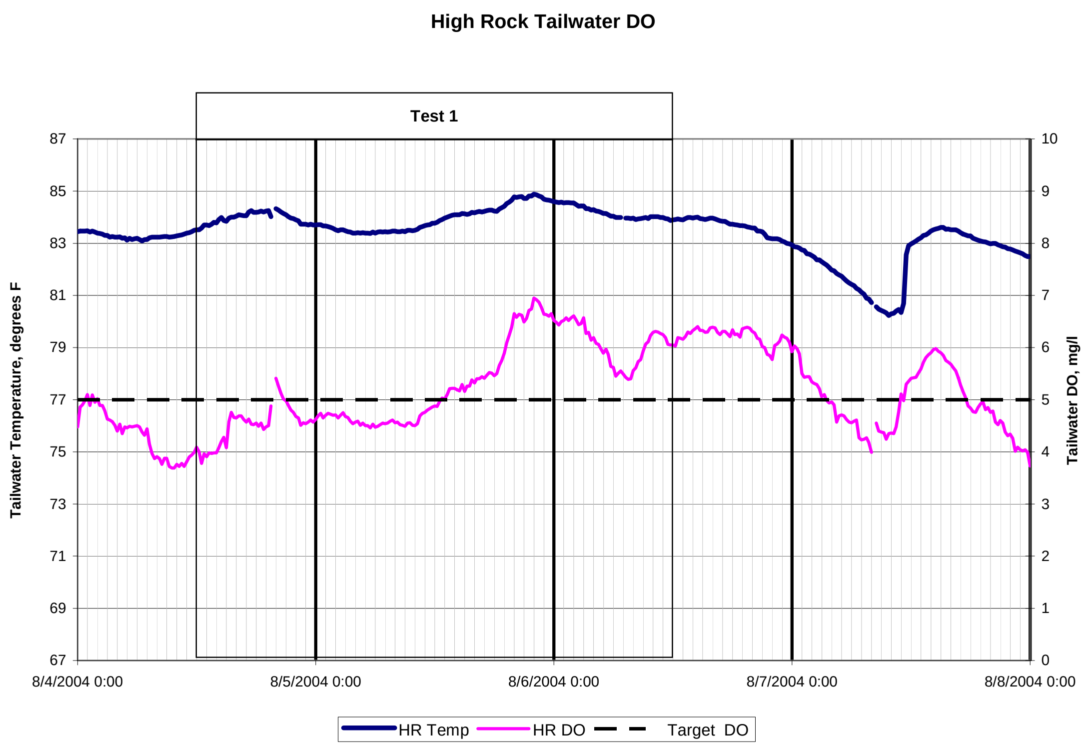


Figure 3.3-10. Rock 2004 Operations Test – Dissolved Oxygen and Temperature

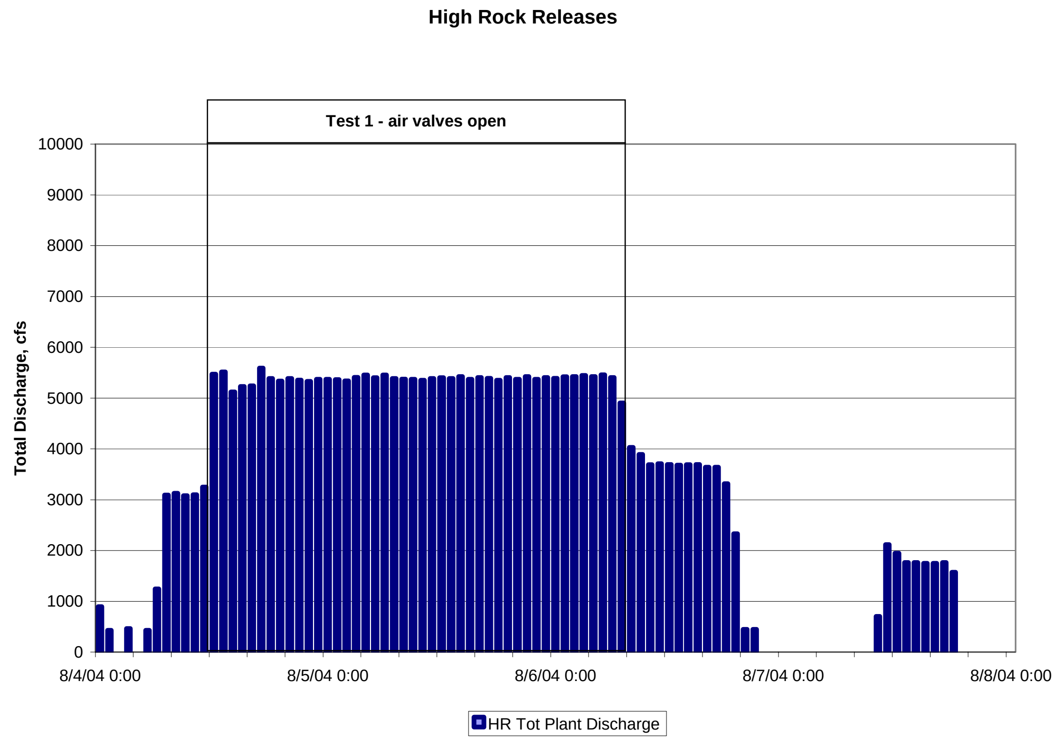


Figure 3.3-11. High Rock 2004 Operations Test – Discharge

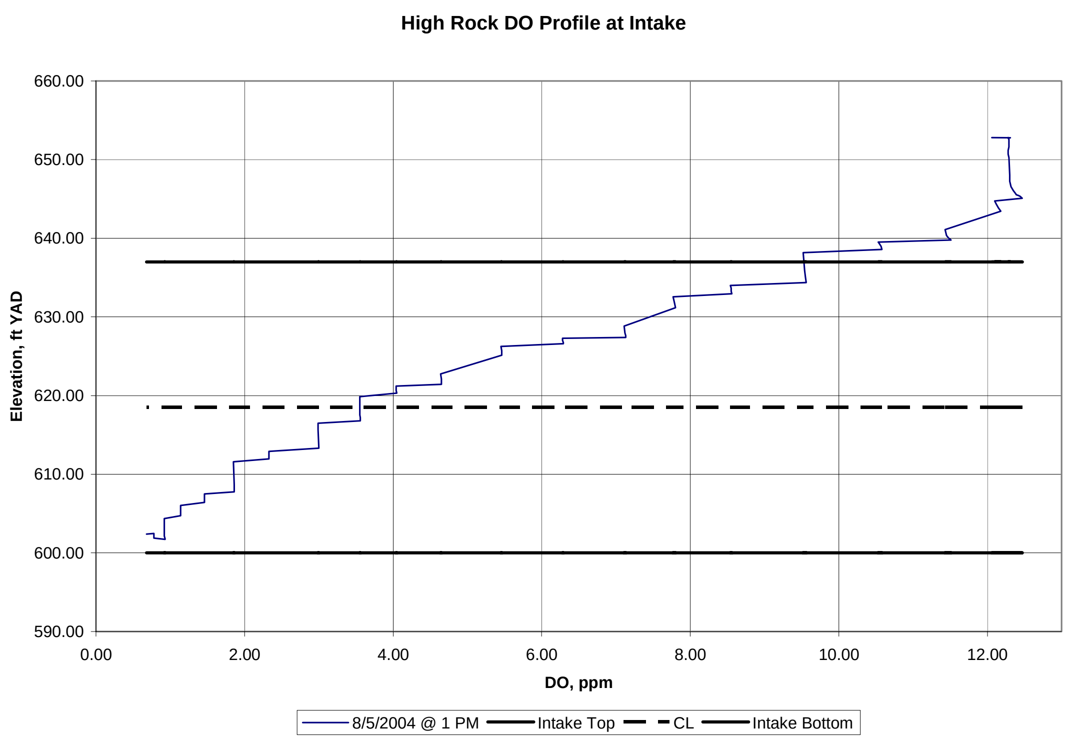


Figure 3.3-12. High Rock 2004 Operations Test – Intake Dissolved Oxygen Profile August 5, 2004

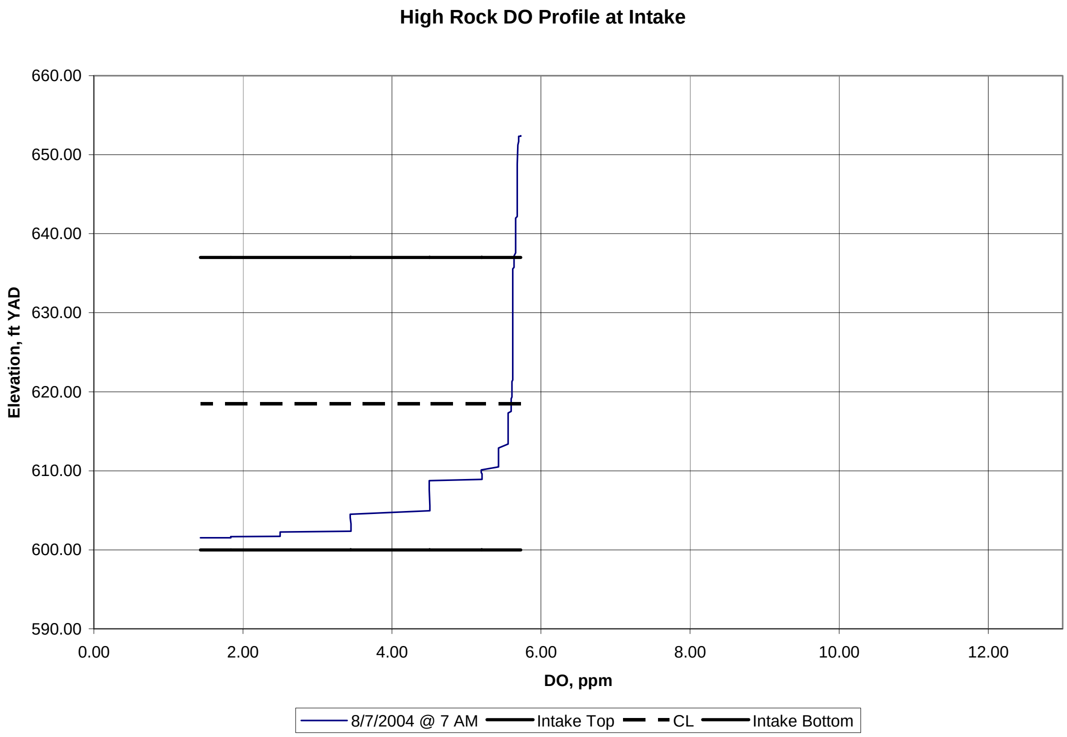


Figure 3.3-13. High Rock 2004 Operations Test – Intake Dissolved Oxygen Profile August 7, 2004.

Tuckertown

The actual dissolved oxygen readings taken at 15-minute intervals in the Tuckertown tailwater are presented in Figure 3.3-14, the Tuckertown discharge data are presented in Figure 3.3-15 and a profile of the intake dissolved oxygen is presented in Figure 3.3-16. The Tuckertown data show that :

- The reservoir dissolved oxygen at the start of the test, as shown in Figure 20, averages about 2 mg/l.
- Since air injection at High Rock did not result in a measurable increase in the High Rock tailwater dissolved oxygen, no response was seen at the Tuckertown tailwater. The changes in tailwater dissolved oxygen appear to be a result of operation of the Tuckertown units. The diurnal cycles in the dissolved oxygen and temperature are not as evident at Tuckertown, possibly because they are obscured by the peaking operations.
- The tailwater dissolved oxygen at Tuckertown increases over the test period, likely the result of improved reservoir dissolved oxygen similar to High Rock.

3.3.3 Conclusions of Operation Testing

Though Yadkin was able to perform only the preliminary testing because of severe weather conditions, in general, the 2004 testing was successful. Where possible, the 2001 data were compared to the 2004 data and the comparison reveals that the trends from 2001 were generally repeated in the 2004 tests. The longer duration of each test in 2004 allowed the dissolved oxygen to come to equilibrium following each configuration change and resulted in fewer erratic swings in dissolved oxygen.

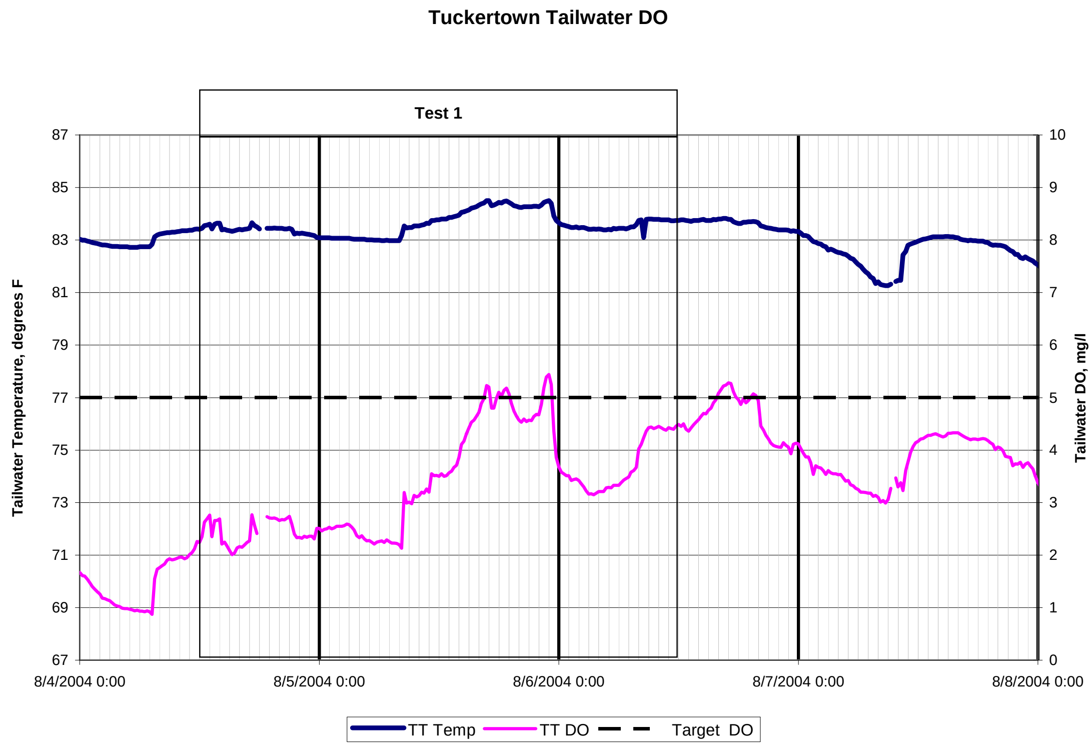


Figure 3.3-14. Tuckertown 2004 Operations Test – Dissolved Oxygen and Temperature

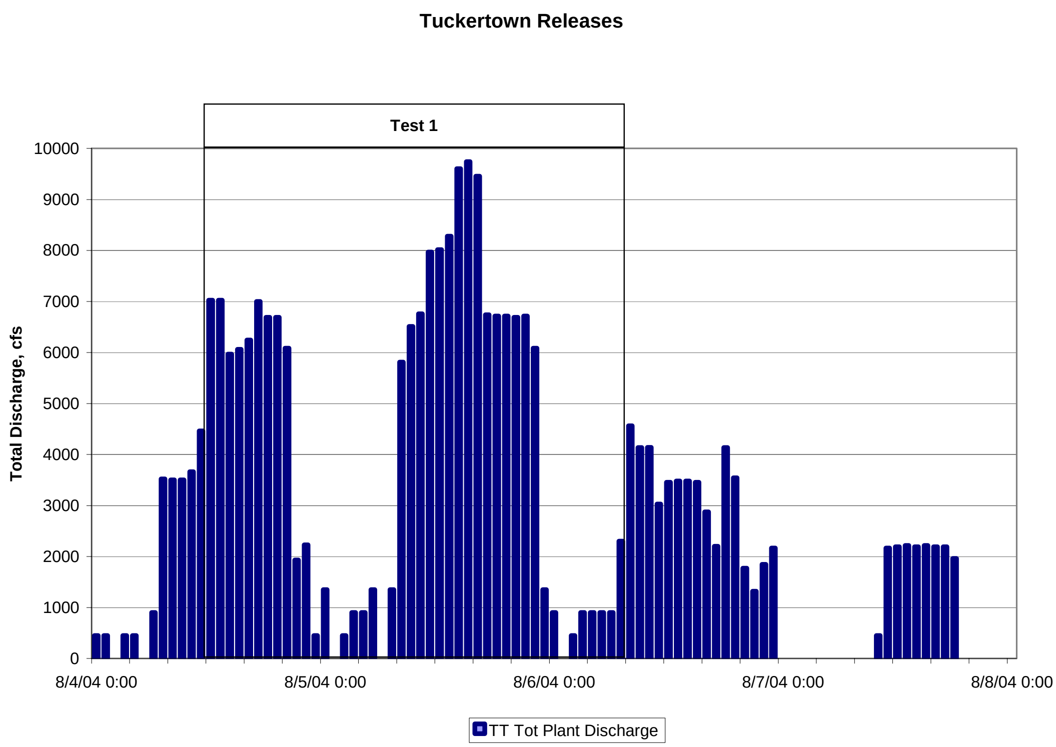


Figure 3.3-15. Tuckertown 2004 Operations Test – Discharge

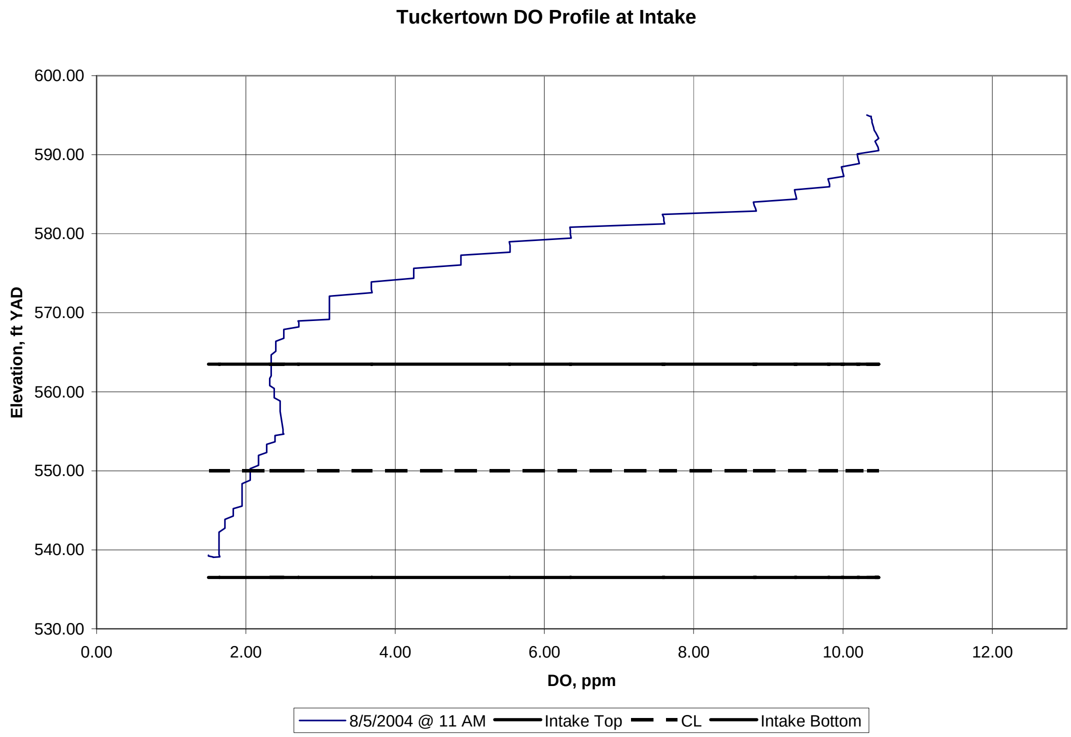


Figure 3.3-16. Tuckertown 2004 Operations Test – Intake Dissolved Oxygen Profile

Narrows

A comparison of the 2001 data to the 2004 data with respect to the effect of the Narrows Unit 4 air valves reveals a response in the tailwater dissolved oxygen that is repeatable. Unit 4, operated alone with two air injection valves open, increases the tailwater dissolved oxygen from 2 to 4 mg/l above operation with no air valves. Operated in this manner, Unit 4 draws in water with a dissolved oxygen of about 1 mg/l from the reservoir and introduces enough air in the water stream to maintain the tailwater dissolved oxygen between 5 to 6 mg/l. The majority of the increase, about 88 percent, is provided by opening the first air valve, and the balance is provided by opening the second valve.

Increasing the Narrows output by the sequential ramp up of Units 1, 2 and 3 to their best efficiency point caused a 2 mg/l drop in the tailwater dissolved oxygen, erasing the dissolved oxygen improvement provided by the Unit 4 valves and dropping the dissolved oxygen to 3 to 4 mg/l. This result leads to the conclusion that the air valves on Unit 4 alone cannot maintain the Narrows tailwater at or above state standards with two or more units operating. And though the operation of Units 1, 2 and 3 at 30 percent gate appeared to add air in the tailrace, the tailwater dissolved oxygen measurements showed only a slight improvement. This result leads to the conclusion that operation of Unit 4 and a combination of Units 1, 2 and 3 operating at either best efficiency or at 30 percent gate will also not maintain the Narrows tailwater at or above state standards.

Falls

When Narrows and Falls are passing similar flows, dissolved oxygen improvements in the Narrows tailwater are reflected in the Falls tailwater dissolved oxygen. When Narrows is operating at 5,000 cfs and higher, dissolved oxygen improvements in the Narrows tailwater are strongly reflected in the Falls tailwater dissolved oxygen within about two hours. As Narrows releases are reduced, dissolved oxygen improvements in the Narrows tailwater have less effect on the Falls tailwater dissolved oxygen.

High Rock/Tuckertown

Injecting air through the bearing riser on the three High Rock units could not introduce enough air into the discharge to improve the High Rock tailwater dissolved oxygen conditions. As a result, no conclusions regarding whether improving High Rock tailwater dissolved oxygen would likewise improve the dissolved oxygen below Tuckertown can be reached based on the 2004 tests.

In summary, the test data point to the following conclusions:

- The air injection on Narrows Unit 4 clearly improves the tailwater dissolved oxygen. When Unit 4 is operated alone with 2 air valves open, the unit takes in water from the reservoir at a dissolved oxygen of about 1 mg/l and introduces enough air in the water stream that the resulting tailwater dissolved oxygen is 5 to 6 mg/l. Given this result it follows that similar air valves on all four Narrows units would likely maintain tailwater dissolved oxygen at or above 5 mg/l when the units are running.
- If state standards are met on a continuous basis in the Narrows tailwater it is likely that no additional improvements will be required at Falls to assure that the Falls tailwater dissolved oxygen meets state standards.
- Because the High Rock units did not improve the High Rock tailwater dissolved oxygen conditions, no conclusions can be reached from the High Rock/Tuckertown test.

3.4 LATERAL AND LONGITUDINAL INVESTIGATION OF DISSOLVED OXYGEN IN THE VICINITY OF THE DAMS

This investigation was undertaken in response to Issue Advisory Group (IAG) comments that suggested that the influence of project operations may extend upstream and downstream beyond the immediate vicinity of the dams during the period of summer stratification. The extremes of normal project operations incorporating full generation and no generation were chosen to illustrate this effect, if present.

The extent and degree of stratification behind each of the dams and downstream was evaluated during one survey. This survey was conducted in August of 2004. A second survey was scheduled for September of 2004 but had to be cancelled due to the presence of high river flows from the remnants of two hurricanes. Two scenarios were evaluated during the survey. One scenario involved monitoring after a prolonged (> 6 hour) period of generation at each facility. Monitoring under the second scenario was after a prolonged (> 6 hour) period with no generation or spills at each facility.

During each reservoir survey, dissolved oxygen and temperature profiles were measured at the quarter points in each of the four impoundments along transects spaced at ¼ mile intervals starting at the buoy line and proceeding upstream. Additional transects were added until two adjacent transects showed similar profiles in terms of the depth of the thermocline and the extent of dissolved oxygen depletion at depth. Reservoir transect locations are presented in Figures 3.4-1 through 3.4-4.

The dynamics of dissolved oxygen and temperature downstream of the dams were evaluated in a similar fashion as the reservoir surveys. Starting at the continuous monitoring locations, dissolved oxygen and temperature were measured by profile at the quarter points in the channel along transects spaced at ¼ mile increments downstream. Additional transects were added until observed

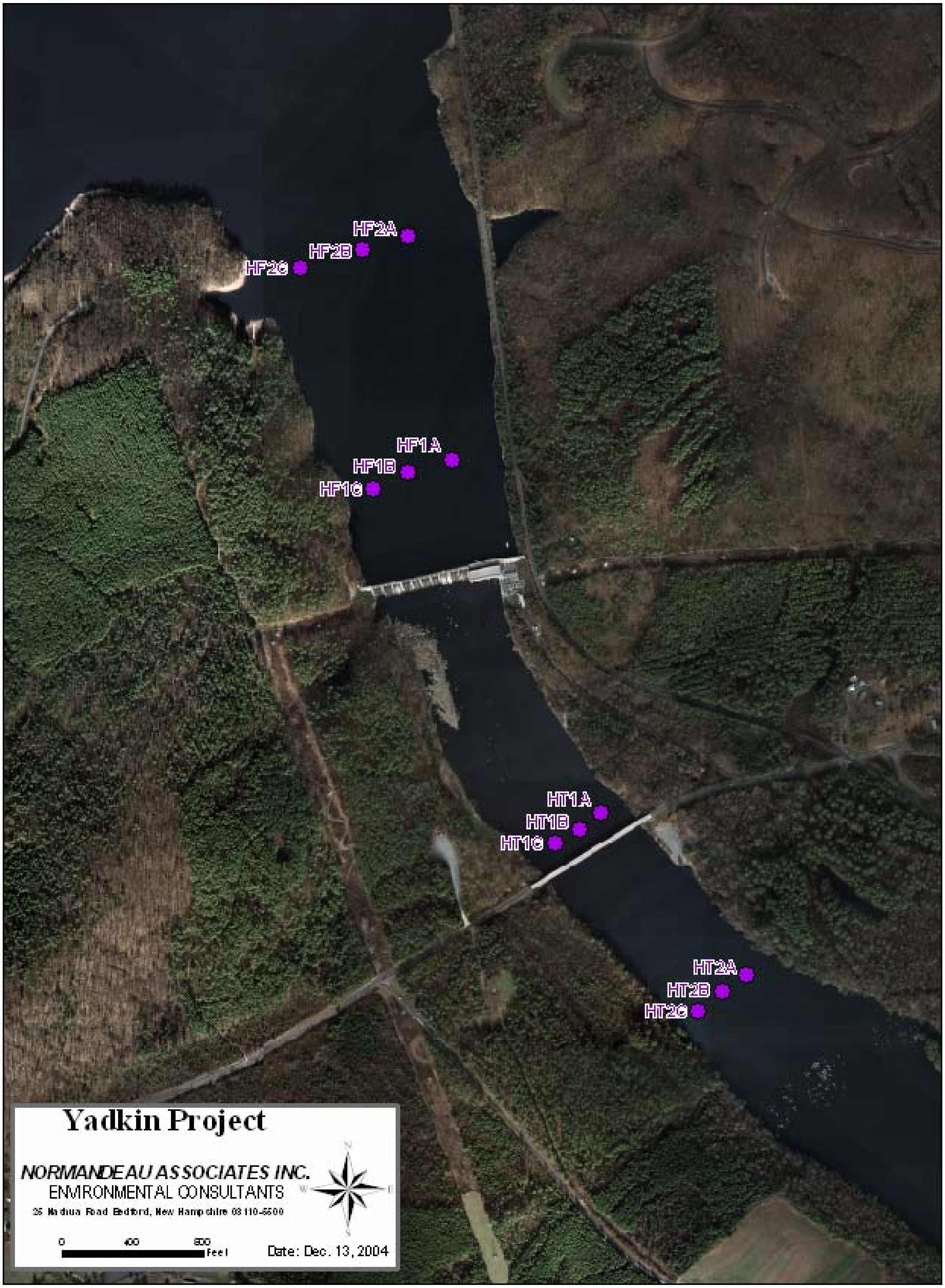


Figure 3.4-1. Location of transects/sampling stations for lateral and longitudinal survey of dissolved oxygen and temperature at High Rock.

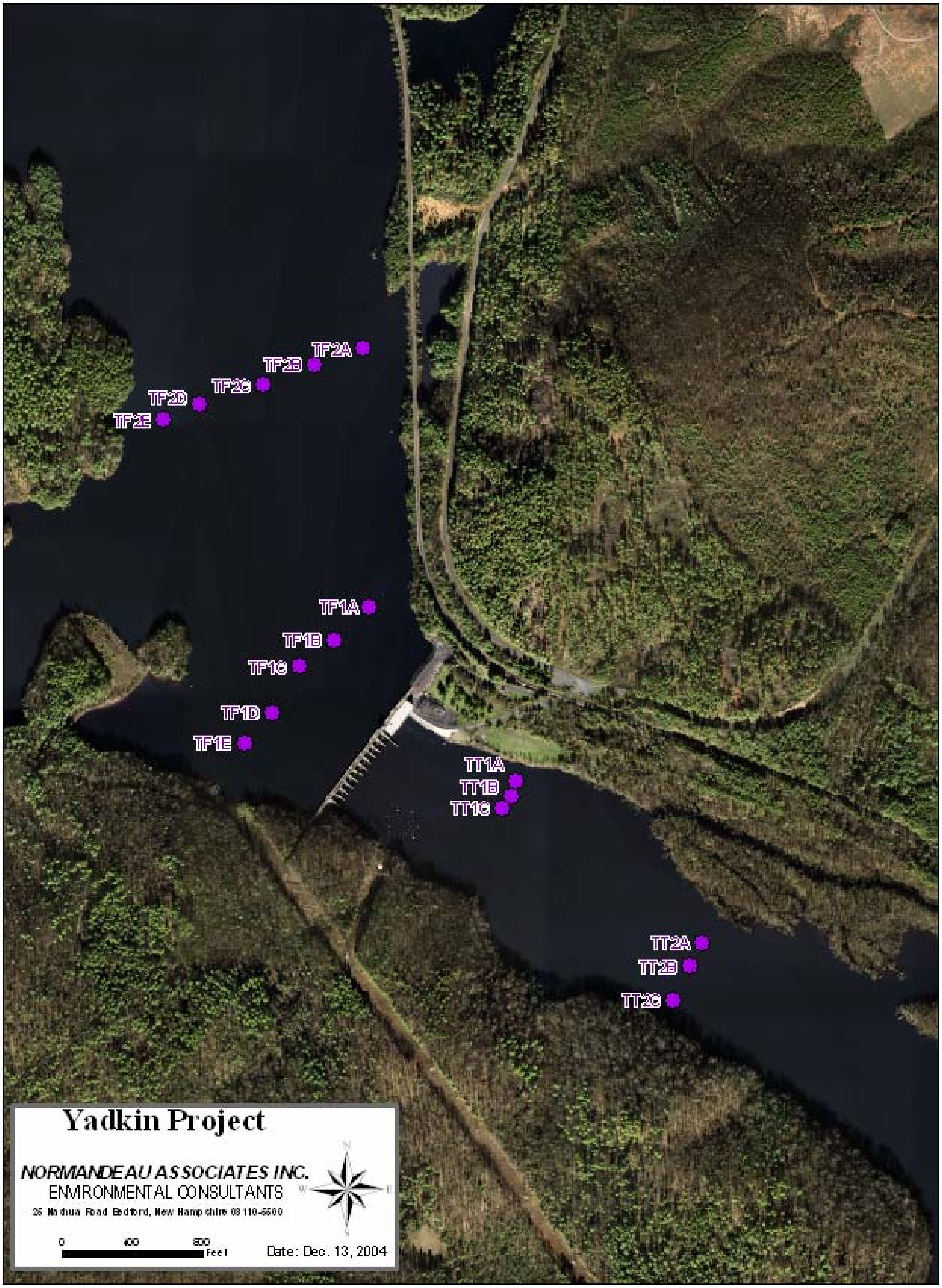


Figure 3.4-2. Location of transects/sampling stations for lateral and longitudinal survey of dissolved oxygen and temperature at Tuckertown.

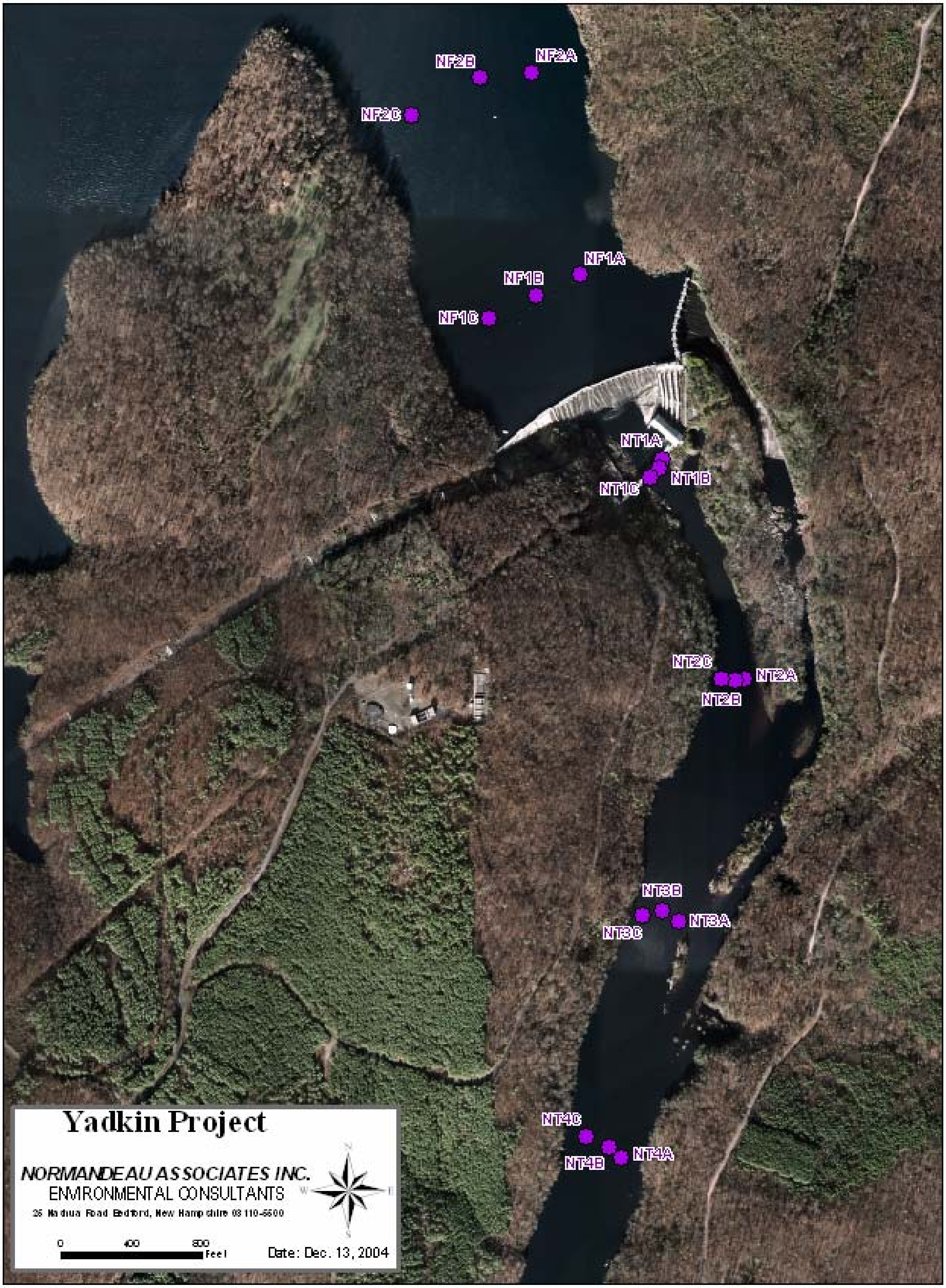


Figure 3.4-3. Location of transects/sampling stations for lateral and longitudinal survey of dissolved oxygen and temperature at Narrows.

Figure 3.4-4. Location of transects/sampling stations for lateral and longitudinal survey of dissolved oxygen and temperature at Falls.

temperature and dissolved oxygen conditions at consecutive transects were similar or the river channel became part of the next downstream impoundment. Tailrace transect locations are presented in Figures 3.4-1 through 3.4-4.

The lateral and longitudinal survey was conducted on August 20 and 21, 2004. A schedule for the full generation survey is presented in Table 3.4-1 while a schedule for the no generation survey is presented in Table 3.4-2. The depth from the normal fill pond elevation to the intakes is presented in

Table 3.4-1. Schedule for lateral and longitudinal survey of dissolved oxygen and temperature after 6 hours of full generation, August 20, 2004.

	High Rock	Tuckertown	Narrows	Falls
Beginning of generation	0700	0800	1100	1100
Beginning of reservoir survey	1200	1211	1446	1523
End of reservoir survey	1226	1312	1525	1550
Beginning of tailwater survey	1315	1404	1629	1649
End of tailwater survey	1334	1429	1700	1715
End of generation	1600	1600	1600[a]	1600[a]

[a] Generation at Narrows and Falls was gradually ramped down from full to zero from 1600 to 2200.

Table 3.4-2. Schedule for lateral and longitudinal survey of dissolved oxygen and temperature after 6 hours with no generation, August 21, 2004.

	High Rock	Tuckertown	Narrows	Falls
Cessation of generation	2400	0100	2200 (8/20)[a]	2200 (8/20)[a]
Beginning of reservoir survey	1623	1425	1136	0926
End of reservoir survey	1641	1458	1159	0948
Beginning of tailwater survey	1536	1220	0959	0828
End of tailwater survey	1546	1230	1029	0844
Start of generation	8/23	8/23	8/23	8/23

[a] Narrows Unit 4 was run at 3 MW or roughly 10% of the full load for that unit throughout the no generation test. This represents the standard no generation operating regime at Narrows due to a standing power contract. Units 1, 2 and 3 were not operated during the test.

Table 3.4-3. The strata entrained in the turbine intakes is critical to the dissolved oxygen concentration in the tailrace and may have an influence on the distribution of nearfield and farfield dissolved oxygen in the impoundments. In general, there was only slight dissolved oxygen and

Table 3.4-3. Depth to intakes from normal full pond elevation.

Project	Depth to Top of Intakes (M)	Depth to Bottom of Intakes (M)
High Rock	5.5	16.8
Tuckertown	9.9	18.1
Narrows	9.5	20.2
Falls	2.1	11.9

temperature variability observed among any of the transects near any of the dams. Minimum, maximum and mean dissolved oxygen by transect is presented in Table 3.4-3. The distribution of dissolved oxygen within each transect was also very similar at each dam whether the units were generating or not.

3.4.1 Results of Lateral and Longitudinal Survey

Summaries of the dissolved oxygen and temperature data are presented in Table 3.4-4 through 3.4-7. Profile data and dissolved oxygen contour plots for each transect monitored during these surveys can be found in Appendix K. Results are described in terms of comparisons between transects under each generation survey, comparisons between profiles along each transect and comparisons of transects between generation scenarios. The depth of the 5 mg/l dissolved oxygen contour is used as a surrogate to evaluate changes in the size of the depleted oxygen zone between surveys and transects (Table 3.4-8). Characteristics of the impoundments and facilities were presented in Table 1.0-1.

High Rock

Profiles taken along the transect F1 at the buoy line in the High Rock impoundment showed minimal thermal stratification (surface – bottom differences of 2-4ºC) but strong dissolved oxygen gradients from top to bottom under both the generation and no generation scenarios (Table 3.4-4). Observed surface dissolved oxygen concentrations were 10-11 mg/l while concentrations near the bottom were 2-3 mg/l. The primary difference between the profiles at this transect under different operational conditions was the expansion of the depleted oxygen zone (Table 3.4-8). Under generation, the waters with dissolved oxygen concentrations below 5 mg/l were found below 7-11 meters (22-35 ft) depth with the greatest effect seen at station 1A (5 mg/l at 6.4 meters) followed by 1B then 1C. Station 1A is on the same side of the river as the intakes for the turbines. Under the no-generation scenario, the depleted oxygen zone (dissolved oxygen < 5 mg/l) was observed below 12 m at all three stations along transect 1. At transect 2, the depleted dissolved oxygen zone was observed below 10 m under both the generation and non-generation scenarios. The impact of generation on reservoir dissolved oxygen in High Rock appears to be restricted to the immediate area of the dam. The turbine intake depth at High Rock is 5.5 m to 16.8 m below the surface (18 to 55 ft below the surface). Water pulled from this interval to the turbines appears to be replaced with water with lower oxygen content deeper in the reservoir.

High Rock tailrace temperatures and dissolved oxygen concentrations were similar at all depths and at both transects under each generating scenario. Temperatures observed at both tailrace transects during the generation survey were 24.9ºC. During the non-generation survey temperatures varied from 25.6ºC to 27.6ºC. Dissolved oxygen concentrations in the tailrace varied from 4.3 and 5.3 mg/l during generation and between 5.4 and 6.0 mg/l during the non-generation survey.

Tuckertown

The Tuckertown Impoundment is of similar depth to the High Rock impoundment. Similarly, it does not thermally stratify to any great degree, however, depleted dissolved oxygen concentrations are observed at depth. During the course of the surveys, there was minimal thermal stratification (surface – bottom differences of 2ºC). At the dam, Tuckertown impoundment is wider than the other three Yadkin APGI impoundments at the dams, so 5 profiles were taken along each transect. Surface dissolved oxygen concentrations were 12-13 mg/l (approximately 150% of saturation) during the generation survey at both transect locations indicating that an intense algae bloom was occurring. This was not observed to the same degree during the non-generation survey despite the fact that the

Table 3.4-4. Summary of lateral and longitudinal dissolved oxygen and temperature results (minimum, maximum and mean values in profiles) at High Rock project. August 20-21, 2004.

			Generating 8/20/04						Non-Generating 8/21/04					
			Temperature °C			Dissolved Oxygen Conc mg/L			Temperature °C			Dissolved Oxygen Conc mg/L		
			Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
	Transect	Station												
Forebay	1	A	23.7	26.8	25.2	2.1	11.2	6.3	23.8	28.5	26.1	1.8	11.1	8.2
		B	23.9	27.0	25.4	3.3	9.8	6.8	24.0	28.2	26.1	2.5	11.0	8.0
		C	24.0	26.7	25.5	3.4	9.6	7.2	24.1	28.2	26.2	2.9	11.3	8.4
	2	A	23.9	26.9	25.7	3.2	11.3	8.6	24.1	27.7	26.2	2.8	9.9	7.8
		B	23.8	26.9	25.5	3.0	11.4	8.0	24.0	27.5	26.1	2.7	10.0	7.9
		C	24.1	27.1	25.9	3.7	11.6	8.6	24.0	28.1	26.3	2.8	10.6	8.5
Tailrace	1	A	24.9	24.9	24.9	4.4	4.6	4.5	26.0	27.5	27.0	5.5	5.6	5.5
		B	24.9	24.9	24.9	4.5	4.6	4.5	25.7	27.6	26.8	5.8	6.0	5.9
		C	24.9	24.9	24.9	4.6	4.7	4.7	26.6	27.2	26.9	6.0	6.0	6.0
	2	A	24.9	24.9	24.9	5.0	5.3	5.2	25.6	27.7	26.5	5.4	5.6	5.5
		B	24.9	24.9	24.9	4.3	4.5	4.4	26.3	27.5	26.9	5.6	5.7	5.6
		C	24.9	24.9	24.9	4.7	4.8	4.7	26.7	27.1	26.9	5.4	5.4	5.4

Table 3.4-5. Summary of lateral and longitudinal dissolved oxygen and temperature results (minimum, maximum and mean values in profiles) at the Tuckertown project, August 20-21, 2004.

			Generating 8/20/04						Non-Generating 8/21/04					
			Temperature °C			Dissolved Oxygen Conc mg/L			Temperature °C			Dissolved Oxygen Conc mg/L		
			Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
	Transect	Station												
Forebay	1	A	25.0	27.8	26.4	3.2	12.4	9.0	25.1	27.9	26.1	3.4	9.5	6.0
		B	25.0	28.0	26.4	3.6	12.2	8.6	25.0	27.8	26.2	3.6	9.7	6.7
		C	25.0	27.4	26.0	3.8	13.0	7.9	24.9	27.1	26.0	3.1	9.8	6.7
		D	25.1	27.1	25.9	3.7	12.1	7.2	25.0	27.5	26.0	3.4	9.1	5.9
		E	25.2	29.1	26.7	4.1	12.7	9.6	25.2	27.4	26.2	3.3	8.9	6.3
	2	A	25.0	28.5	26.6	3.1	13.3	9.5	25.1	27.6	26.4	3.8	8.6	6.7
		B	25.0	28.4	26.5	3.3	12.6	8.5	25.0	27.4	26.2	3.5	8.5	6.6
		C	25.0	28.2	26.5	3.7	12.7	8.9	24.9	27.1	26.0	3.2	8.4	5.9
		D	25.1	28.4	26.4	4.3	12.7	8.4	25.0	27.2	26.1	3.7	7.7	6.0
		E	25.1	28.0	26.4	3.9	11.9	8.0	25.0	27.3	26.0	3.2	7.4	5.4
Tailrace	1	A	25.7	25.7	25.7	4.3	4.5	4.4	26.3	27.6	27.2	8.7	8.9	8.8
		B	25.7	25.7	25.7	4.5	4.6	4.6	26.9	27.6	27.3	9.0	9.1	9.0
		C	25.7	25.7	25.7	4.5	4.6	4.6	27.6	27.7	27.6	8.9	8.9	8.9
	2	A	25.7	25.7	25.7	4.4	4.5	4.5	26.0	28.2	27.3	8.7	9.6	9.4
		B	25.8	25.8	25.8	4.5	4.5	4.5	26.5	28.1	27.5	8.8	9.4	9.3
		C	25.7	25.8	25.7	4.2	4.3	4.2	26.2	28.3	27.6	9.2	9.6	9.4

Table 3.4-6. Summary of lateral and longitudinal dissolved oxygen and temperature results (minimum, maximum and mean values in profiles) at the Narrows project. August 20-21, 2004.

			Generating 8/20/04						Non-Generating 8/21/04					
			Temperature °C			Dissolved Oxygen Conc mg/L			Temperature °C			Dissolved Oxygen Conc mg/L		
			Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
	Transect	Station												
Forebay	1	A	7.6	27.5	19.8	0.6	9.0	3.9	8.0	26.7	20.5	1.1	5.9	3.0
		B	7.5	27.4	17.8	0.7	8.0	3.4	7.4	26.7	16.7	0.5	6.5	2.4
		C	8.1	27.2	21.2	0.9	6.8	3.8	7.7	26.8	19.9	0.8	6.4	3.0
	2	A	13.4	27.8	25.9	1.3	9.1	5.3	11.4	26.7	24.5	1.3	5.7	3.6
		B	7.6	27.6	19.1	0.5	8.6	3.7	7.5	26.7	18.8	0.6	6.4	2.9
		C	7.8	27.8	19.8	0.8	7.7	4.0	7.5	26.7	18.5	0.7	5.9	2.7
Tailrace	1	A	26.4	26.5	26.4	5.8	6.2	6.0	26.3	26.3	26.3	6.8	6.8	6.8
		B	26.2	26.2	26.2	4.3	4.4	4.4	26.3	26.3	26.3	6.9	6.9	6.9
		C	26.1	26.1	26.1	4.1	4.2	4.2	26.3	26.3	26.3	6.9	6.9	6.9
	2	A	26.3	26.3	26.3	5.3	5.4	5.3	26.3	26.3	26.3	6.7	6.7	6.7
		B	26.2	26.2	26.2	5.1	5.1	5.1	26.3	26.3	26.3	6.8	6.8	6.8
		C	26.1	26.1	26.1	4.9	4.9	4.9	26.3	26.3	26.3	6.8	6.8	6.8
	3	A	26.4	26.4	26.4	4.4	4.6	4.5	26.2	26.3	26.2	6.6	7.1	6.8
		B	26.3	26.3	26.3	5.1	5.1	5.1	26.3	26.3	26.3	6.6	6.7	6.6
		C	26.1	26.2	26.2	4.8	5.1	5.0	26.3	26.3	26.3	6.6	6.7	6.7
	4	A	26.4	26.4	26.4	4.7	4.7	4.7	26.2	26.2	26.2	6.4	6.6	6.5
		B	26.4	26.5	26.5	4.7	4.8	4.8	26.2	26.2	26.2	6.5	6.7	6.6
		C	26.2	26.2	26.2	4.6	4.7	4.6	26.2	26.3	26.2	6.5	6.6	6.6

Table 3.4-7. Summary of lateral and longitudinal dissolved oxygen and temperature results (minimum, maximum and mean values in profiles) at the Falls project. August 20-21, 2004.

			Generating 8/20/04						Non-Generating 8/21/04					
			Temperature °C			Dissolved Oxygen Conc mg/L			Temperature °C			Dissolved Oxygen Conc mg/L		
			Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
	Transect	Station												
Forebay	1	A	26.3	27.1	26.7	5.5	6.4	6.1	26.3	26.4	26.3	4.1	5.0	4.7
		B	26.3	27.0	26.6	5.3	6.0	5.6	26.3	26.4	26.3	3.9	4.8	4.4
		C	26.2	27.4	26.6	5.2	5.8	5.5	26.2	26.4	26.3	3.6	5.3	4.4
	2	A	26.3	27.6	26.8	4.7	6.0	5.5	26.3	26.4	26.3	4.0	4.9	4.6
		B	26.3	27.1	26.6	4.6	5.5	5.0	26.2	26.4	26.3	3.0	4.9	4.4
		C	26.4	26.8	26.5	4.7	5.3	5.1	26.2	26.4	26.3	3.7	4.8	4.2
Tailrace	1	A	26.6	26.6	26.6	6.0	6.0	6.0	26.0	26.1	26.1	5.0	5.0	5.0
		B	26.6	26.6	26.6	5.9	5.9	5.9	26.1	26.1	26.1	4.8	4.8	4.8
		C	26.6	26.7	26.6	5.8	5.8	5.8	26.1	26.2	26.2	5.0	5.1	5.1
	2	A	26.7	26.8	26.7	6.0	6.0	6.0	25.9	26.0	25.9	5.3	5.3	5.3
		B	26.6	26.6	26.6	5.9	5.9	5.9	26.1	26.1	26.1	5.4	5.4	5.4
		C	26.7	26.7	26.7	5.8	5.8	5.8	26.1	26.1	26.1	5.2	5.2	5.2

Table 3.4-8. Depth to 5 mg/l dissolved oxygen contour in Yadkin Project Impoundments during lateral and longitudinal surveys. August 20-21, 2004.

First Forebay Depth Observation where Dissolved Oxygen <5 mg/l

		Generating August 20,2004		Non-generating August 21, 2004	
		Depth (meters)	Temperature (°C)	Depth (meters)	Temperature (°C)
Dam	File				
High Rock	HF1A	6.4	25.3	12.6	24.3
	HF1B	9.8	25.0	12.0	24.8
	HF1C	10.8	24.9	11.6	24.9
	HF2A	11.4	24.6	10.8	25.0
	HF2B	12.3	24.4	11.5	24.7
	HF2C	10.9	24.7	12.1	24.3
Tuckertown	TF1A	14.1	25.3	7.1	25.7
	TF1B	13.6	25.3	11.0	25.5
	TF1C	11.4	25.5	10.7	25.5
	TF1D	9.6	25.5	8.4	25.7
	TF1E	11.5	25.4	7.1	25.9
	TF2A	11.6	25.5	10.5	25.5
	TF2B	11.7	25.5	11.0	25.5
	TF2C	12.5	25.4	9.0	25.6
	TF2D	11.3	25.5	9.2	25.7
	TF2E	9.4	25.6	7.5	25.8
Narrows	NF1A	10.1	26.5	5.8	26.5
	NF1B	13.8	26.5	7.5	26.5
	NF1C	11.0	26.6	7.2	26.5
	NF2A	10.9	26.5	8.9	26.5
	NF2B	12.6	26.5	9.4	26.5
	NF2C	14.5	26.5	6.5	26.5
Falls	FF1A	see Note	see Note	0.1	26.4
	FF1B	see Note	see Note	0.1	26.4
	FF1C	see Note	see Note	1.6	26.4
	FF2A	11.6	26.4	0.2	26.4
	FF2B	10.4	26.4	0.2	26.4
	FF2C	12.1	26.4	0.4	26.4

Note: Dissolved oxygen $5/mg/l at all depths.

surveys were conducted at a similar time of day and within one day of each other (Tables 3.4-1 and 3.4-2). During the non-generation survey, dissolved oxygen concentrations near the surface were 8-10 mg/l. During both surveys, dissolved oxygen concentrations near the bottom were 3.0-4.0 mg/l (Appendix K).

At transect 1 the waters with dissolved oxygen concentrations < 5 mg/l were below 9.5-14.0 m (31-46 feet) during generation and below 7.0-11.0 m during non-generation (Table 3.4-8). The differences in the profiles between surveys were more pronounced at the ends of transect 1 than at the mid-channel stations. Mid-channel profiles were similar for both surveys. During generation, dissolved oxygen concentrations less than 5 mg/l were found at depths below 9.5-12.5 m (31-41 feet) along transect 2. During non-generation transect 2 waters with dissolved oxygen concentrations below 5 mg/l were found below 7-11 m, similar to observations at transect 1..

At Tuckertown, generation appears to increase the volume of oxygenated water in the vicinity of the intakes. The 5 mg/l contour is at a greater depth during generation. The turbine intake depth at Tuckertown is slightly deeper than that at High Rock ranging from 9.9 meters below the surface to 18.1 meters (32-59 feet) or essentially just above the maximum depth of the reservoir. Generation appears to draw oxygenated surface water downward towards the intakes in the Tuckertown impoundment. This effect is most pronounced in the immediate vicinity of the intakes but is also observed to a lesser degree ¼ mile upstream at transect 2.

Tuckertown tailrace dissolved oxygen concentrations were markedly different between the generation and non-generation surveys (Table 3.4-5). During the generation survey, dissolved oxygen concentrations ranged from 4.2-4.6 mg/l while during the non-generation survey, concentrations were between 8.7 and 9.6 mg/l. Algal cells from the Tuckertown headpond were likely carried into the tailrace during the generation survey and produced substantial amounts of oxygen during the non-generation survey. Continuous monitoring data from the Tuckertown tailrace (Section 2.4, Appendix I) shows tailrace dissolved oxygen concentrations of 3.65 at 0100 on August 21 when generation ceased. Dissolved oxygen remained at or slightly below that concentration until daylight. The concentration steadily increased to around 10 mg/l at the time of the survey (1400) suggesting substantial algal oxygen production.

Narrows

The Narrows impoundment is the only impoundment in the Yadkin Project system that is frequently thermally stratified. During the course of the two surveys, differences between surface and bottom temperatures were on the order of 10-20ºC which indicates relatively strong thermal stratification (Table 3.4-6, Appendix K).

During both surveys, dissolved oxygen near the bottom of both transects was below 1 mg/l. At the surface, concentrations varied from 6.5-9.0 mg/l at transect 1 during generation (Appendix K). At transect 2 this variability in dissolved oxygen concentration at the surface was not as great (concentrations from 6.0-8.2 mg/l) during generation. During the generation surveys, the maximum observed dissolved oxygen concentration was not at the surface in all instances (Appendix K) but was observed within the upper 10 meters (33 feet). During non-generation, surface concentrations were similar at both transects (5.7-6.5 mg/l, Appendix K). At transect 1, dissolved oxygen concentrations below 5 mg/l were found from 10-13 m during generation with the greatest volume of water with depleted dissolved oxygen being observed at station C which is furthest from the intakes (Table 3.4-8). During non-generation at transect 1, water with dissolved oxygen concentrations below 5 mg/l was observed below 5.5 m at all stations along the transect (Table 3.4-8). At transect 2 concentrations below 5 mg/l were observed below 10.5-14.0 m during generation and 6.5-9.0 m during non-generation. The influence of generation appears to be to draw oxygenated water deeper into the impoundment. This phenomenon is further illustrated in Figure 3.4-5. The intake depth is above the thermocline so water entrained in the turbines is freely mixed to the surface. When generation is not occurring, the water at the bottom of the epilimnion lacks oxygen. This is likely attributable to the microbial decomposition of algal cells below the photic zone.

In the Narrows tailrace, concentration of dissolved oxygen under generation ranged from 4.1-6.2 (Table 3.4-6, Appendix K). The majority of the readings ranged from 4.5-5.2 mg/l. The two notable

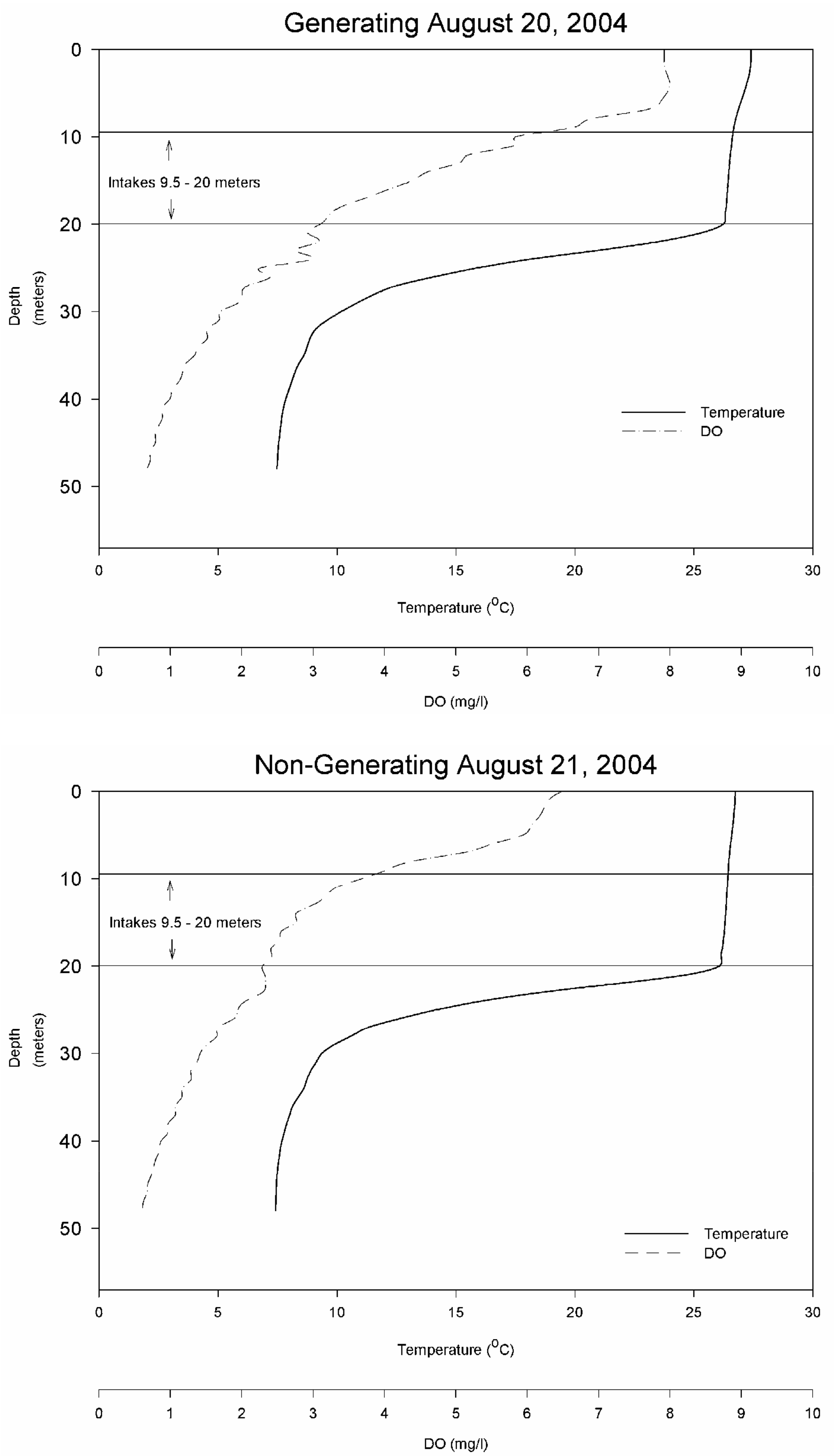


Figure 3.4-5. Temperature and dissolved oxygen at Transect 1 Station B, Narrows impoundment.

exceptions were the readings at station 1A closest to unit 4 (with air injection) where the highest readings were observed and at the surface at station 1C where a concentration of 4.1 was observed. This concentration was isolated to this station and may have been related to water from units 1, 2 and 3 with no air injection. Readings from the center station of transect 1 (1B) where the continuous monitor is located were consistent with readings observed at downstream transects. Under the no-generation scenario, all four transects exhibited concentrations of 6.5-7.1 mg/l (Appendix K).

Falls

Thermal stratification was not observed in the Falls impoundment. Differences between the surface and bottom were less than 1ºC. The distribution of dissolved oxygen in the impoundment was similar between transects during both generating and non-generating scenarios (Appendix K). During the non-generating scenarios, dissolved oxygen concentrations ranged from 3.0 to 5.3. During the generating scenarios, dissolved oxygen concentrations ranged from 4.6 to 6.4 (Table 3.4-7). Because the Falls impoundment is so small, it is likely that the observed impoundment dissolved oxygen concentrations are more closely related to generation at Narrows than generation at Falls. The reservoir is well mixed. The slightly lower concentrations observed during the non-generating survey could be related to the timing of the surveys and diurnal fluctuation of dissolved oxygen concentrations related to algal effects. The generating survey was conducted in the afternoon (15:23-15:50) when net algal oxygen production would be near peak while the non-generating survey was conducted fairly early the following morning (09:26-09:48) when net algal oxygen production would be lower. At the transect closest to the dam dissolved oxygen was greater than 5 mg/l at all depths during the generation survey (Table 3.4-8). At transect 2, the depth where dissolved oxygen was less than 5 mg/l was 10.4-12.1 m. During non-generation nearly the entire water column had dissolved oxygen concentrations <5 mg/l at both transects.

Tailrace dissolved oxygen concentrations below Falls ranged from 5.8-6.0 at both transects during generation and from 4.8-5.4 at both transects during non-generation (Table 3.4-7). These observations are consistent with readings from the Falls impoundment and are likely (especially for the generation scenario) highly influenced by operations at Narrows.

3.5 SUSPENDED SOLIDS TRANSPORT THROUGH THE YADKIN APGI SYSTEM

Total Suspended Solids

Total suspended solids (TSS) were monitored monthly from June 1999 to December 2003 at 20 stations located on the Yadkin River and in the Yadkin Project reservoirs. To evaluate the transport of TSS through the Yadkin Project, the data for the monitoring stations located along the mainstem of the Yadkin River were analyzed including:

High Rock Reservoir: H1, H3, H7 and H10
Tuckertown Reservoir: T1, T2 and T3
Narrows Reservoir: N1, N2 and N4
Falls Reservoir: F1, F2 and F3

concentrations for these stations were then plotted versus distance downstream from monitoring station H1 (Figure 3.5-1). Average TSS concentration decreases from 46.9 mg/L where the Yadkin River enters High Rock Reservoir (Station H1) to 2.8 mg/L in the Yadkin River downstream of the Falls Dam (Station F3). This represents a decrease in TSS concentration of 94 percent. The greatest change, by concentration, consistently occurred in High Rock Reservoir where the average TSS

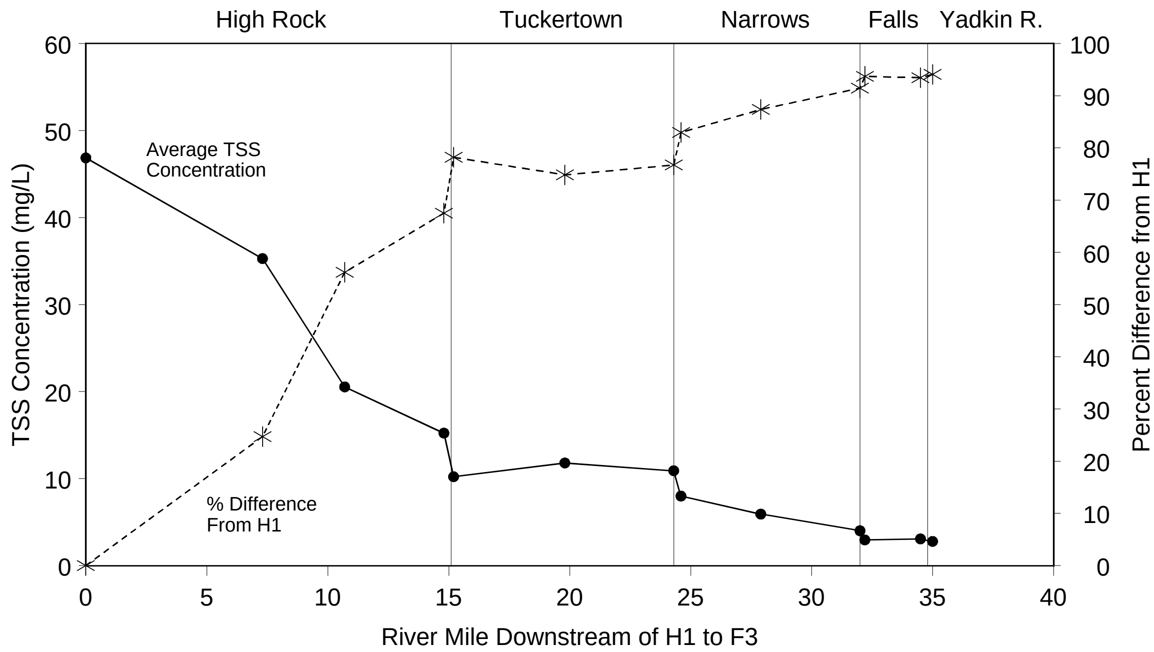


Figure 3.5-1. Average TSS Concentration vs. Distance Downstream of H1, June 1999 through 2003.

concentration decreased by 31.6 mg/L between the upper most monitoring station (H1) and the lower most monitoring station (H10). On average, TSS concentrations decreased by 4.0 mg/L in Narrows Reservoir and 0.2 mg/L in Falls Reservoir. Tuckertown was the only reservoir to have an increase in average TSS concentrations, although relatively small (0.7 mg/L). The increase usually occurred between monitoring stations T1 and T2. Lick Creek, Cabin Creek, Flat Creek and at least two unnamed tributaries are possible sources of sediment input in this reach of Tuckertown Reservoir.

The range in TSS concentrations through the Yadkin Project is shown in Figure 3.5-2. The greatest range in TSS concentrations has been experienced in High Rock Reservoir, while downstream, the range in TSS concentrations form a much narrower band around the mean. Also, the range in TSS concentrations decreases through High Rock Reservoir. This suggests that the greatest variability is associated with the sediment transport associated with the Yadkin River, which decreases as flow passes through High Rock Reservoir. This variability is most likely due to the relationship between discharge and TSS concentration. As shown in Figure 3.5-3, the highest average TSS concentrations in High Rock Reservoir (Station H1) typically occur in response to high discharge events that occur either in the late winter/early spring or in the summer/late fall. These high discharge events are associated with regional storm systems that produce significant runoff which entrains sediment from the drainage basin and transports it to the Yadkin River and its tributaries.

The percent change in the average TSS concentrations within each impoundment and their cumulative values through the Yadkin Project were calculated (Table 3.5-1) and the results are presented in Figure 3.5-4. By impoundment, the average TSS concentration decreased in High Rock Reservoir, Narrows Reservoir and in the Falls Reservoir, while they increased slightly in Tuckertown Reservoir. High Rock Reservoir had the greatest percentage decrease in TSS concentration, averaging 58 percent over the period of record, followed by Narrows (47.4 percent) and Falls (2.6 percent). As mentioned previously, average TSS concentrations increased in the Tuckertown Reservoir (6.5 percent). Again, these data indicate that High Rock Reservoir is the principal sink for TSS in the Yadkin Project system, with additional TSS retention in Narrows and Falls. Although there is an increase in TSS in the Tuckertown Reservoir, this gain is most likely reduced by losses in the Narrows and Falls Reservoirs.

3.6 BIOLOGICAL ISSUES

There are numerous biological issues related to the operation of the Yadkin APGI Facilities. Fisheries, wetlands and wildlife issues are covered companion reports to this report (Normandeau 2004, Normandeau 2005a, Normandeau 2005b). Two issues not covered in companion reports, mercury in fish tissue and bacterial contamination are discussed below.

3.6.1 Mercury in Fish Tissue

From September 1 to 3, 2003, ten specimens each of largemouth bass, black crappie and channel catfish were collected from the vicinity of the Tuckertown Dam tailrace (upper Narrows Reservoir) for the purpose of testing mercury accumulation in fish tissue. The mercury concentration in fish fillets was analyzed. Specimens were collected by Normandeau Associates personnel by a combination of gill nets and electrofishing. Samples were sent to Microbac Laboratories, Inc. for analysis using standard methods EPA 245.1.

The mercury concentrations were below the detection in all the fish that were collected (Table 3.5-1). The detection limit (0.145 mg/kg) was below the US FDA action level of 1 mg/kg.

Note – the reservoir labels are text boxes grouped with the chart image.

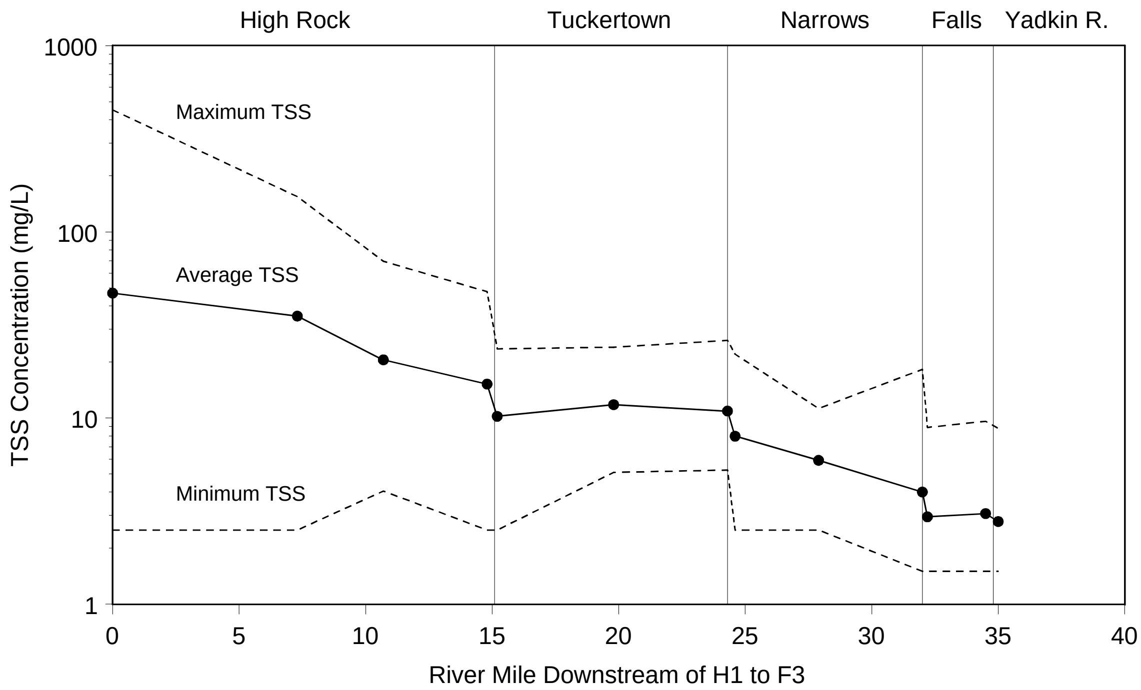


Figure 3.5-2. Range in TSS Values vs. Distance Downstream of H1, June 1999 through 2003.

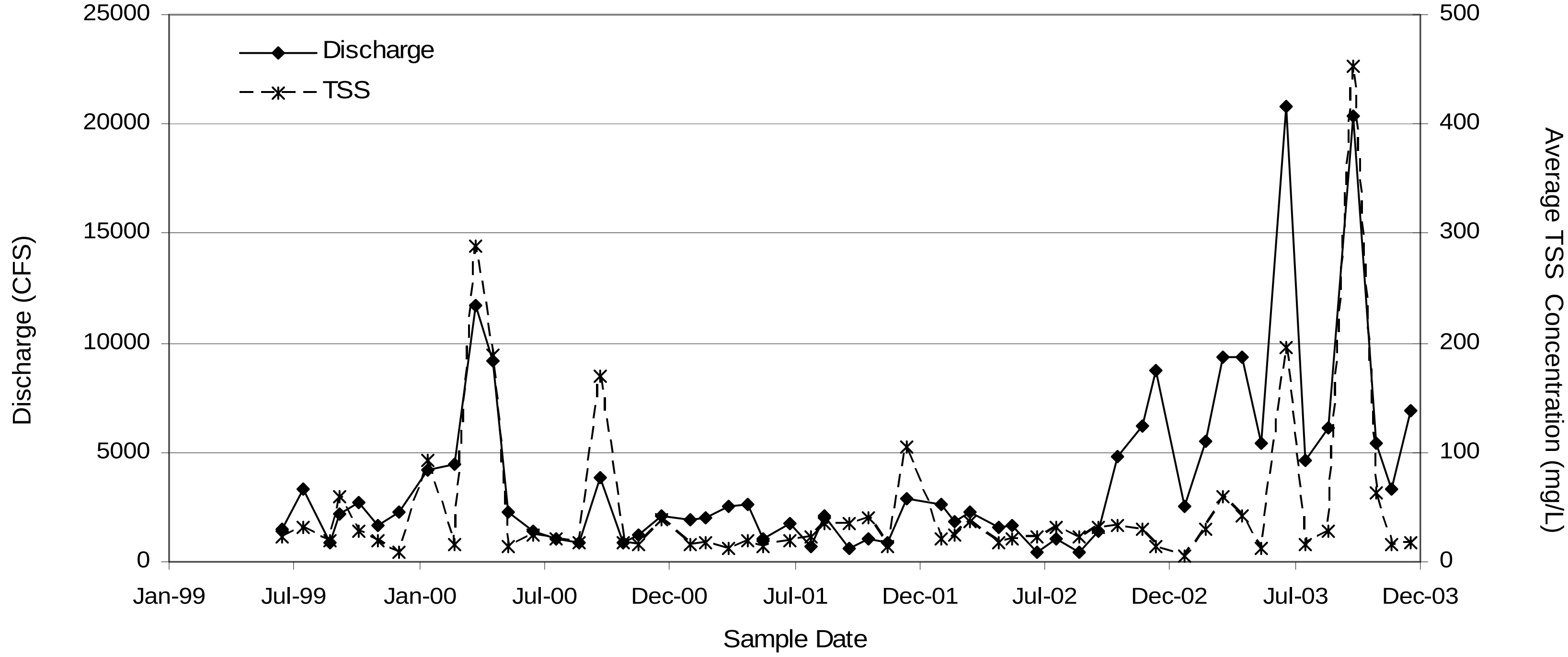


Figure 3.5-3. Daily Inflow to High Rock Reservoir and Average TSS Concentration at Station H1 High Rock Reservoir, June 1999 through 2003.

Table 3.5-1. Summary of Average Annual TSS Concentration (mg/L) for Monitoring Stations along the Mainstem of the Yadkin River from June 1999 through 2003.

Reservoir and Station	1999 TSS Conc.	1999 % Cum. Δ	2000 TSS Conc.	2000 % Cum. Δ	2001 TSS Conc.	2001 % Cum. Δ	2002 TSS Conc.	2002 % Cum. Δ	2003 TSS Conc.	2003 % Cum. Δ	Average Annual
High Rock											
H1	26.8		75.3		28.8		25.7		77.7		46.9
H3	30.4	-0.1	42.7	0.4	47.0	-0.7	25.2	0.0	31.1	0.6	35.3
H7	21.0	0.4	26.4	0.2	20.5	1.0	18.2	0.3	16.6	0.2	20.5
H10	15.7	0.2	18.3	0.1	14.1	0.2	16.2	0.1	11.8	0.1	15.2
Conc. Change in Impound.	11.1		56.9		14.7		9.5		65.9		31.6
%Impoundment Change	0.4	0.4	0.8	0.8	0.5	0.6	0.4	0.4	0.8	0.9	0.6
Tuckertown											
T1	10.8	0.2	11.6	0.1	10.3	0.1	9.4	0.3	8.9	0.0	10.2
T2	13.2	-0.1	11.8	0.0	12.4	-0.1	10.7	-0.1	10.9	0.0	11.8
T3	12.2	0.0	12.2	0.0	11.2	0.0	10.7	0.0	8.2	0.0	10.9
Conc. Change in Impound.	-1.5		-0.6		-0.9		-1.3		0.7		-0.7
%Impoundment Change	-0.1	0.1	-0.1	0.1	-0.1	0.1	-0.1	0.2	0.1	0.0	-0.1
Narrows											
N1	10.6	0.1	8.6	0.0	6.8	0.2	6.5	0.2	7.4	0.0	8.0
N2	5.8	0.2	5.9	0.0	5.7	0.0	4.9	0.1	7.3	0.0	5.9
N4	2.8	0.1	3.0	0.0	3.3	0.1	3.0	0.1	8.0	0.0	4.0
Conc. Change in Impound.	7.8		5.7		3.6		3.5		-0.6		4.0
%Impoundment Change	0.7	0.4	0.7	0.1	0.5	0.3	0.5	0.3	-0.1	0.0	0.5
Falls											
F1	1.8	0.0	4.0	0.0	2.5	0.0	2.9	0.0	3.6	0.1	2.9
F2	3.0	0.0	3.1	0.0	3.1	0.0	2.6	0.0	3.5	0.0	3.1
F3	2.0	0.0	2.7	0.0	2.7	0.0	2.7	0.0	3.8	0.0	2.8
Conc. Change in Impound.	-0.2		1.3		-0.2		0.2		-0.2		0.2
%Impoundment Change	-0.1	0.0	0.3	0.0	-0.1	0.0	0.1	0.0	-0.1	0.1	0.0
Total Conc. Change H1-F3	24.8		72.5		26.1		23.0		74.0		44.1
% Total Change in TSS	0.9	1.0	1.0	1.0	0.9	1.0	0.9	1.0	1.0	1.0	0.9

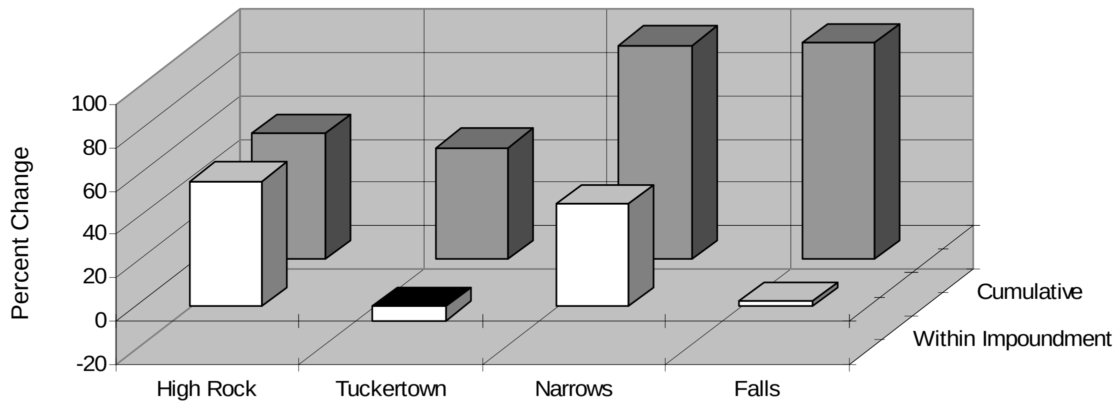


Figure 3.5-4. Average percent change in TSS concentration by impoundment and cumulatively, June 1999 through 2003.

In general, state water quality standards to protect aquatic life for non-carcinogenic substances are more stringent than numerical standards to protect human health from consumption of fish. Mercury is probably not accumulating in fish tissue to levels that pose a threat to human health.

3.6.2 Fecal Coliform Monitoring

Monitoring for fecal coliform in waters associated with the High Rock, Tuckertown, Narrows and Falls developments of the Pee Dee River is handled by both the State's Division of Water Quality and, as needed, by the Health Department at the County level.

Through the NCDENR Division of Water Quality, the State monitors fecal coliform on a five-year cycle, with 2005 being the next sampling year. Grab samples are collected at the surface of the lake in the mainstem of the lakes; most likely rendering them not representative of conditions associated with swimming or developed areas. Table 3.6-2 shows collected data for the High Rock Lake, Tuckertown Reservoir and Badin Lake for the years 1999 to 2001; the Falls Reservoir was last sampled in 1994. All of the samples were below the State standard for Class C waters of 200 per 100 ml.

Concerns or complaints expressed by the local population generally get directed to the Health Department within the respective County. Stanly, Davidson and Rowan Counties had no logged complaints requiring any fecal coliform monitoring.

Table 3.6-1. The concentration of mercury in fish tissue of largemouth bass, black crappie and channel catfish collected in Tuckertown tailrace (upper Narrows reservoir) September 1-3, 2003.

	Length	Mercury
	mm	mg/kg
Species		
Largemouth Bass	438	<0.144
Largemouth Bass	444	<0.145
Largemouth Bass	458	<0.147
Largemouth Bass	432	<0.144
Largemouth Bass	413	<0.145
Largemouth Bass	443	<0.147
Largemouth Bass	357	<0.146
Largemouth Bass	371	<0.145
Largemouth Bass	355	<0.147
Largemouth Bass	377	<0.145
Black Crappie	297	<0.146
Black Crappie	255	<0.146
Black Crappie	255	<0.148
Black Crappie	292	<0.144
Black Crappie	291	<0.147
Black Crappie	244	<0.143
Black Crappie	223	<0.149
Black Crappie	235	<0.148
Black Crappie	246	<0.147
Black Crappie	225	<0.149
Channel Catfish	373	<0.144
Channel Catfish	449	<0.142
Channel Catfish	355	<0.148
Channel Catfish	440	<0.145
Channel Catfish	414	<0.148
Channel Catfish	473	<0.146
Channel Catfish	466	<0.147
Channel Catfish	389	<0.146
Channel Catfish	466	<0.144
Channel Catfish	405	<0.150

Table 3.6-2 Fecal coliform data collected by NCDENR in the Yadkin reservoirs.

Lake Name	Date m/d/yr	Sampling Station	Fecal Coliform per 100 ml
High Rock Lake	August 16, 2001	YAD152A	6
High Rock Lake	August 16, 2001	YAD152C	1
High Rock Lake	August 16, 2001	YAD156A	1
High Rock Lake	August 16, 2001	YAD169A	1
High Rock Lake	August 16, 2001	YAD169B	1
High Rock Lake	August 16, 2001	YAD169E	1
High Rock Lake	August 16, 2001	YAD169F	1
High Rock Lake	July 31, 2001	YAD169E	2
High Rock Lake	August 1, 2000	YAD152A	<10
High Rock Lake	August 1, 2000	YAD152C	<10
High Rock Lake	August 1, 2000	YAD156A	<10
High Rock Lake	August 1, 2000	YAD169A	<10
High Rock Lake	August 1, 2000	YAD169B	<10
High Rock Lake	August 1, 2000	YAD169E	<10
High Rock Lake	August 1, 2000	YAD169F	<10
High Rock Lake	July 5, 2000	YAD1391A	73
High Rock Lake	July 5, 2000	YAD152A	<10
High Rock Lake	July 5, 2000	YAD152C	<10
High Rock Lake	July 5, 2000	YAD156A	<10
High Rock Lake	July 5, 2000	YAD169A	27
High Rock Lake	July 5, 2000	YAD169B	<10
High Rock Lake	July 5, 2000	YAD169E	<10
High Rock Lake	July 5, 2000	YAD169F	<10
High Rock Lake	June 20, 2000	YAD1391A	64
High Rock Lake	June 20, 2000	YAD152A	<10
High Rock Lake	June 20, 2000	YAD152C	<10
High Rock Lake	June 20, 2000	YAD156A	<10
High Rock Lake	June 20, 2000	YAD169A	<10
High Rock Lake	June 20, 2000	YAD169B	<10
High Rock Lake	June 20, 2000	YAD169E	<10
High Rock Lake	June 20, 2000	YAD169F	<10
High Rock Lake	August 26, 1999	YAD152A	10
High Rock Lake	August 26, 1999	YAD152C	30
High Rock Lake	August 26, 1999	YAD156A	<10
High Rock Lake	August 26, 1999	YAD169A	<10
High Rock Lake	August 26, 1999	YAD169B	<10
High Rock Lake	August 26, 1999	YAD169E	<10
High Rock Lake	August 26, 1999	YAD169F	10

(continued)

Table 3.6-2 (Continued)

Lake Name	Date m/d/yr	Sampling Station	Fecal Coliform per 100 ml
High Rock Lake	July 15, 1999	YAD1391A	70
High Rock Lake	July 15, 1999	YAD152A	<10
High Rock Lake	July 15, 1999	YAD152C	<10
High Rock Lake	July 15, 1999	YAD156A	<10
High Rock Lake	July 15, 1999	YAD169A	10
High Rock Lake	July 15, 1999	YAD169B	<10
High Rock Lake	July 15, 1999	YAD169E	<10
High Rock Lake	July 15, 1999	YAD169F	10
High Rock Lake	June 3, 1999	YAD1391A	<10
High Rock Lake	June 3, 1999	YAD152A	<10
High Rock Lake	June 3, 1999	YAD152C	<10
High Rock Lake	June 3, 1999	YAD156A	<10
High Rock Lake	June 3, 1999	YAD169A	30
High Rock Lake	June 3, 1999	YAD169B	<10
High Rock Lake	June 3, 1999	YAD169E	<10
High Rock Lake	June 3, 1999	YAD169F	<10
Tuckertown Reservoir	August 3, 1999	YAD172C	10
Tuckertown Reservoir	August 3, 1999	YAD1780A	<10
Tuckertown Reservoir	July 8, 1999	YAD172C	<10
Tuckertown Reservoir	July 8, 1999	YAD1780A	<10
Tuckertown Reservoir	June 3, 1999	YAD172C	<10
Tuckertown Reservoir	June 3, 1999	YAD1780A	<10
Badin Lake	August 3, 1999	YAD178B	<10
Badin Lake	August 3, 1999	YAD178E	<10
Badin Lake	August 3, 1999	YAD178F	<10
Badin Lake	August 3, 1999	YAD178F1	<10
Badin Lake	July 8, 1999	YAD178B	<10
Badin Lake	July 8, 1999	YAD178E	<10
Badin Lake	July 8, 1999	YAD178F	<10
Badin Lake	July 8, 1999	YAD178F1	<10
Badin Lake	June 7, 1999	YAD178B	<10
Badin Lake	June 7, 1999	YAD178F1	<10

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