TEMPERATURE AND DISSOLVED OXYGEN

MISSION PROJECT

INTRODUCTION

Even though the North Carolina Department of Environment and Natural Resources, Division of Water Quality (NCDENR, DWQ) has reported that the water quality in the Hiwassee River supported its designated use, the measurement of water quality is a portion of the basic information requirement of 18CFR4.51 and 18CFR4.61. Pursuant to obtaining a Federal Energy Regulatory Commission (FERC) license, a State 401 water quality certification (maintenance of water quality standards associated with a project) is required for the project.

Traditionally, temperature and dissolved oxygen are the primary water quality parameters used to assess the habitability and suitability for many aquatic organisms. The NCDENR-DWQ has established water quality standards for these parameters for all waters of the State. The standards involve two primary considerations: 1) the designated water uses for each reach of stream (Table 1), and, 2) water quality limits required to protect those uses. The applicable water quality limits are summarized as follows (NCDENR-DWQ, 2002):

(b) Dissolved oxygen: not less than 6.0 mg/l daily average for trout waters; for non-trout waters, not less than a daily average of 5.0 mg/l with a instantaneous minimum value of not less than 4.0 mg/l. Swamp waters, lake coves, or backwaters, and lake bottom waters may have lower values if caused by natural conditions;

(j) Temperature: not to exceed 2.8 degrees C (5.04 degrees F) above the natural water temperature, and in no case to exceed 29 degrees C (84.2 degrees F) for mountain and upper piedmont waters and 32 degrees C (89.6 degrees F) for lower piedmont and coastal plain waters. The temperature for trout waters shall not be increased by more than 0.5 degrees C (0.9 degrees F) due to the discharge of heated liquids, but in no case to exceed 20 degrees C (68 degrees F);

The NCDENR water quality temperature standard for Class C waters (Table 1) is an upper limit of 29°C. Wildlife resource agencies (most notably the North Carolina Wildlife Resources Commission and the United States Fish and Wildlife Service) have requested the characterization of the water temperature and dissolved oxygen concentrations associated the Mission Project to provide information regarding the management of aquatic wildlife.

Since Mission dam provides minimum water storage, the operation of the three turbines are controlled by a forebay float system. As pond levels increase, the three units incrementally begin generation. If inflow to the Mission Pond exceeds the capacity of the three turbines, Mission dam spills water. Even though the watershed upstream of Mission and downstream from Chatuge periodically discharges more water than Mission's capacity, typically, the flow in the Hiwassee River is controlled by the Tennessee Valley Authority's Chatuge Project.

Chatuge is typically operated as a 'peaking' facility (TVA, 1978). As part of the TVA's River Improvement Plan (TVA, 1990), TVA constructed an infuser weir (completed in Nov 1992) about 0.9

miles downstream from Chatuge Dam. The weir was designed to reregulate turbine flows to provide a minimum flow and to aerate the hypolimnetic discharges from Chatuge. When peaking power is not needed, Chatuge hydro generates power for short intervals to supplement the water in the reregulation pool (upstream of the weir) to maintain minimum flow in the Hiwassee River (Hauser, 2002). The increase in minimum flows below Chatuge improved flow conditions at Mission. Before the weir was installed below Chatuge, there was an average of 62 days per year when flow below Chatuge was near zero. Since 1993, the minimum flow has been between 60 and 70 cfs. Even though the infuser weir was designed to aerate the water to 4 mg/l, the actual aeration exceeds the design levels with dissolved oxygen increases to at least 4 mg/l between generation periods and 6 mg/l during generation.

TVA has set up a computer model for flow and water quality in the Hiwassee River, from Chatuge Dam to Murphy, NC. The model is the ADYN-RQUAL model that simulates water transport in the river as well as temperature and dissolved oxygen. The model was calibrated using the data collected during this study. The model was developed as part of the TVA Reservoir Operations Study. TVA plans to use the model to evaluate reservoir operational scenarios that are being considered on the Hiwassee River. Further information on the model can be obtained from Kathy Lindquist at the TVA Engineering Laboratory in Norris, TN.

The objectives of this report are to describe the temperature and dissolved oxygen concentrations in the Hiwassee River. Comparisons to state water quality standards and differences in upstream versus. downstream locations will be used to assess the impact of the Mission Project on the temperature and dissolved oxygen concentration downstream of the project.

Table 1. Temperature and Dissolved Oxygen Sampling Locations Associated with the Mission Hydroelectric Project - Period of Deployments, Stream Classifications, and Available Historical Data

Site Location	River Mile	Current Study *Period of Deployment* *(% Data Recovery)*		Historical Data *Period of Record* *(Stream Classification)*		
		Temperature Loggers	Hydrolabs 2001	NCDENR-DWQ	Fish and Wildlife Associates, Inc.	Tennessee Valley Authority
Hiwassee River - at old USGS gage, downstream of Tusquitee Creek	114.4	10 May 2001 to 15 May 2002 *(100%)*	23-28 Sept *(100 %)*	*(C, WS-IV)*	N/A	N/A
Hiwassee River - at Shallow Ford Bridge, upstream of Mission Pond	108.3	10 May 2001 to 15 May 2002 *(100%)*	23-28 Sept *(100 %)*	*(C, WS-IV)*	N/A	N/A
Hiwassee River - Mission Powerhouse flow	105.0	10 May 2001 to 15 May, 2002 *(100%)*	23-28 Sept *(100 %)*	*(C, WS-IV)*	N/A	N/A
Hiwassee River -at USGS gage at Murphy	99.1	10 May 2001 to 15 May, 2002 *(100%)*	23-28 Sept *(100 %)*	*(C, WS-IV)* 1981 - 2001 *(C)*	N/A	N/A

Stream Classification		Water Quality Standards	
Symbol	**Designated Use**	**Temperature**	**Dissolved Oxygen**
WS-IV	Municipal Water Supply, highly developed watershed	less than 29°C	5 mg/l daily mean, 4 mg/l minimum
C	Secondary Recreation	less than 29°C	5 mg/l daily mean, 4 mg/l minimum

METHODS

Fish and Wildlife Associates, Inc. (FWA) deployed Onset Stowaway XTI temperature loggers above and below the Mission Project in 2000 (Nantahala Power and Light, 2000). Since only temperature data from the site upstream of the Mission Project were recovered in 2000, comparisons to upstream and downstream cannot be made and therefore not used for this report.

In May 2001, recording thermistors (StowAway®Tidbit®, Onset Computer Corp.) were programmed by Duke Power Company (DPC) to record temperatures at 15-minute intervals. The temperature loggers were deployed in the Hiwassee River at four locations (Figure 1 and Table 1). The thermistors were deployed beginning on 10 May 2001 and recorded temperatures for a period of 370 days.

The loggers were attached to a loop of ⅛" wire rope cable. The loop was crimped with stainless steel sleeves. The tethered loggers were usually placed in a deep pool. The shore end of the cable was looped around an inconspicuous tree (or other permanent object), and again crimped with stainless steel sleeves. Two temperature loggers were deployed at each location (Figure 1 and Table 1) to provide redundancy in the event of logger failure and to minimize the loss of data due to vandalism (most loggers were deployed on individual tethers).

Data were downloaded from the loggers at approximately monthly intervals. For each deployment period, data editing involved plotting and comparing the data from individual loggers from each site and then comparing the similarity in trends and magnitude of differences to data from the nearest upstream or downstream location. Data that were obviously erroneous were discarded. The process of double deployment and monthly data retrieval resulted in a temperature data recovery of 100 % from all of the Hiwassee River sites (Table 1). The 15-minute temperature data from each location were averaged from midnight to midnight resulting in the daily average temperatures for each river location. Daily minimum and maximum values represent the range of individual readings during the given 24-hr period.

Dissolved oxygen measurements (as well as conductivity, temperature, and depth) were collected with programmable Hydrolab DataSondes®. The DataSondes were suspended off the bottom by an anchored float (Knight, 1998) at all the temperature recording locations. The Hydrolabs were programmed to record data at 5-minute intervals during a 4-day period in September 2001. According to the preliminary ADYN-RQUAL model simulations, this deployment time coincided with minimum flow from Chatuge, but with releases of lowest dissolved oxygen and warmest temperatures. September typically represents the time of the year when the lowest dissolved oxygen concentrations occur in the river.

Even though the North Carolina Certified Laboratory Procedures only require calibration of *in situ* monitors according to the manufacturer's recommendation, additional quality control procedures designed to measure the accuracy and precision of the instruments were employed prior to and after the river deployments. The recording thermistors were placed in a controlled temperature oil bath (traceable to NBS standards). The oil bath was adjusted in ~5C° increments while the instruments recorded the temperature at minute intervals. These data were within the manufacturer's specifications.

The Hydrolab DataSondes® were calibrated for dissolved oxygen, conductivity, and depth prior to each deployment. After initial calibration, the instruments were placed in a circulating water bath. The oxygen concentrations in the water bath were lowered by bubbling nitrogen or increased by bubbling oxygen. The DataSondes recorded the changes at one-minute intervals. After each change of oxygen concentration, a Winkler determination was made from the water bath. The dissolved oxygen concentrations recorded by the Hydrolabs and the Winkler method were compared over the range of dissolved oxygen concentrations. Results showed that the Hydrolab DataSonde dissolved oxygen concentrations were within the manufacturer's specifications prior to deployment; but, after deployment, the oxygen concentrations recorded by the Hydrolabs were slightly lower than the concentrations determined by the Winkler method. This instrument drift indicated slight membrane fouling during the time the instruments were in the river. No attempt was made to adjust the data recorded during the river deployments for this fouling. Therefore, the oxygen concentrations reported would represent slight underestimates of the actual river concentrations.

Historical records of stream flow (mean daily discharge) were obtained from the USGS (**http://waterdata.usgs.gov/nwis/sw**). Mean daily summer flows (June - September) were calculated for each year for the period of record (1898 - 2001). Summer flows within ±25% of the 'grand' mean summer flow for the period of record were designated as normal flow years. The years where mean summer flows were greater than 25% of the 'grand' mean were designated as high flow, conversely, those years with summer flows less than 25% of the 'grand' mean were considered low flow years. Historical records of water quality (temperature and dissolved oxygen, monthly grab samples) collected at the USGS gage upstream of Murphy were obtained from NCDENR, DWQ (Sauber, 2002). Data collected from 4 other river locations by NCDENR, DWQ from 1973-1981 were not used for this report.

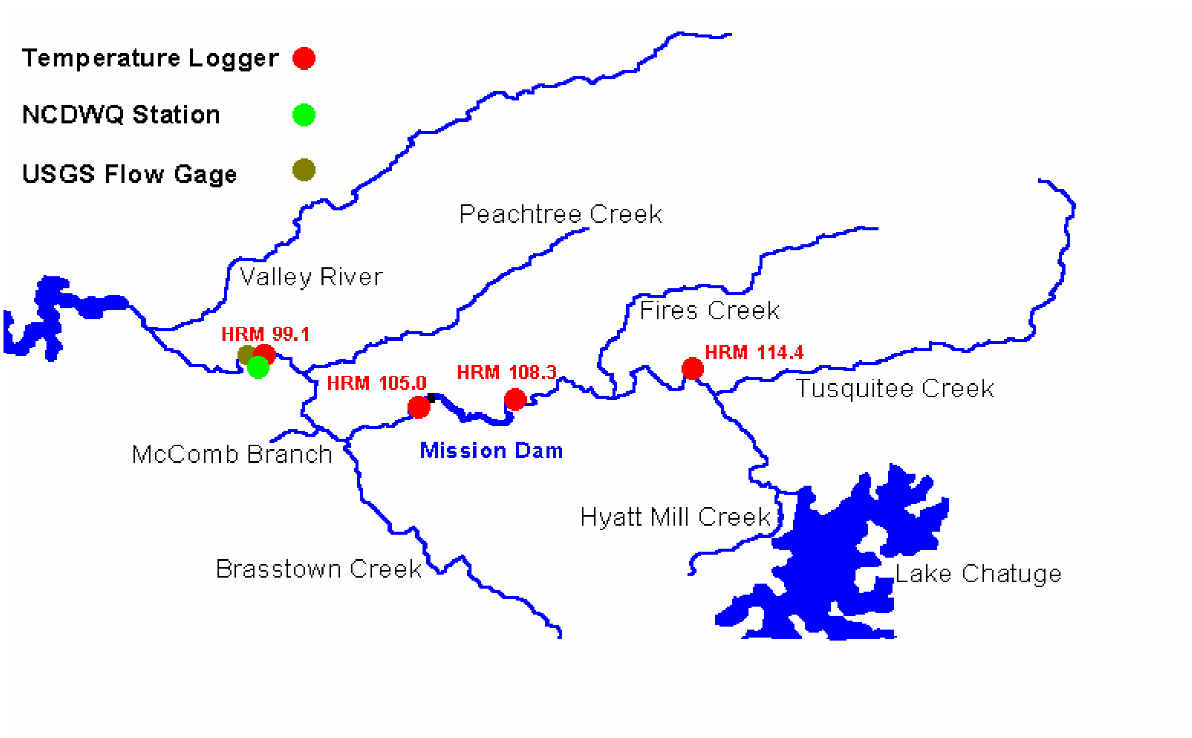

Figure 1. Map of Temperature and Dissolved Oxygen Sampling Locations in the Hiwassee River - River Miles and Historical Data Collection Sites

RESULTS

Temperature

Continuous Water Temperature

Hiwassee River

The Hiwassee River flows were dominated by the cool, hypolimnetic releases from the Chatuge hydroelectric station. The daily minimum temperatures during the summer, measured at River Mile 114.4 (Figure 2), were a result of the cool Chatuge turbine releases and the subsequent meteorological heating or cooling in the 6.5 miles downstream from Chatuge. The maximum daily summer temperatures at RM 114.4 probably represent the heating from the prevailing meteorological conditions of the minimum flow released by the infuser weir. Conversely, the daily maximum temperatures during the fall and winter probably represent the temperature of the higher flows released from Chatuge, while the minimum daily temperatures were indicative of the meteorological cooling of the Chatuge releases. As the water flowed downstream, the daily minimum and maximum temperatures warmed or cooled as a function of the meteorological conditions and amount of discharge in the river (Figures 3 - 5).

The daily mean temperatures increased downstream during the summer and early fall (Figure 6). The daily average temperatures in the river were generally higher in June and July, and notably decreased starting in August. This drop in temperatures in August is probably related to the higher levels of week-day flows in the river due to hydropower operations at Chatuge. TVA's current reservoir operating policy involves limiting pool level drawdowns until August 1 for lake recreation purposes, and this policy results in significant increases in hydropower generation starting in August. In October, as the water temperatures of the Chatuge releases approached the temperatures imposed by the prevailing meteorological conditions, the river temperatures downstream were very similar at all locations. When Chatuge Reservoir began to thermally stratify in April, cool water, relative to temperatures controlled by the meteorology, was again released to the Hiwassee River and the progressive warming downstream became evident (Figure 6).

Examination of the individual temperature measurements (15-minute intervals) during the 12-day warmest period (Figure 7) revealed the diel temperature cycles at all sites. The diel water temperatures measured furthest downstream (RM 99.1, at Murphy) revealed the diel meteorological pattern. However, the release of cool, hypolimnetic water from Chatuge Reservoir was very evident at RM 114.4. As the cool water flowed downstream, the water warmed and the pattern of heating and cooling resembled that of water equilibrating with the meteorology. However, the cooling effect of the coldwater pulses from Chatuge can be noted in the temperature peaks at the inflow to Mission (i.e., HRM 108.3) especially for the dates July 7 and July 15-17. On these dates, it is likely that more water was released from Chatuge than on the other dates included in this 12-day period.

The 'peaks and valleys' of the diel temperature cycles (Figure 7) occurred at the same time during the day at all sites except the Mission power house flow, indicating that the river temperatures responded very rapidly to the prevailing meteorological conditions. However, as observed in Lake Ela (Nantahala Power and Light. 2002), the power house flow not only exhibited a 'delay' in the time of maximum and minimum temperatures, but also showed a smaller diel temperature variation than the other river sites. Again, as with Lake Ela, this trend of diel temperatures is attributed to the deeper depths of Mission Pond, the travel time through Mission Pond, and the withdrawal of water from deeper depths in the pond by the hydro.

The seasonal heating and cooling of the Hiwassee River (as ± Cº/mile, Table 2) revealed the same pattern of warming the Chatuge releases during the spring and summer, while the water from Chatuge cools as it travels downstream during the winter. However, during August through December, as the water passed through Mission Pond, the warming and cooling were generally opposite that of the rest of the river. Differential selective withdrawal of the deeper water, smaller diel changes during the cooling period in the deeper water, or longer retention times during reduced flow may have influenced the different heating and cooling rates of the water released from the Mission project.

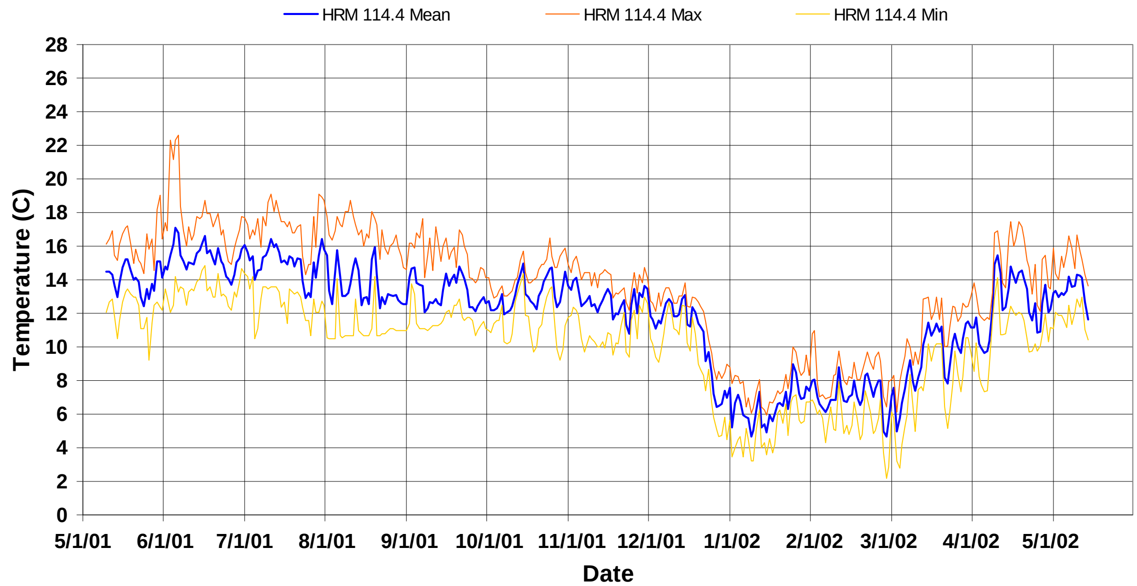

Figure 2. Mean, Minimum, and Maximum Daily Water Temperatures, Hiwassee River - RM 114.4 (Old USGS gage, downstream of Tusquitee Creek)

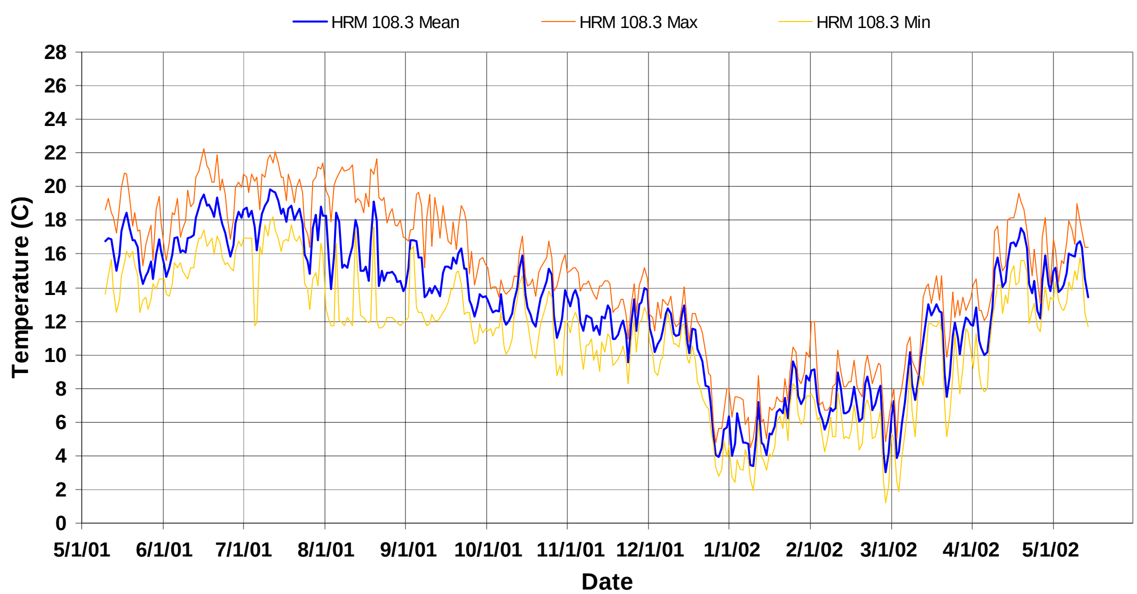

Figure 3. Mean, Minimum, and Maximum Daily Water Temperatures, Hiwassee River - RM 108.3 (Shallow Ford Bridge, Upstream of Mission Pond)

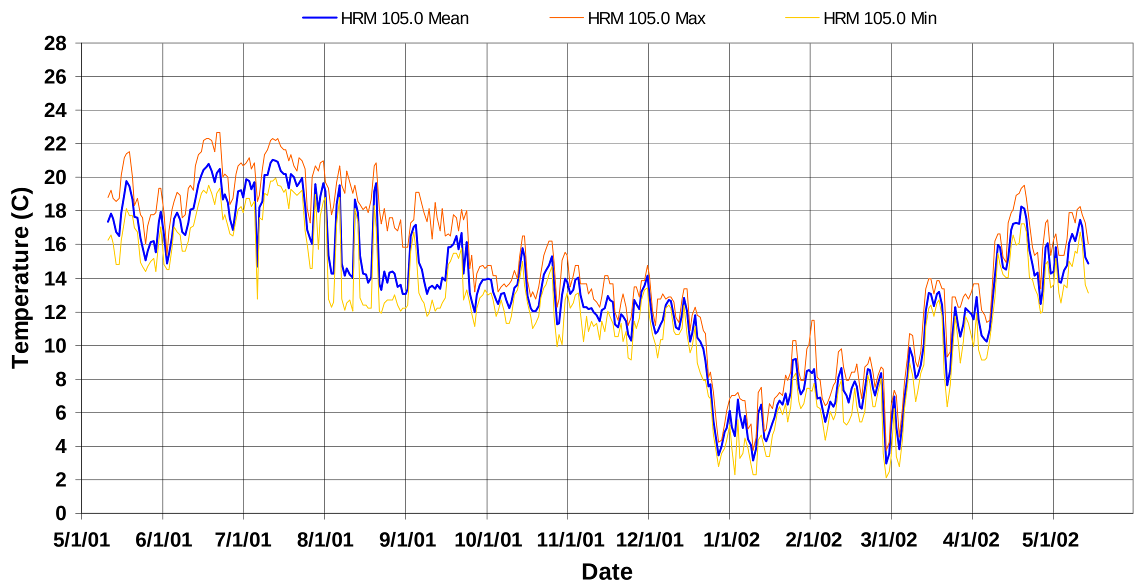

Figure 4. Mean, Minimum, and Maximum Daily Water Temperatures, Hiwassee River - RM 105.5 (Mission Powerhouse Flow)

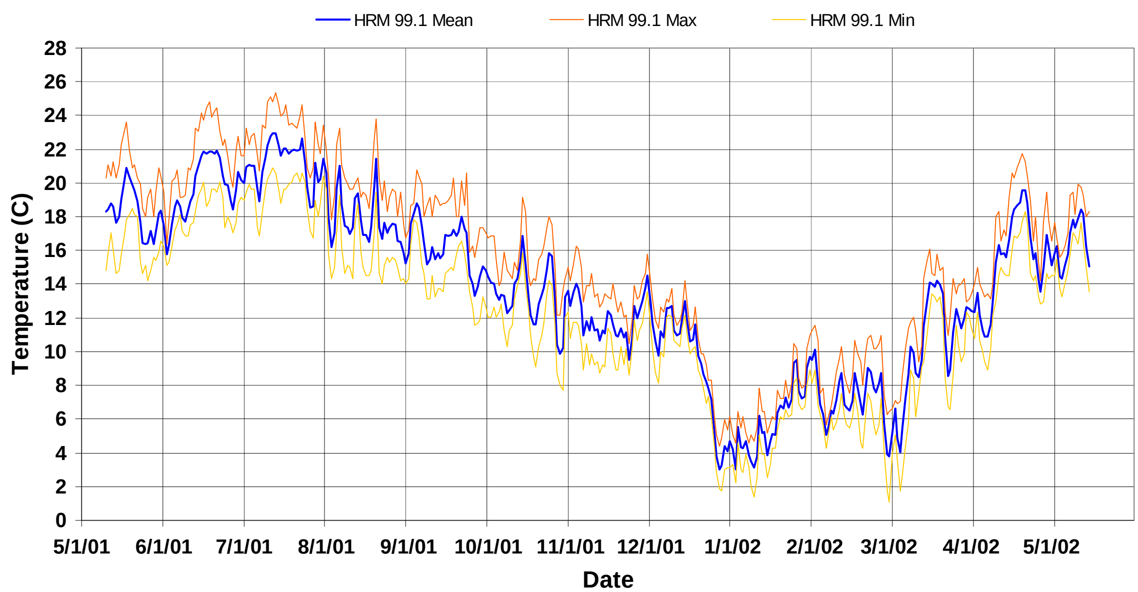

Figure 5. Mean, Minimum, and Maximum Daily Water Temperatures, Hiwassee River - RM 99.1 (USGS gage at Murphy)

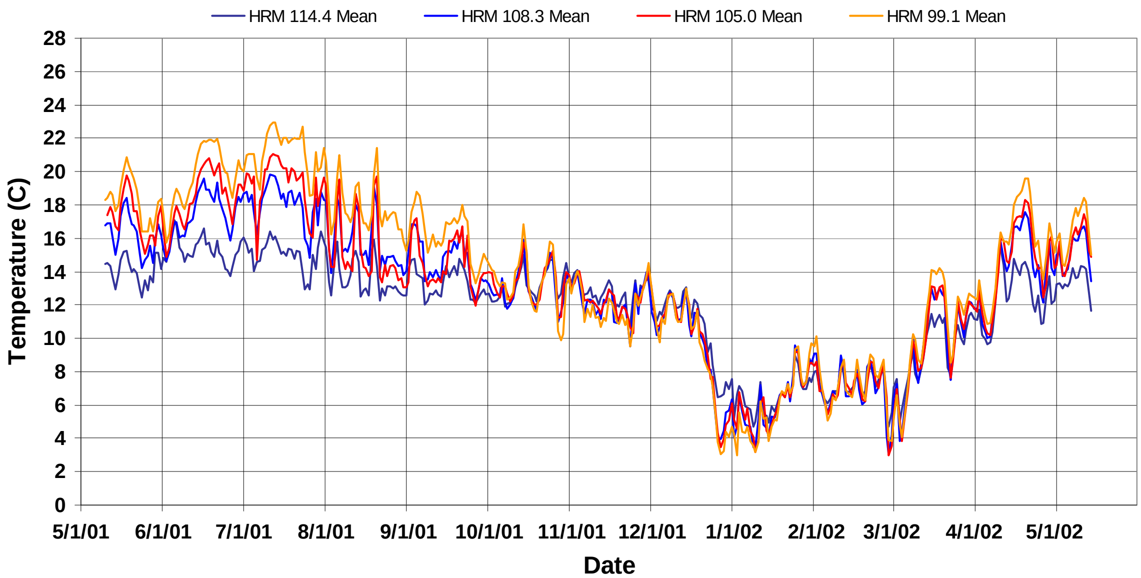

Figure 6. Mean Daily Water Temperatures, Hiwassee River - All locations

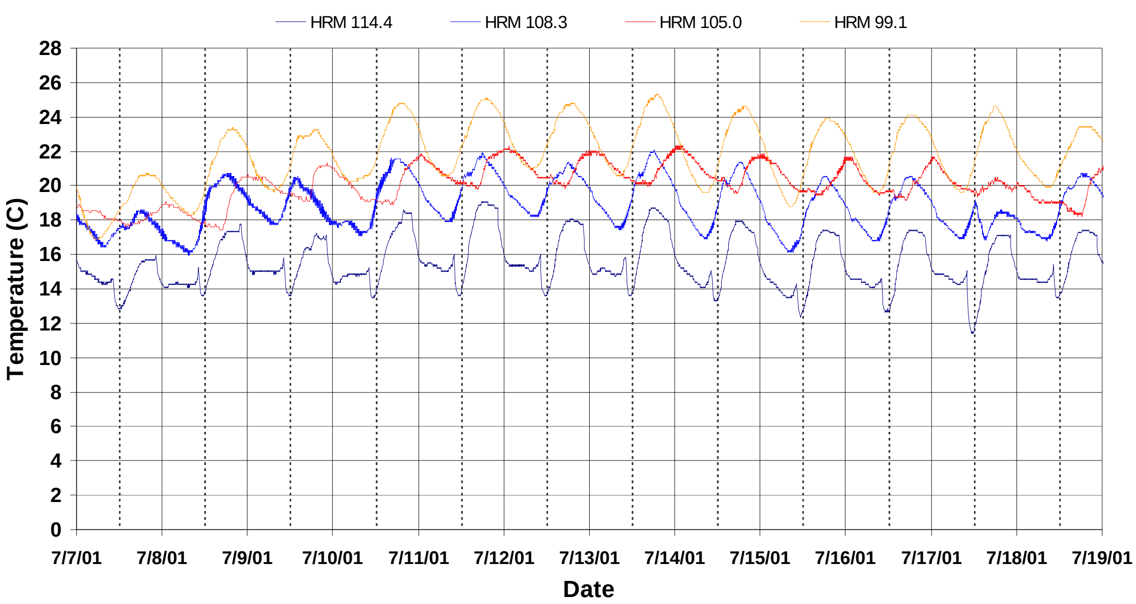

Figure 7. Comparison of 15-minute Water Temperatures, Hiwassee River, All Locations

Table 2. Mean Monthly Temperatures Change (Cº/mile), Hiwassee River, Upstream and Downstream of Mission Project, 2001 - 2002.

River Section	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
RM 114.4 to 108.3 (Old USGS gage to Shallow Ford Bridge)	-0.05	-0.03	0.07	0.25	0.33	0.34	0.50	0.35	0.22	-0.01	-0.08	-0.16
RM 108.3 to 105.0 (Shallow Ford Bridge to Mission Powerhouse)	-0.01	0.03	0.00	0.11	0.22	0.31	0.33	-0.15	-0.04	0.08	0.04	0.03
RM 105.0 to 99.1 (Mission Powerhouse to USGS gage - Murphy)	-0.03	0.04	0.10	0.16	0.17	0.21	0.33	0.44	0.29	0.01	-0.07	-0.06

Historical Water Temperature

The twenty years of monthly 'grab' temperature data collected by the NCDENR-DWQ at the USGS gage at Murphy (Figure 8) revealed temperatures that were consistently less than the state water quality standard of 29ºC for Class C waters. The monthly 'grab' samples illustrated a high degree of variability between the various years in the Hiwassee River. This variability is not unexpected since, as mentioned in the previous section, the river temperatures responded very rapidly to changing meteorological conditions; hence, the water temperatures reflect the meteorological and river flow conditions immediately prior to sampling. In addition, the very high variability of water temperatures during the summer also reflect the stratification patterns and subsequent water release from Chatuge Reservoir.

The historical 'grab' samples of temperature do reveal that the years with low and mid-range summer flows usually exhibited warmer summertime temperatures than the years with high summer flows (Figure 8). But, the high variability of summer time temperatures also reveal the significant influence that the water temperatures and flows from Chatuge also have on downstream water temperatures. Higher flows in August and September starting in 1991 (the first year of TVA's current pool level operating policy), especially for normal and high flow years, typically resulted in lower temperatures during that time.

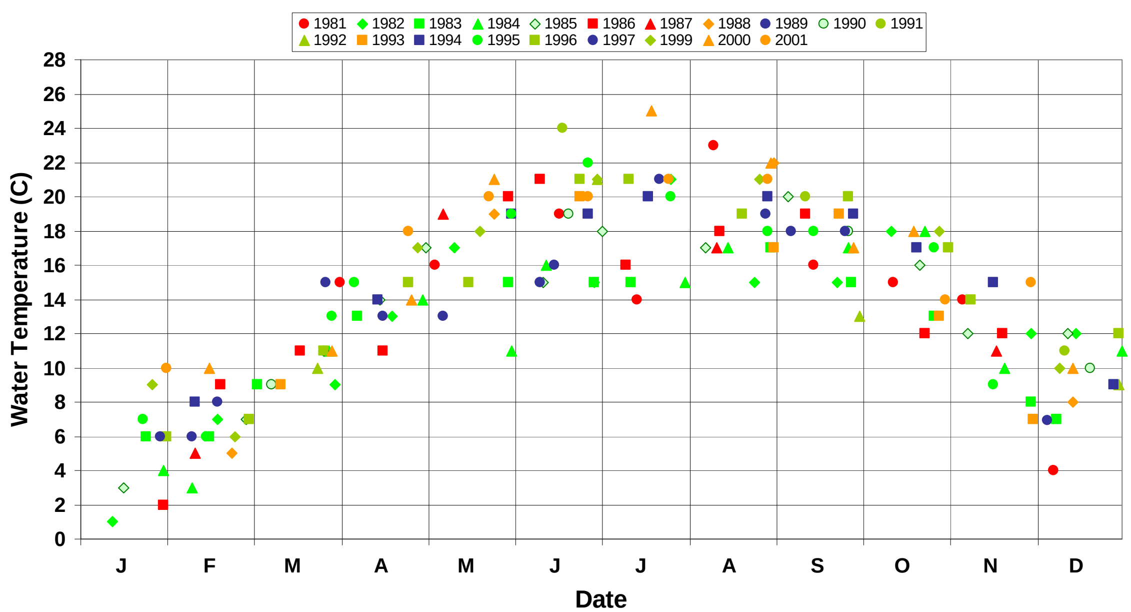

Figure 8. Monthly 'grab' Water Temperatures Collected by NCDENR-DWQ at RM 99.1 (USGS gage at Murphy), Hiwassee River (blue = summer flow > 970, green = 582 < summer flow > 970, and red = summer flow < 582)

Dissolved Oxygen

Dissolved Oxygen Deployments

Minimum dissolved oxygen concentrations in rivers typically are observed during the late summer when temperatures were warm and the growing season of aquatic plants had peaked. At warmer water temperatures, the amount of dissolved oxygen in equilibrium with the atmosphere (saturation) decreases, while biological metabolism (photosynthesis and respiration rates) increases. Hence, the lowest dissolved oxygen concentrations were expected during September.

The dissolved oxygen concentrations measured at 5-minute intervals in the Hiwassee River at all locations (Figure 9) were at least 4 mg/l, greater than the 4 mg/l instantaneous minimum standard for Class C waters. The dissolved oxygen concentrations downstream of the Mission Project were 1 mg/l greater than the oxygen recorded from the sites upstream of Mission dam. (The erratic pattern and lower values recorded at RM 108.3 were attributed to leaf litter that had accumulated and 'packed' the Hydrolab sensor guard during the deployment). The lowest dissolved oxygen concentrations were observed at RM 114.4, indicating that significant aeration occurred as the water moved downstream. Daily average dissolved oxygen concentrations were at least 3 to 4 mg/l greater than the State standard of 5 mg/l oxygen.

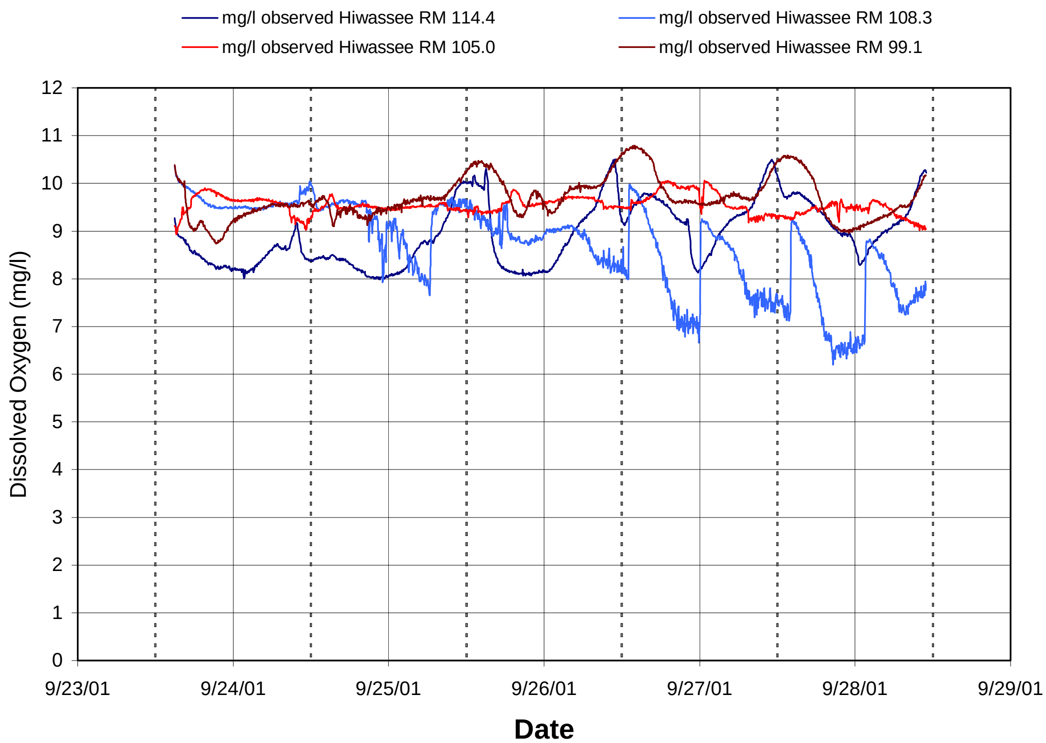

Figure 9. Comparison of the observed 5 minute Dissolved Oxygen Concentrations, Hiwassee River, All Locations

The diel patterns of dissolved oxygen concentrations in the Hiwassee River downstream of Chatuge dam and the infuser weir (Figure 10) were a result of water of lower dissolved oxygen released from the infuser weir (periods of higher river stage), atmospheric aeration, most noticeable during the periods of low flow (low river stage), and biological metabolism (most evident during the small pulses of water to maintain minimum flow (September 27th and 28th).

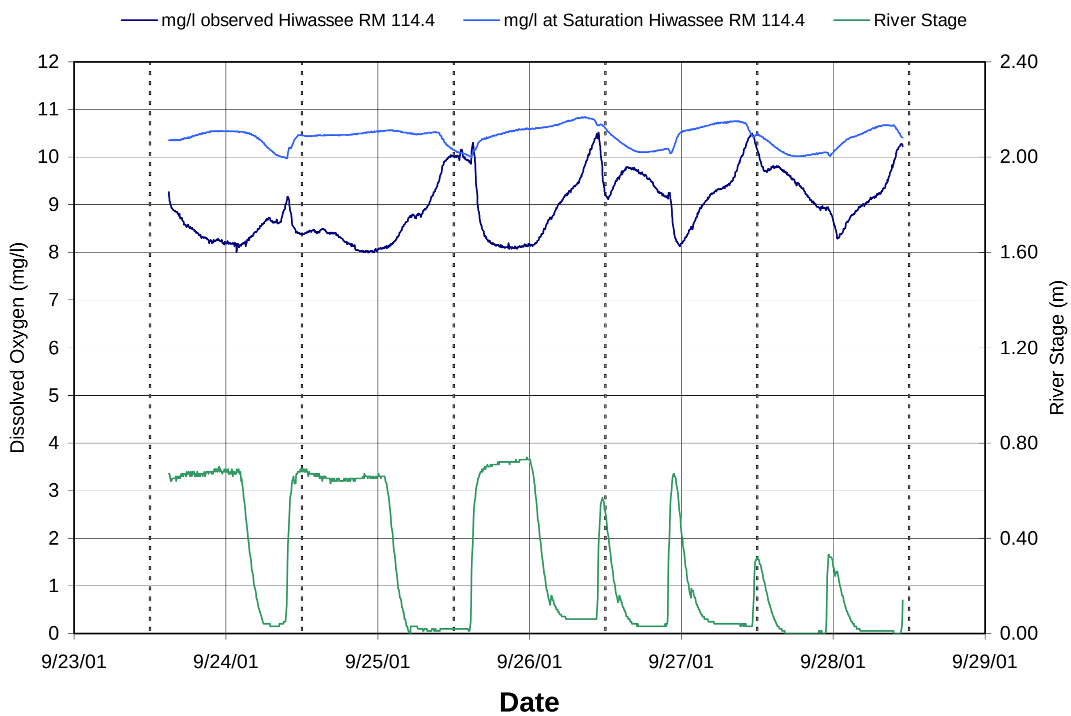

Figure 10. Comparison of the observed 5 minute Dissolved Oxygen Concentrations, Calculated Oxygen Saturation Concentrations, and River Stage, September, 2001, Hiwassee River - RM 114.4 (Old USGS gage, downstream of Tusquitee Creek)

The actual pattern of dissolved oxygen concentrations in the Hiwassee River upstream of Mission Pond, RM 108.3 (Figure 11) were obscured due to the leaf material that had accumulated around the dissolved oxygen sensor. The higher flows probably allowed a better exchange of river water around the sensor causing the dissolved oxygen concentration to increase during those times. However, the dissolved oxygen concentrations in the river probably approached 100% saturation, as evidenced by the dissolved oxygen concentrations recorded on September 23rd and 24th (before the leaf material had restricted the flow of water around the sensor).

The dissolved oxygen concentrations in the Mission power house flow at RM 105.0 (Figure 12) were at or near atmospheric saturation. The concentrations were very consistent throughout the deployments. Since the power house flow released water from mid to lower depths in Mission Pond, the dissolved oxygen concentrations probably reflected the integrated biological metabolism at the different depths, e.g. predominantly respiration in the bottom waters and photosynthesis in the upper levels. The initial stage change (September 23rd) was probably a result of the float system moving on the hard rock bottom during the higher flows.

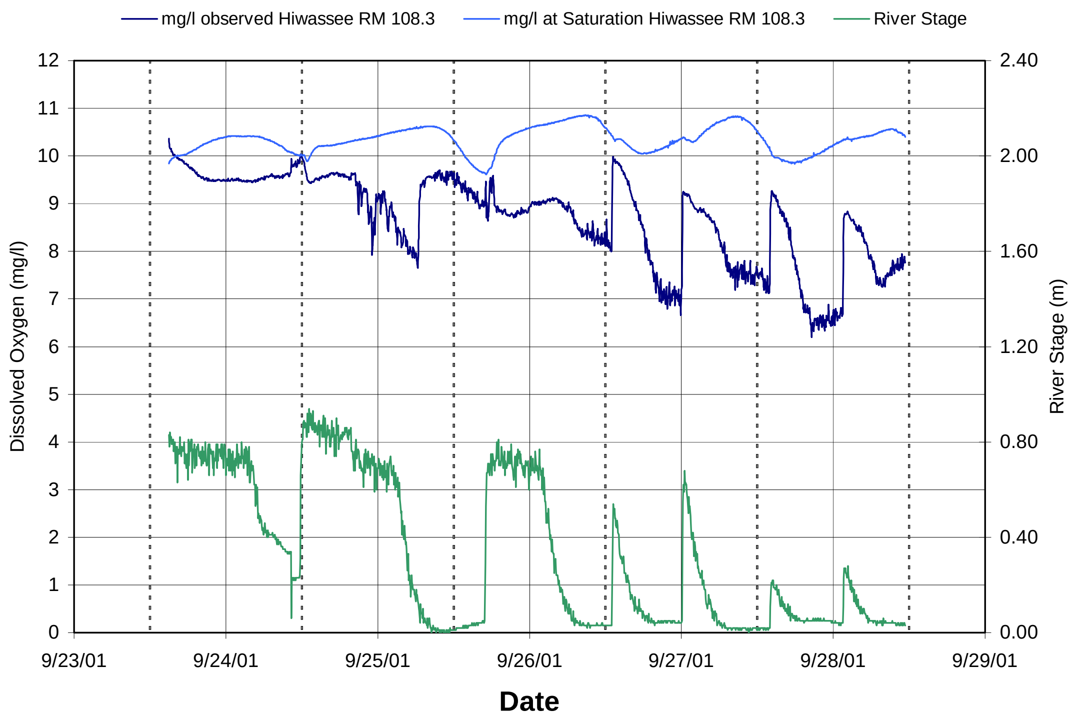

Figure 11. Comparison of the observed 5 minute Dissolved Oxygen Concentrations, Calculated Oxygen Saturation Concentrations, and River Stage, September, 2001, Hiwassee River - RM 108.3 (Shallow Ford Bridge, Upstream of Mission Pond)

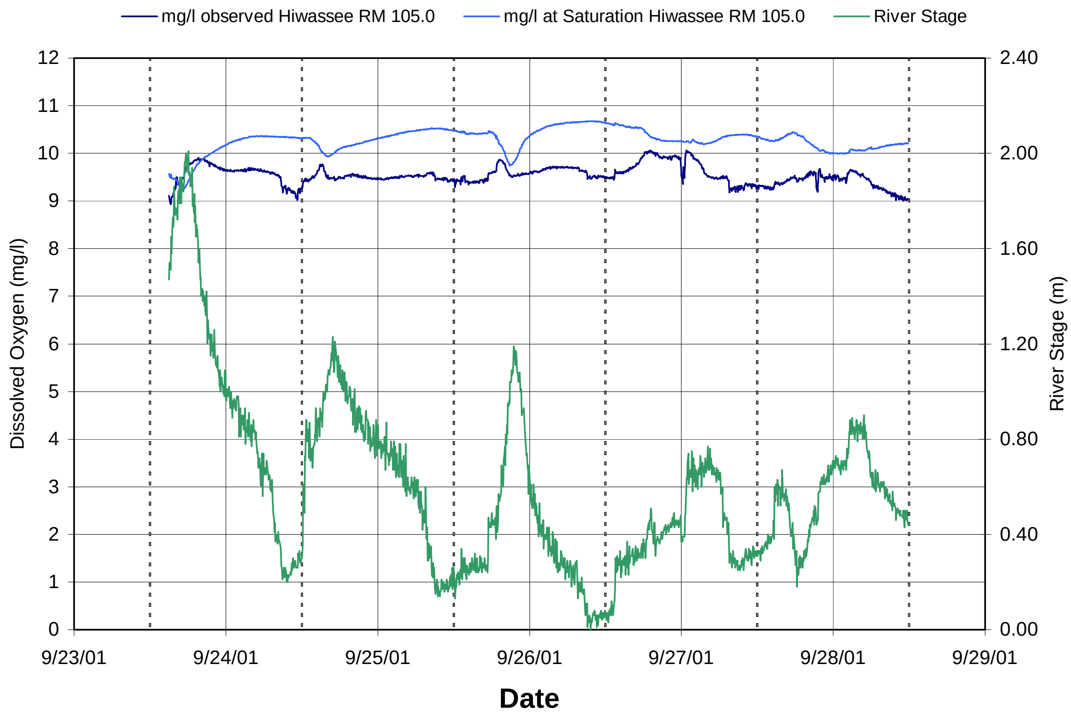

Figure 12. Comparison of the observed 5 minute Dissolved Oxygen Concentrations, Calculated Oxygen Saturation Concentrations, and River Stage, September, 2001, Hiwassee River - RM 105.0 (Mission Powerhouse Flow)

The dissolved oxygen patterns of increased oxygen from photosynthesis during the day and respiration consumption of oxygen at night, particularly during low flows, was the predominant factor influencing the dissolved oxygen concentrations at the downstream site, RM 99.1. The oxygen concentrations exceeded 100% saturation, indicating significant aquatic plant photosynthetic activity in the Hiwassee River. At higher flows, the biological metabolism contributed to dissolved oxygen concentration changes, but was not a predominant factor due to higher volumes of water in the river at higher flows.

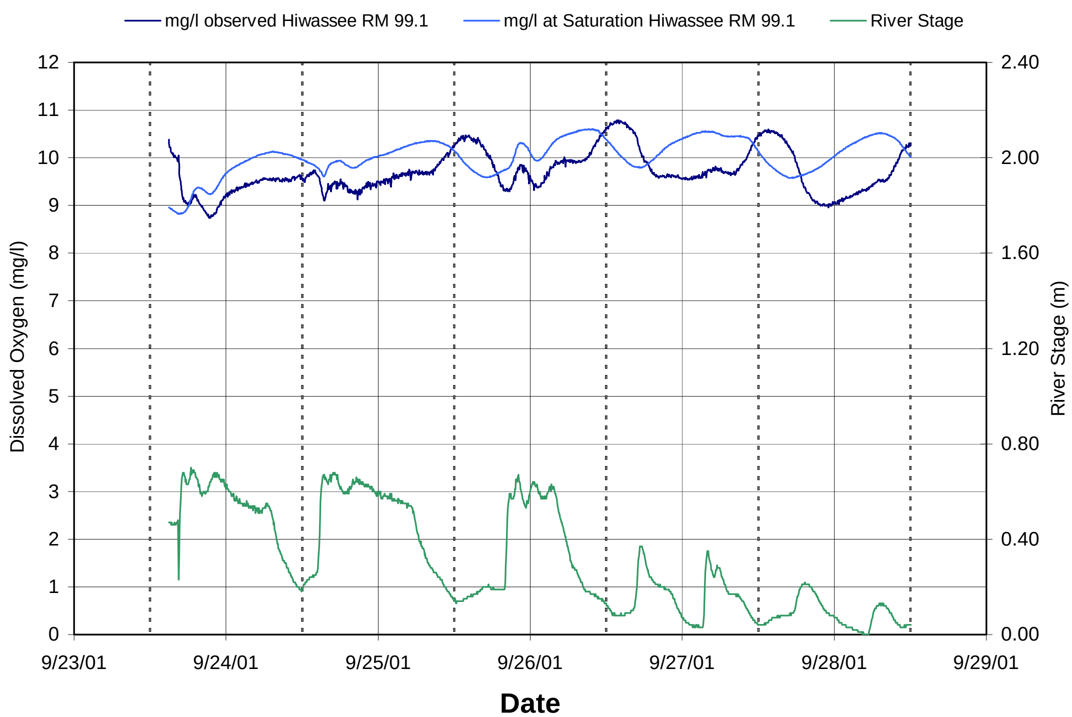

Figure 13. Comparison of the observed 5 minute Dissolved Oxygen Concentrations, Calculated Oxygen Saturation Concentrations, and River Stage, September, 2001, Hiwassee River - RM 99.1 (USGS gage at Murphy)

Historical Dissolved Oxygen Concentrations

The 20 years of monthly grab samples from the Hiwassee River upstream of Murphy (Figure 14) indicated that the Hiwassee River consistently had oxygen concentrations greater than state water quality standards. Unlike the temperature data, summertime flow did not appear to influence the oxygen concentrations. The concentrations probably reflected the relative flow and the relative amount of biological metabolism in the river at the time of collection.

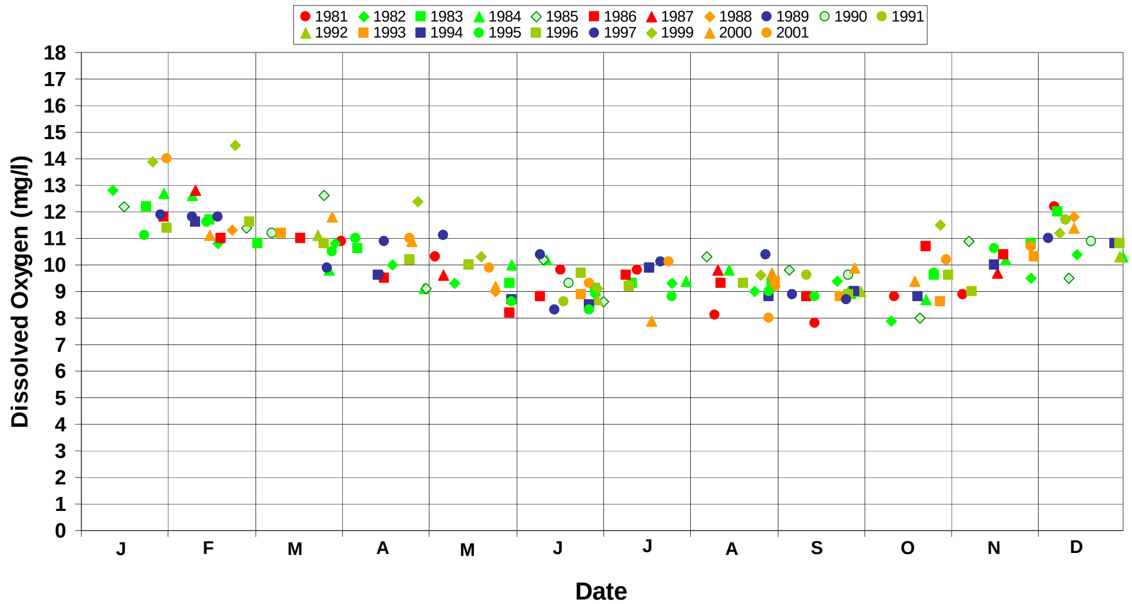

Figure 14. Monthly 'grab' Dissolved Oxygen Concentrations Collected by NCDENR-DWQ at RM 99.1 (USGS gage at Murphy), Hiwassee River (blue = summer flow > 970, green = 582 < summer flow > 970, and red = summer flow < 582)

CONCLUSIONS

The water flow and subsequent water temperatures in the Hiwassee River upstream of the Mission Project were controlled by the hypolimnetic release of water from TVA's Chatuge Hydroelectric Station. In 1992, TVA constructed an infuser weir 0.9 miles downstream from Chatuge to provide minimum flow and to aerate the hypolimnetic water. As the water travels downstream from the Chatuge Project to the USGS gage upstream of Murphy, NC, water temperatures in the Hiwassee River responded rapidly to changing meteorological conditions as evidenced by similar daily, weekly, and seasonal changes of water temperature from all locations. The hypolimnetic water warmed as it traveled downstream during the spring and summer, and cooled during the fall and winter. The local meteorology forced the heating and cooling of the Hiwassee River as the river temperatures responded to the meteorological equilibrium conditions. The net effect of the Mission project was to slightly increase the retention time and depth of the water which, coupled with deeper water withdrawal for power production, resulted in smaller diel temperature changes during the warmest time of the year and 'buffered' the heating and cooling during the fall and winter. On the average, the river gained 0.24ºC per mile during the summer, and lost 0.03ºC per mile during the winter. At no time did the river temperatures exceed the state water quality standards of 29ºC.

The September dissolved oxygen concentrations were lowest at the upstream location below Chatuge Reservoir. Aeration, either atmospheric addition or photosynthetic activity, increased the dissolved oxygen concentrations downstream to near saturation levels. Based upon dissolved oxygen data collected in 2001 and the NCDENR-DWQ historical data, oxygen concentrations consistently exceeded the minimum concentrations established by State water quality standards for the Hiwassee River.

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