

TEMPERATURE AND DISSOLVED OXYGEN

FRANKLIN 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 Little Tennessee 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) for the project is required.

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 designated trout waters is an upper limit of 20°C. However, in much of the United States, ambient water temperatures often exceed 20° C, even in natural trout streams (Ruane, 2002). 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 with the Franklin Project to provide information regarding the management of aquatic wildlife.

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

Table 1. Temperature and Dissolved Oxygen Sampling Locations Associated with the Franklin 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
Cullasaja River - upstream of Porter Cove	1.2	10 May 2001 to 15 May 2002 (82%)	N/A	(B;Tr)	N/A	N/A
Little Tennessee River - upstream of confluence with Cullasaja River	117.6	10 May 2001 to 15 May 2002 (100%)	N/A	(Prentiss) 1981 - 2001 (C)	Temp 4 Jan, 2000 to 1 Nov, 2000	N/A
Little Tennessee River - powerhouse flow downstream of Franklin Dam	113.0	10 May 2001 to 15 May 2002 (100%)	6 Aug - 10 Aug (100 %) & 16 Sep - 20 Sep (100 %)	(Iotla) 1974 - 2001 (C)	Temp 4 Jan, 2000 to 1 Nov, 2000	N/A

Stream Classification		Water Quality Standards	
Symbol	Designated Use	Temperature	Dissolved Oxygen
B	Primary Recreation	less than 29°C	5 mg/l mean, 4 mg/l instantaneous
C	Secondary Recreation	less than 29°C	5 mg/l daily mean, 4 mg/l minimum
Tr	Trout Water	less than or equal to 20°C	6 mg/l daily mean, 5 mg/l minimum

METHODS

Fish and Wildlife Associates, Inc. (FWA) deployed Onset Stowaway XTI temperature loggers above and below the Franklin Project in 2000. The temperature data were recorded at approximately 4-hour intervals (Nantahala Power and Light, 2000) .

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 Little Tennessee River at approximately the same locations as FWA in 2000 (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 ½” 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 an average temperature data recovery of 100 % from the Little Tennessee River and 82% from the Cullasaja River (Table 1). The loss of data from the Cullasaja River was the result of a faulty ‘data Shuttle’ supplied by Onset Computer Corporation. After the loss of data from the Cullasaja River, data was downloaded directly into a computer and the ‘data shuttle’ was not used for any other data retrieval. The temperature data from both the FWA and DPC loggers 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, depth, and pH) were collected with a programmable Hydrolab DataSonde®. The DataSonde was suspended off the bottom by an anchored float (Knight, 1998) in the powerhouse flow downstream of the Franklin Project. The Hydrolab was programmed to record data at 5-minute intervals during a 4-day period in August 2001, and a 4-day period in September 2001. This deployment was conducted during times when baseflow was low (minimum rainfall) but with normal project operations. August and September were the warmest months and were used to represent the lowest dissolved oxygen concentrations exhibited during the year.

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 ~5°C increments while the instruments recorded the temperature at minute intervals. These data were within the manufacturer’s specifications.

The Hydrolab DataSonde® was calibrated for dissolved oxygen, conductivity, depth, and pH 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 DataSonde recorded the changes at 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 (1944 - 2001). Summer flows within $\pm 25\%$ 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) were obtained from NCDENR, DWQ (Sauber, 2002).

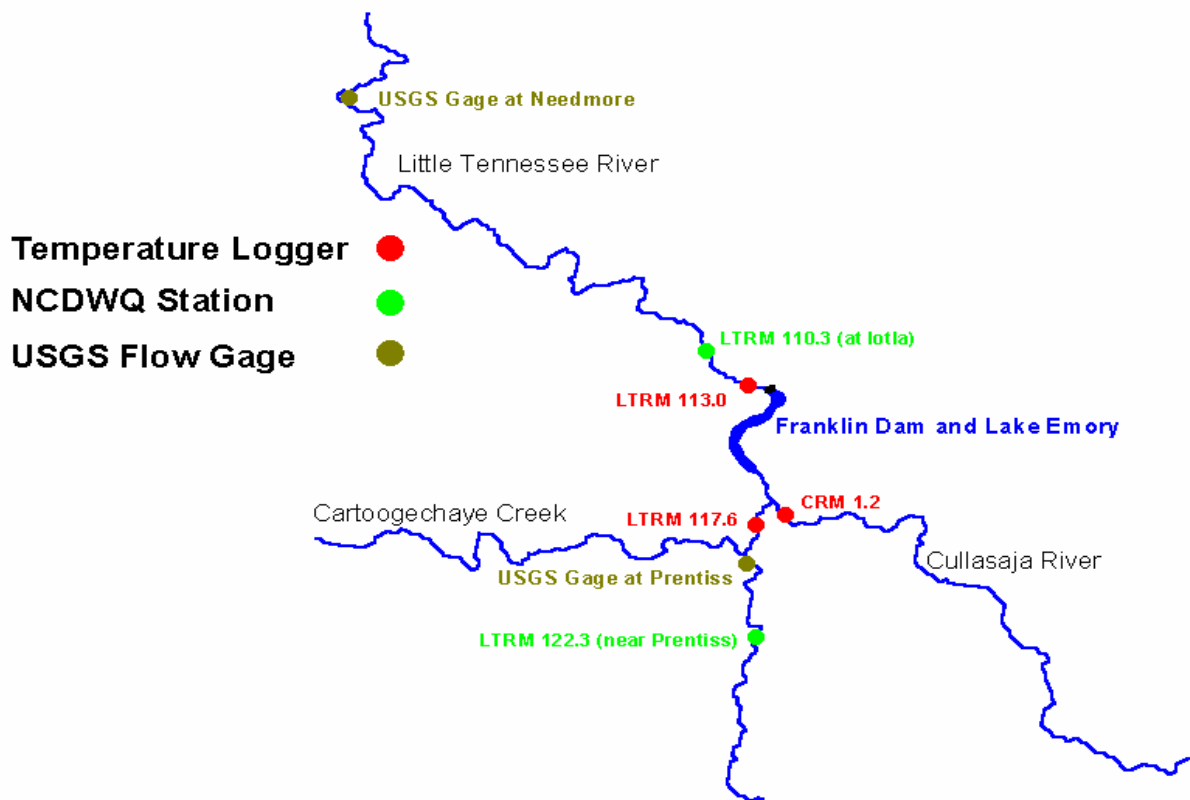


Figure 1. Map of Temperature and Dissolved Oxygen Sampling Locations in the Little Tennessee and Cullasaja Rivers - River Miles and Historical Data Collection Sites

RESULTS

Temperature

Continuous Water Temperature

Cullasaja River

The 2001-02 daily average, minimum, and maximum temperatures, calculated from the 15-minute temperature recordings from Cullasaja River upstream of the project at river mile 1.2 (Figure 2), exhibited warmest temperatures during July and August with coolest temperatures in January. Within the general seasonal trends of temperature, shorter intervals of heating and cooling periods were observed, indicating a rapid response of river temperatures to the prevailing meteorological conditions. Beginning in June and continuing into September 2001, ambient river temperatures of the Cullasaja River routinely exceeded the state water quality standard of 20°C for trout waters.

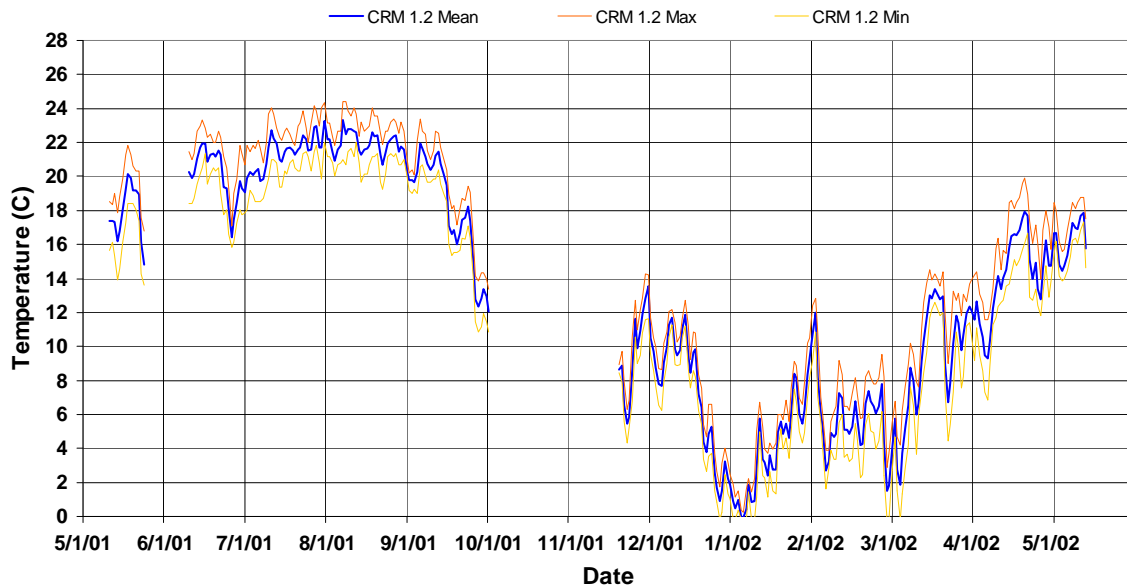


Figure 2. Mean, Minimum, and Maximum Daily Water Temperatures, Cullasaja River - Upstream of Franklin Project

Little Tennessee River

The daily average, minimum, and maximum temperatures calculated from the Little Tennessee River upstream of the Franklin Project in 2000 (Figure 3) and 2001-02 (Figure 4) exhibited the warmest temperatures during July and August, with slightly warmer temperatures observed in 2000. The coldest temperatures in 2000 were observed in late January - early February, while 2002 had a brief cold period in early January. As with the Cullasaja River (Figure 2), the ambient river temperatures in the Little Tennessee River (upstream of the Franklin Project) indicated a rapid response to the prevailing meteorological conditions. Since the Little Tennessee River was not classified as trout waters, temperatures did not exceed state water quality standards (29°C).

The daily average, minimum, and maximum temperatures calculated from the Little Tennessee River downstream of the Franklin Project in 2000 (Figure 5) and 2001-02 (Figure 6) exhibited identical trends as the temperatures recorded upstream of the Franklin Project. Comparison of the daily mean temperatures upstream and downstream of the Franklin Project (Figures 7 and 8) indicated very little difference between the sites during the winter and spring seasons. However, water temperatures during the summer and fall months were slightly warmer downstream of Lake Emory, but were well below state water temperature standards.

Examination of the individual temperature measurements (\approx 4-hour intervals in 2000 and 15-minute intervals in 2001) during the warmest period (Figures 9 and 10) revealed the significant diel temperature cycles at all sites. During this summer period of warm temperatures, the diel temperature changes often exceeded 2°C at all sites; maximum diel temperatures were observed downstream of the Franklin Project while minimum diel temperatures were observed upstream of Franklin, usually in the Cullasaja River (Figure 10). The 'peaks and valleys' of the diel temperature cycles occurred at the same time during the day at all sites indicating that the river temperatures at all sites responded very rapidly to the prevailing meteorological conditions. However, Lake Emory exhibited characteristics of a large pool in the river where retention time, depth, and width of the river increased (relative to the original river channel), but maintained sufficient mixing to prevent thermal stratification (Nantahala Power and Light, 2000). These characteristics enabled the water in Lake Emory to achieve slightly warmer temperatures (closer to equilibrium with the meteorological conditions) during the warmer times of the year.

The tendency of Lake Emory to achieve temperatures closer to equilibrium with the conditions imposed by the weather was also reflected in the mean monthly and seasonal temperatures (Table 2). Average seasonal water temperatures in 2000 were 1.1°C warmer than in 2001 (average difference in the Little Tennessee River upstream of the project between the two years). The average seasonal temperature of the water downstream of Lake Emory was 1.2°C warmer in 2000, compared to 0.9°C in 2001. These data again illustrate the rapid response of water temperature to the prevailing meteorological conditions, but that the net effect of Lake Emory during the warmest time of the year was to increase the retention time of the water to allow the water to achieve temperatures closer to equilibrium with the prevailing meteorology. During the winter - spring period, when flows were typically greater (reduced retention time) and meteorological conditions were changing rapidly (evidenced by wide fluctuations in water temperatures), at all locations, the river exhibited similarly large heat fluxes due to large differences between meteorological equilibrium and water temperatures.

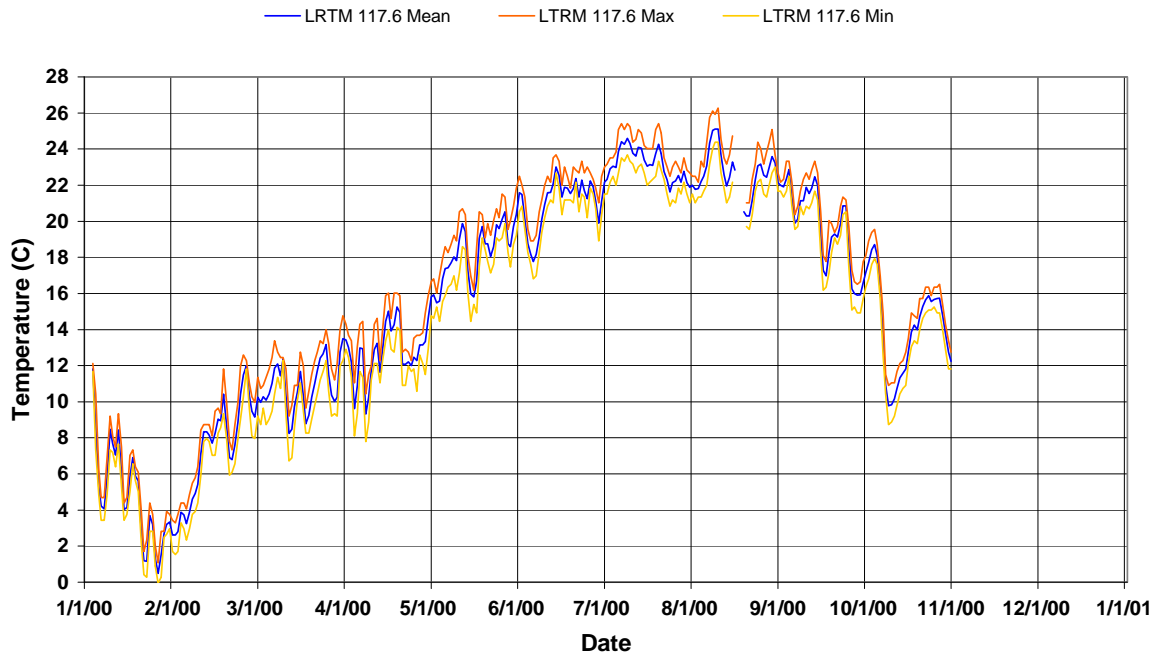


Figure 3. Mean, Minimum, and Maximum Daily Water Temperatures, Little Tennessee River - Upstream of Franklin Project at River Mile 117.6 (FWA)

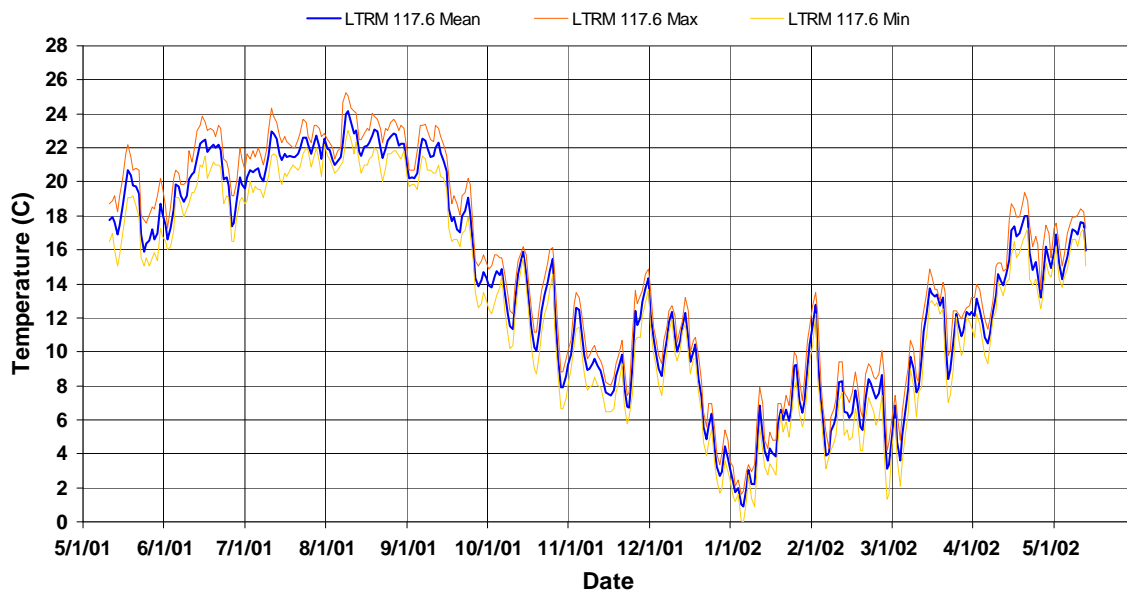


Figure 4. Mean, Minimum, and Maximum Daily Water Temperatures, Little Tennessee River - Upstream of Franklin Project at River Mile 117.6

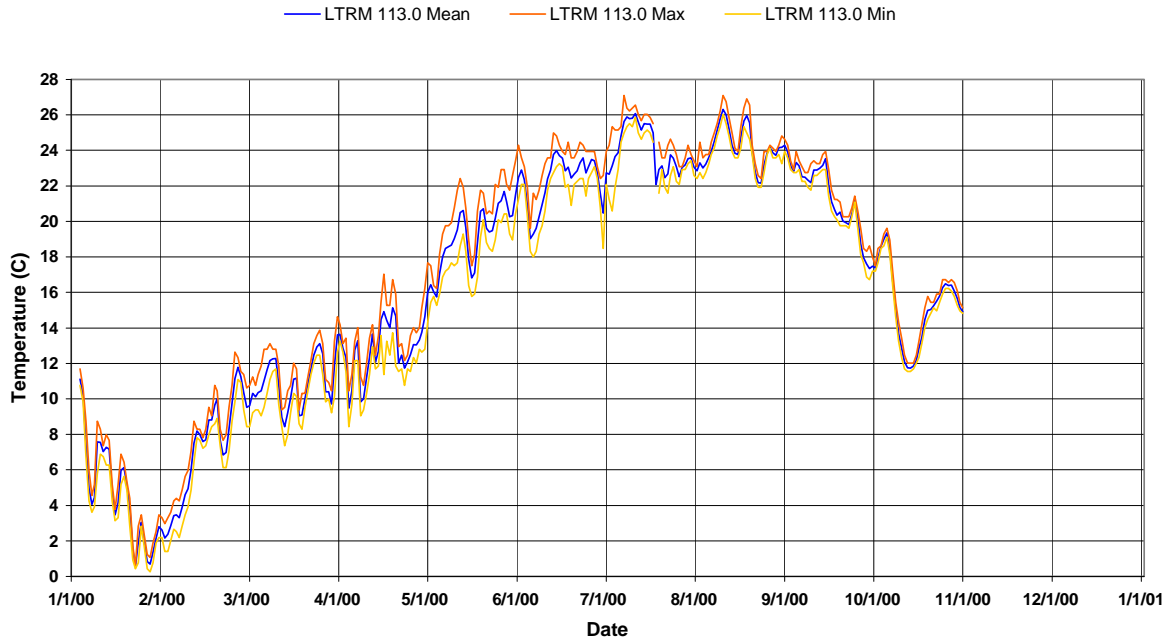


Figure 5. Mean, Minimum, and Maximum Daily Water Temperatures, Little Tennessee River - Downstream of Franklin Project at River Mile 113.0 (FWA)

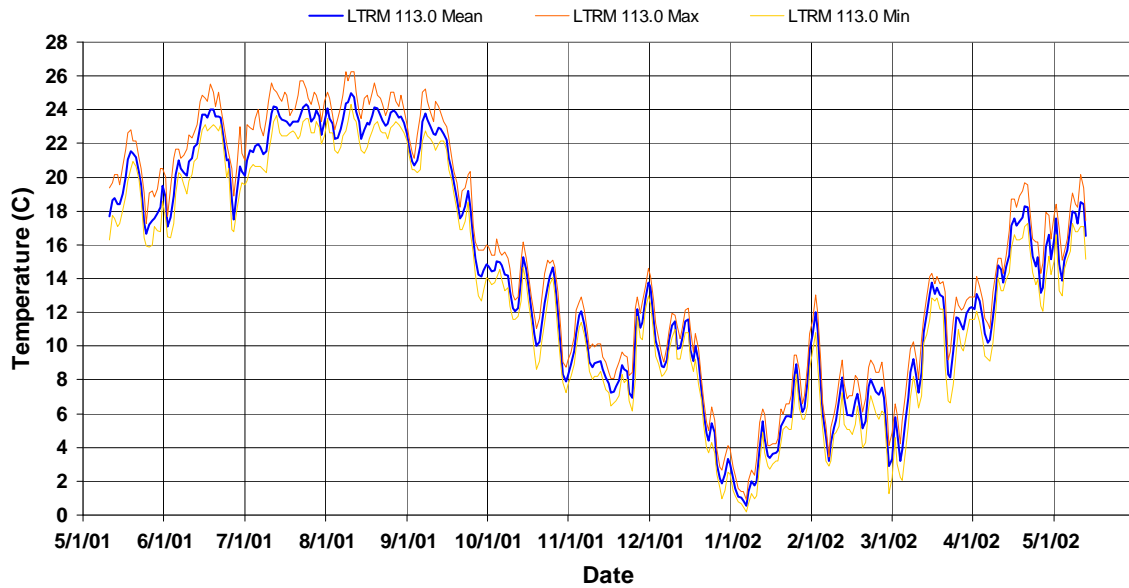


Figure 6. Mean, Minimum, and Maximum Daily Water Temperatures, Little Tennessee River - Downstream of Franklin Project at River Mile 113.0

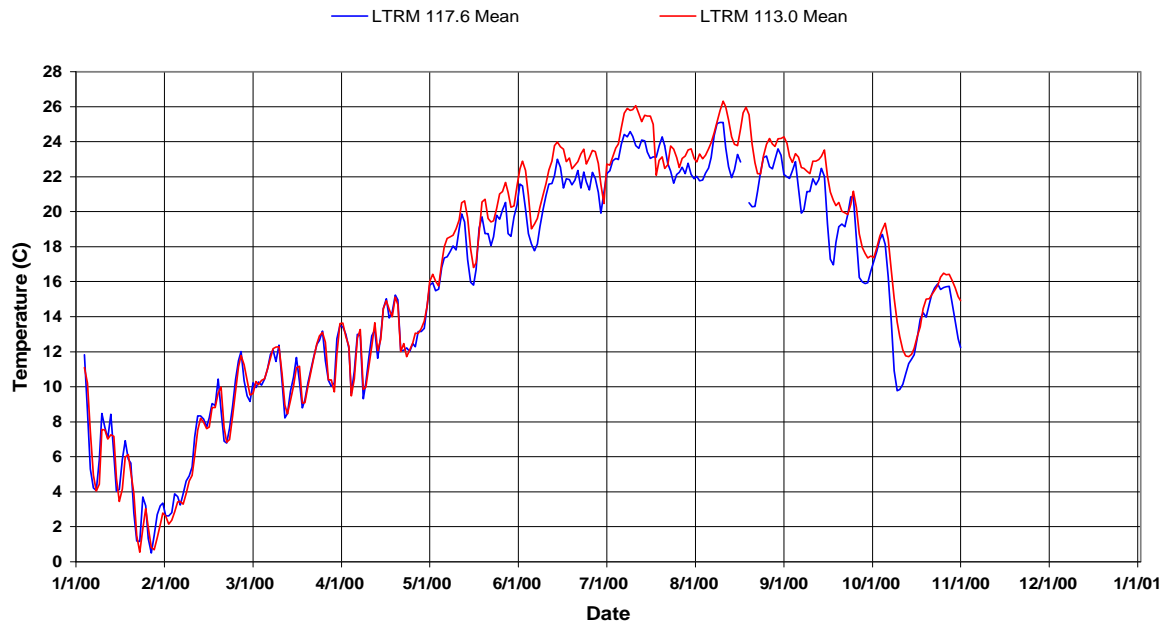


Figure 7. Comparison of the Mean Daily Water Temperatures, Little Tennessee River - Upstream and Downstream of Franklin Project (RM 117.6 and 113.0, respectively) (FWA)

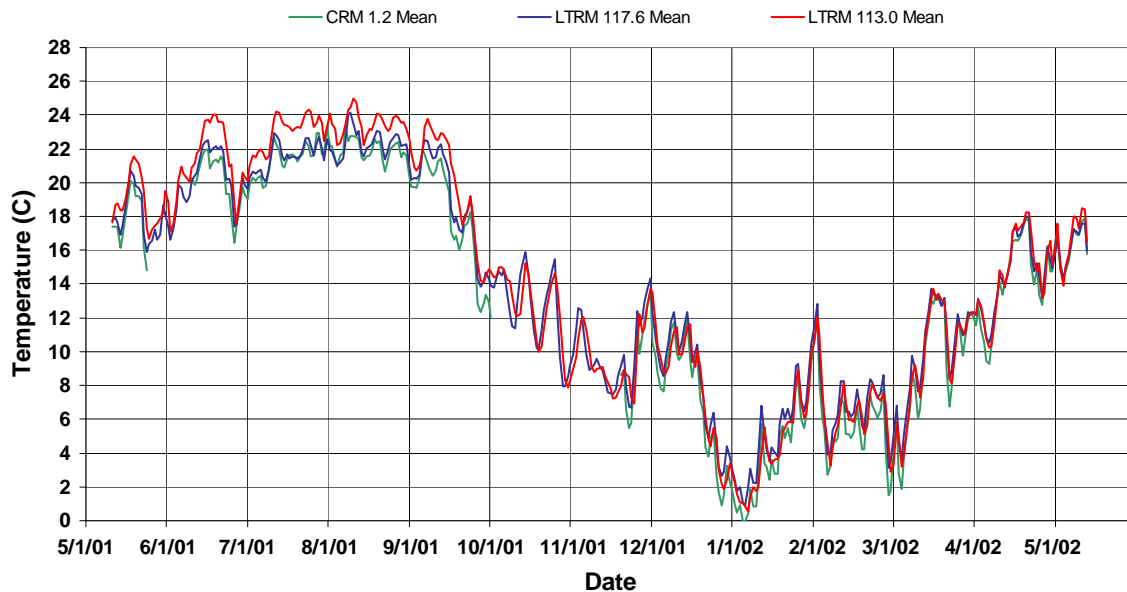


Figure 8. Comparison of the Mean Daily Water Temperatures, Upstream of the Franklin Project (Little Tennessee River, RM 117.6 and the Cullasaja River, RM 1.2) and Downstream of Franklin Project (Little Tennessee River, RM 113.0)

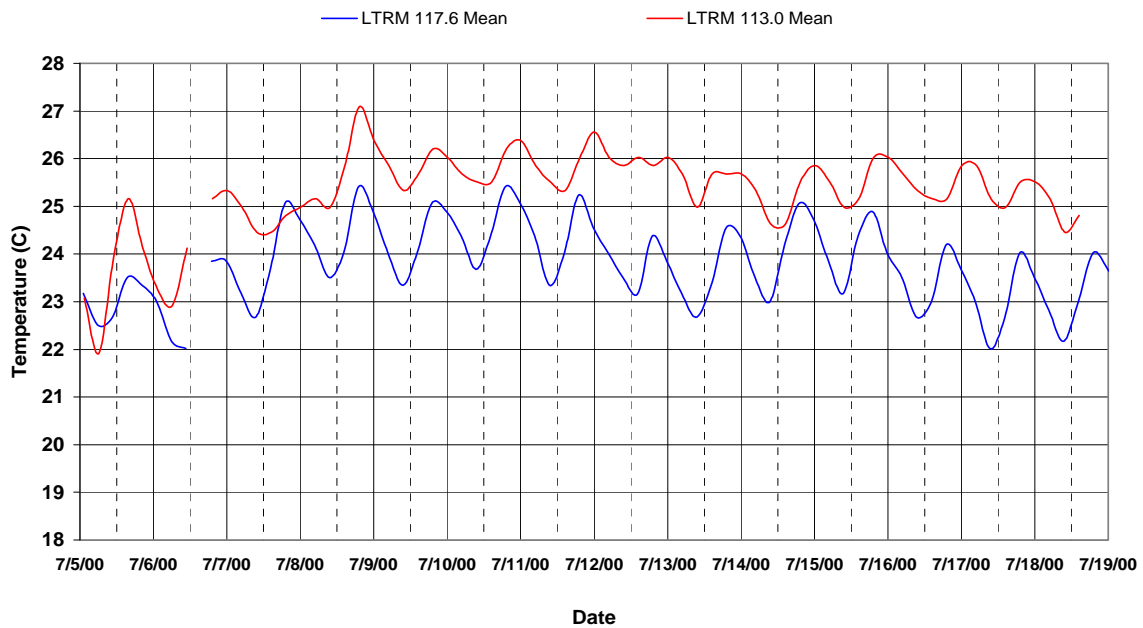


Figure 9. Comparison of 5-hour Water Temperatures, Little Tennessee River - Upstream and Downstream of Franklin Project (RM 117.6 and 113.0, respectively) (FWA)

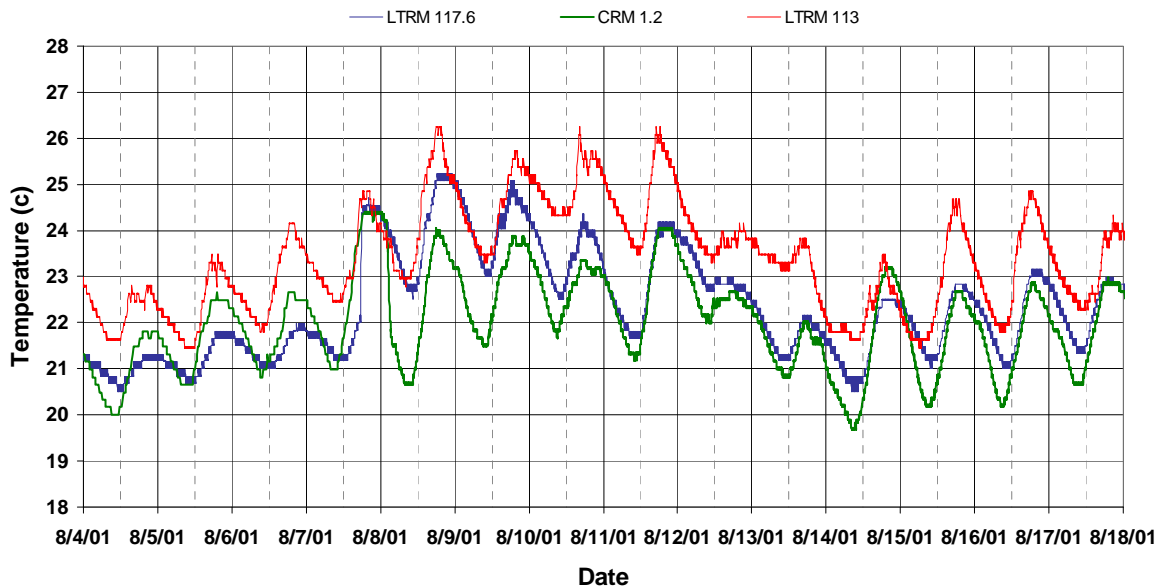


Figure 10. Comparison of 15-minute Water Temperatures, Upstream of the Franklin Project (Little Tennessee River, RM 117.6 and the Cullasaja River, RM 1.2) and Downstream of Franklin Project (Little Tennessee River, RM 113.0)

Table 2. Mean Monthly Temperatures (°C), Little Tennessee River, Upstream and Downstream of Franklin Project, 2000 and 2001.

	June		July		August		September		October		Mean Temperature June - Oct	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
Little Tennessee River Upstream Franklin Project	21.0	20.1	23.1	21.5	22.7	22.3	19.9	19.0	14.3	12.6	20.2	19.1
Little Tennessee River Downstream Franklin Project	22.3	21.1	23.9	22.9	24.1	23.5	21.5	19.9	15.4	12.7	21.4	20.0
Mean Temperature Difference (Downstream - Upstream)	1.3	1.0	0.8	1.4	1.5	1.2	1.5	0.9	1.1	0.1	1.2	0.9

Historical Water Temperature

The twenty years of monthly ‘grab’ temperature data collected by the NCDENR-DWQ upstream of USGS gage at Prentiss (Figure 11) and the 27 years of monthly ‘grab’ samples collected downstream of the Franklin Project at Iotla (Figure 12) revealed temperatures that were consistently less than the state water quality standard of 29°C for Class C waters. Even though the temperature values from both sites followed typical seasonal trends, the monthly ‘grab’ samples from both sites illustrated a high degree of variability between the various years in the Little Tennessee 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 conditions immediately prior to sampling.

The historical ‘grab’ samples of temperature do reveal that the years with low- and mid-range summer flows exhibited warmer summertime temperatures than the years with high summer flows (Figures 11 and 12). In addition, the historical data from the Iotla site, downstream of the Franklin Project, were typically warmer than the water from the Prentiss site. Analogous to the seasonal average temperatures calculated in Table 2, the average temperature of all data collected June through October for the low, mid, and high flow periods, revealed that mean temperatures were 0.1°C, 1.4°C, and 2.0°C warmer downstream of the Franklin Project for the high, mid, and low flow years, respectively. As discussed in the previous section of continuously recorded temperatures, these ‘grab’ sample averages again illustrate the rapid response of water temperature to the prevailing meteorological conditions, and that the net effect of Lake Emory during the warmest time of the year was to increase the retention time of the water to allow the water to achieve temperatures closer to equilibrium with the prevailing meteorology.

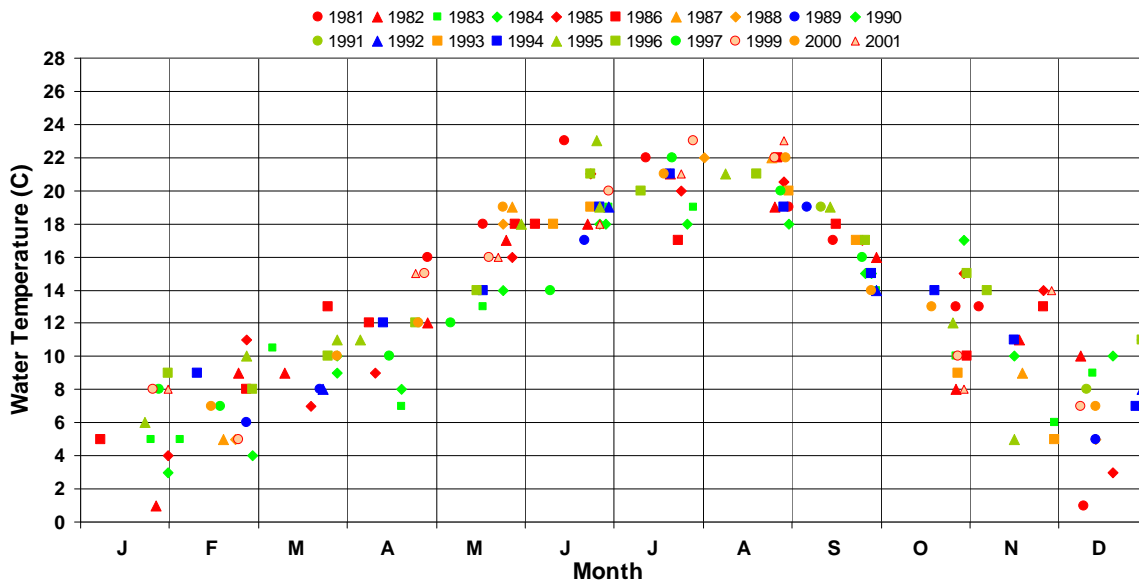


Figure 11. Monthly 'grab' Water Temperatures Collected by NCDENR-DWQ at RM 122.3 upstream of USGS gage at Prentiss), Little Tennessee River (USGS flows from Prentiss: blue = summer flow > 329, green = 197 < summers flow < 329, and red = summer flow < 197)

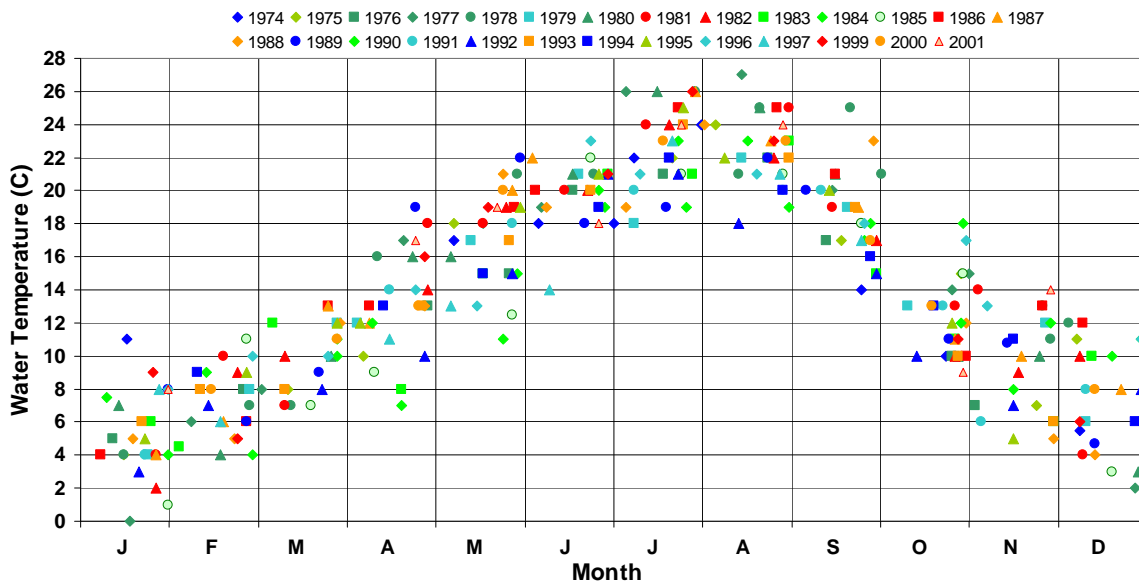


Figure 12. Monthly 'grab' Water Temperatures Collected by NCDENR-DWQ at RM 110.3 (near Iotla), Little Tennessee River (USGS flows from Needmore: blue = summer flow > 529, green = 891 < summer flow < 881, and red = summer flow < 529)

Dissolved Oxygen

Dissolved Oxygen and General Water Quality

As mentioned in the Methods Sections, the temperature data were downloaded from the ‘Tidbits’ were at approximately monthly intervals. During these monthly trips, water quality data were measured with a calibrated Hydrolab in the immediate tailrace of the Franklin Hydroelectric Station (Table 3). Temperature, dissolved oxygen concentrations, and pH were well within state water quality standards. Conductivity values, a measure of total dissolved solids (no state standard applies), were relatively low, even though the Little Tennessee River had 39 point source discharges upstream of the Franklin Project (Nantahala Power and Light, 2002).

Table 3. Water Quality ‘Grab’ Samples, Little Tennessee River, Downstream of Franklin Project, 2001.

DATE	TIME	TEMP. (deg-C)	DO (mg/l)	COND. (uSi/cm)	pH (units)	REMARKS
05/17/01	2:15 PM	19.5	8.9	71	7.0	Franklin generating
06/10/01	10:21 AM	19.9	7.3	61	6.8	Franklin generating
07/11/01	9:10 AM	22.6	7.3	49	6.8	Franklin generating
08/10/01	9:55 AM	24.4	6.8	80	6.8	Franklin generating
09/06/01	1:15 PM	23.7	7.1	109	6.8	Franklin generating
10/01/01	3:15 PM	14.9	9.5	86	6.6	Franklin generating
11/19/01	2:26 PM	8.7	11.7	108	6.9	Franklin generating

Dissolved Oxygen Deployments

The times of the measurement of dissolved oxygen monitoring at the Franklin Project were chosen during the late summer when dissolved oxygen concentrations were expected to be lowest. Minimum dissolved oxygen concentrations in rivers typically were 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 August and September.

Little Tennessee River

The dissolved oxygen concentrations measured at 5-minute intervals in the Little Tennessee River during August and September (Figures 12 and 13) were at least 2 - 3 mg/l greater than the 4 mg/l minimum standard for Class C waters. The lowest recorded dissolved oxygen concentration was 6.8 mg/l for a brief period on September 16th. Daily average dissolved oxygen concentrations were at least 2 mg/l greater than the state standard of 5 mg/l oxygen.

The diel patterns of dissolved oxygen concentrations in the Little Tennessee River below Lake Emory (Figure 12 and 13) were consistent with the biological metabolism patterns of increased oxygen from photosynthesis during the day and respiration consumption of oxygen at night. The oxygen concentrations in August exceeded 100% saturation, indicating significant aquatic plant photosynthetic activity in Lake Emory. Even though September oxygen concentrations did not exceed saturation levels, oxygen concentrations followed the same diel pattern as in August, again indicating significant aquatic plant metabolism. Fish and Wildlife Associates (Nantahala Power and Light, 2000) reported slightly reduced oxygen concentrations in the deeper areas of Lake Emory. The biological respiration rates lowered the dissolved oxygen in the reservoir, but the water retention time and depth of Lake Emory were low enough to prevent significant oxygen depletion. The September concentrations, even though well above state standards, were probably representative of low concentrations originating from Lake Emory.

Historical Dissolved Oxygen Concentrations

The 20 years of monthly grab samples from the Little Tennessee River at Prentiss and the 27 years of monthly samples from the Iotla site (Figures 16 and 17) indicate that the Little Tennessee 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.

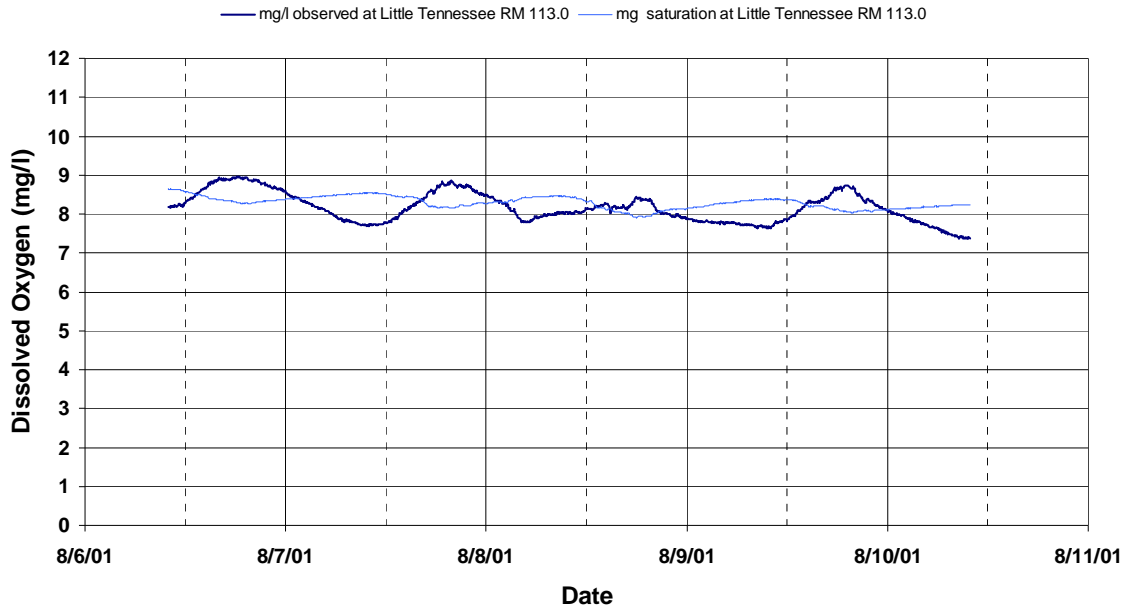


Figure 12. Comparison of the observed 5 minute Dissolved Oxygen Concentrations and Calculated Oxygen Saturation Concentrations, August 2001, Little Tennessee River - Downstream of the Franklin Project (RM 113.0)

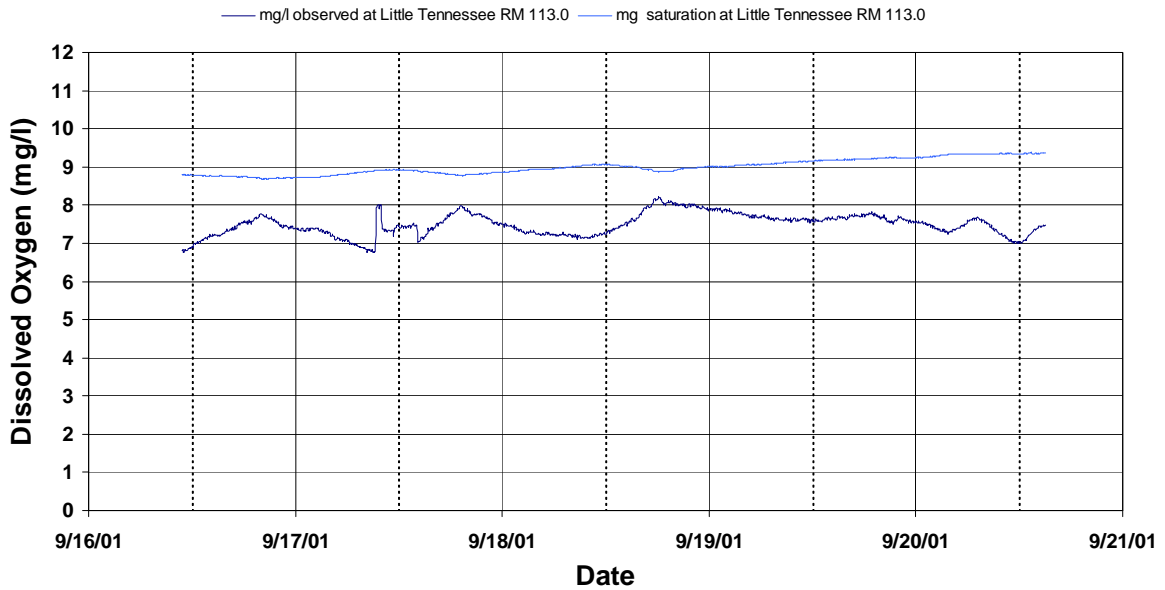


Figure 13. Comparison of the observed 5 minute Dissolved Oxygen Concentrations and Calculated Oxygen Saturation Concentrations, September, 2001, Little Tennessee River - Downstream of the Franklin Project (RM 113.0)

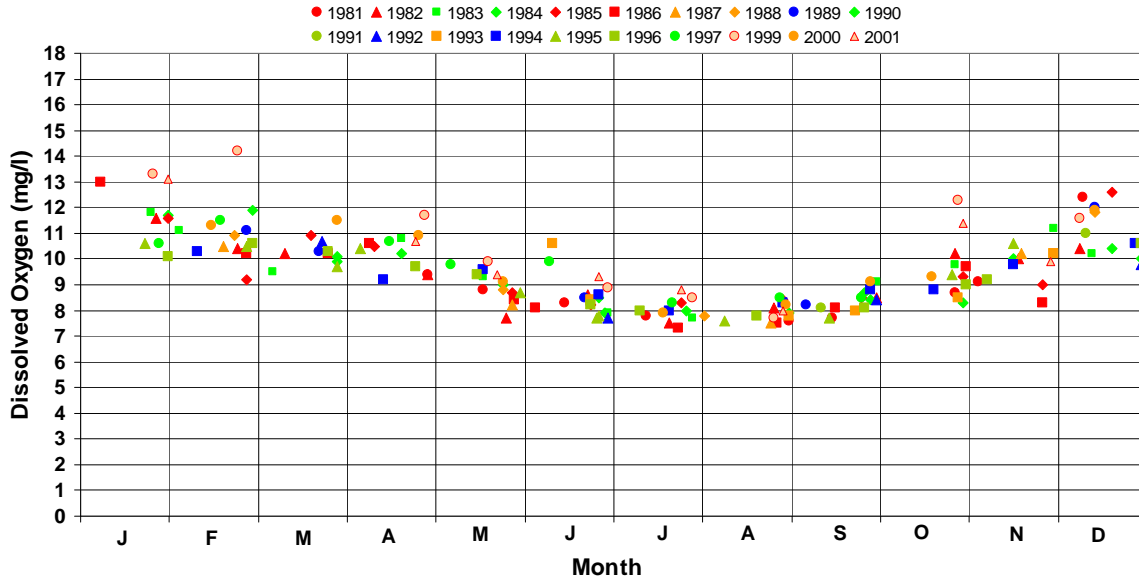


Figure 16. Monthly 'grab' Dissolved Oxygen Concentrations Collected by NCDENR-DWQ at RM 122.3 (upstream of USGS gage at Prentiss), Little Tennessee River (USGS flows from Prentiss: blue = summer flow > 329, green = 197 < summers flow > 329, and red = summer flow < 197)

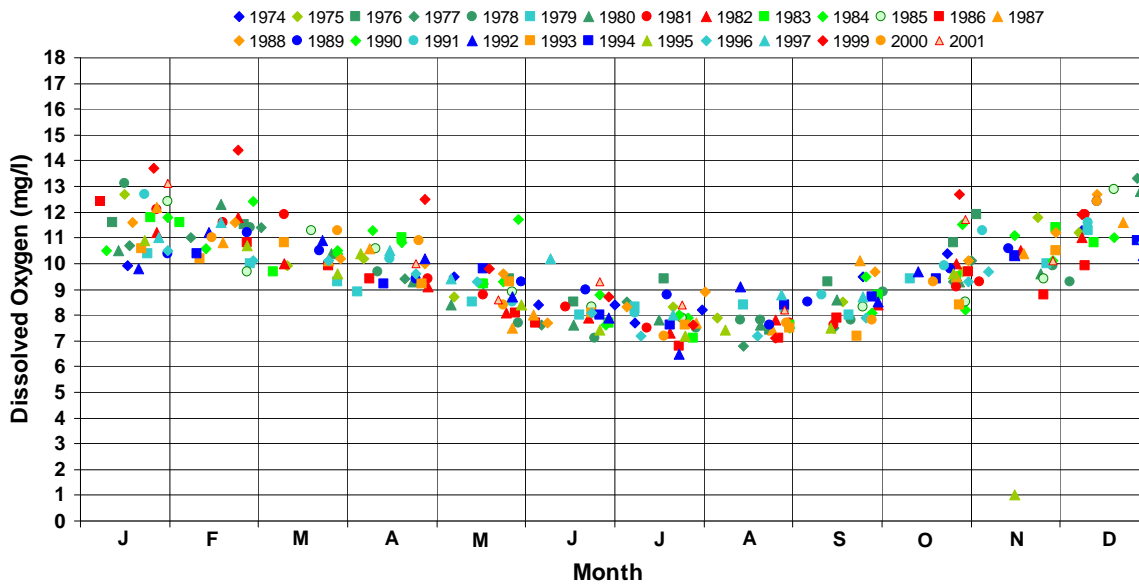


Figure 17. Monthly 'grab' Dissolved Oxygen Concentrations Collected by NCDENR-DWQ at RM 110.3 (near Iotla), Little Tennessee River (USGS flows from Needmore: blue = summer flow > 529, green = 891 < summer flow < 881, and red = summer flow < 529)

CONCLUSIONS

Water temperatures in both the Little Tennessee River and Cullasaja River responded rapidly to changing meteorological conditions as evidenced by similar daily, weekly, and seasonal changes of water temperature from all locations. The local meteorological conditions created ambient river temperatures that periodically exceeded state water quality standards for trout waters (20°C) in the Cullasaja River, but not for non-trout waters (29°C). The net effect of the Franklin project (Lake Emory) during the warmest time of the year was to increase the retention time of the water to allow the water to achieve temperatures closer to equilibrium with the prevailing meteorology. During low to average summer flows, temperatures increased by 1-2°C through Lake Emory. During summer high flow times and during the winter - spring periods, Lake Emory water temperatures were very similar to those temperatures above the project.

The August dissolved oxygen concentrations immediately downstream of the Franklin Project typically exceeded saturation concentrations during the day, but dropped below saturation concentrations at night. This diel pattern strongly suggests the role of aquatic plant metabolism on the oxygen dynamics within Lake Emory. The slightly lower dissolved oxygen concentrations in September were also influenced of by aquatic plant metabolism within Lake Emory but resulted in slightly lower oxygen concentrations below the project. 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 both the Tennessee River.

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