TEMPERATURE AND DISSOLVED OXYGEN STUDY

BRYSON 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 Oconaluftee River and lower Tuckasegee River supports the 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 20º 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 regimes upstream and downstream of the Bryson impoundment 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 Oconaluftee River and lower Tuckasegee River. Comparisons to state water quality standards and differences in upstream versus. downstream locations will be used to assess the impact of the Bryson project on the temperatures and dissolved oxygen concentrations downstream of the project.

Table 1. Temperature and Dissolved Oxygen Sampling Locations in the Oconaluftee and Tuckasegee Rivers - 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**
Oconaluftee River - upstream of Bryson Dam at USGS gage at Birdtown	3.2	10 May, 2001 to 15 May, 2002 *(91.2%)*	6 Aug - 10 Aug *(100 %)* & 16 Sep - 20 Sep *(100 %)*	1985 - 2000 *(C;Tr; HQW)*	N/A	N/A
Oconaluftee River - powerhouse flow downstream of Bryson Dam	0.3	10 May, 2001 to 15 May, 2002 *(100%)*	6 Aug - 10 Aug *(100 %)* & 16 Sep - 20 Sep *(100 %)*	N/A *(C;Tr; HQW)*	N/A	N/A
Tuckasegee River - upstream of confluence with Oconaluftee River	19.2	10 May, 2001 to 15 May, 2002 *(100%)*	6 Aug - 10 Aug *(100 %)* & 16 Sep - 20 Sep *(100 %)*	N/A *(C)*	N/A	N/A
Tuckasegee River - downstream of confluence with Oconaluftee River, at USGS gage at Bryson City	12.7	10 May, 2001 to 15 May, 2002 *(95.1%)*	6 Aug - 10 Aug *(100 %)* & 16 Sep - 20 Sep *(59.5 %)*	1976 - 2001 *(C)*	N/A	N/A

Stream Classification		**Water Quality Standards**	
Symbol	**Designated Use**	**Temperature**	**Dissolved Oxygen**
C	Secondary Recreation	less than 29^{o}C	5 mg/l daily mean, 4 mg/l minimum
Tr	Trout Water	less than or equal to 20^{o}C	6 mg/l daily mean, 5 mg/ minimum
HQW	High Quality Water	N/A	N/A

METHODS

Recording thermistors (StowAway®Tidbit®, Onset Computer Corp.) were programmed to record temperature at 15-minute intervals. The Tidbits were deployed at each location (Figure 1 and Table 1) beginning on 10 May 2001. The river temperatures were recorded 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. Examples of erroneous data included (1) periods when the loggers were vandalized, (2) logger malfunction, and (3) logged data during the downloading process. The process of double deployment and monthly data retrieval resulted in an average temperature data recovery of 96.4 % (Table 1). The loss of data during a deployment at both USGS gage sites was the result of tampering, during which the thermistors were pulled from the river and left lying on the bank. The edited data from the 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 programmable Hydrolab DataSondes®. The DataSondes were suspended off the bottom by an anchored float (Knight, 1998) in a deep pool at each location (Figure 1 and Table 1). The Hydrolabs were programmed to record data at 5-minute intervals during a 4-day period in August 2001, and a 4-day period in September 2001. These deployment were conducted during times when baseflow was low (minimum rainfall) but with normal project perorations. 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 DataSondes® were 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 DataSondes 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 discharges within 25% of the mean summer flows (calculated for each June - September time for the entire period of record) were designated as normal flow years, while summer mean flows either greater than or less than 25% of the mean were designated as high or low flows, respectively. Historical records of water quality (temperature and dissolved oxygen, monthly grab samples) were obtained from NCDENR, DWQ (Sauber, 2002).

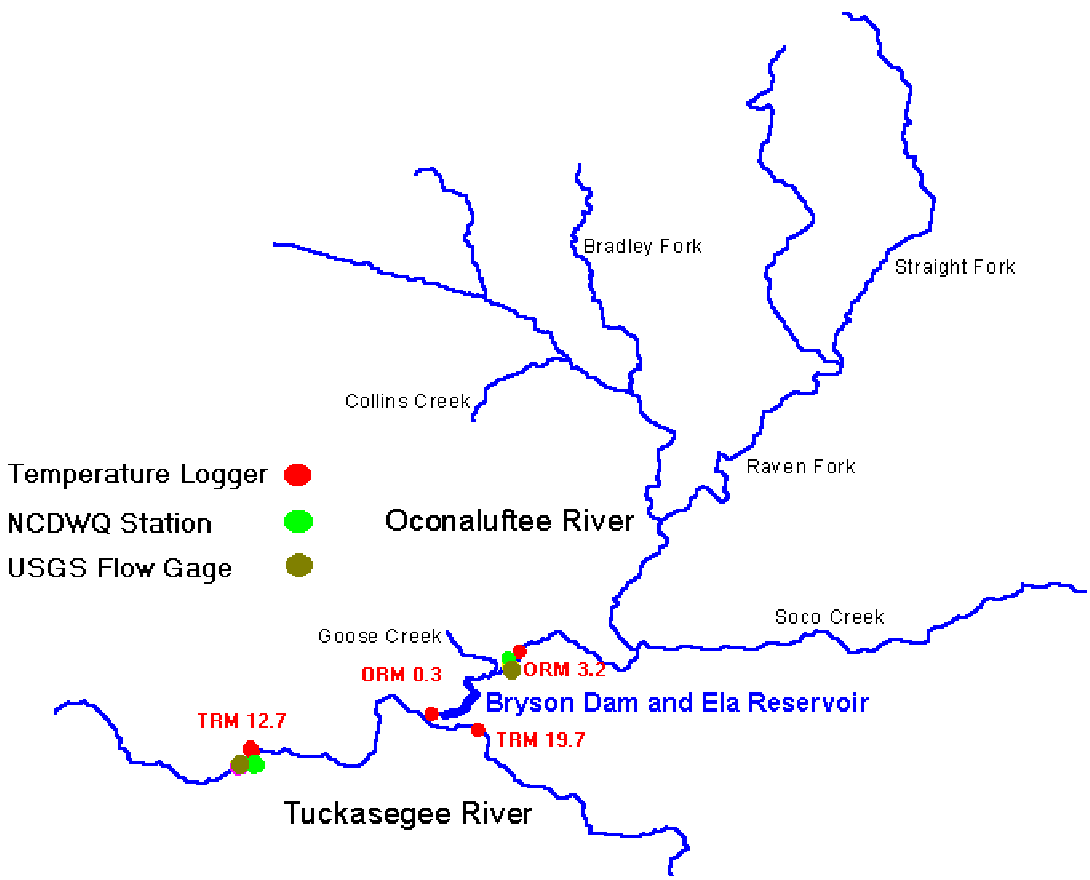

Figure 1. Map of Temperature and Dissolved Oxygen Sampling Locations in the Oconaluftee and Tuckasegee Rivers - River Miles and Historical Data Collection Sites

RESULTS

Temperature

Continuous Water Temperature

Oconaluftee River

The daily average, minimum, and maximum temperatures calculated from the 15-minute temperature recordings from Oconaluftee upstream of the project at river mile 3.2 (Figure 2) and downstream of the project at river mile 0.3 (Figure 3) 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. Ambient river temperatures (measured upstream of the project) routinely exceeded the state water quality standard of 20°C for trout waters beginning in June and continuing into September 2001. Comparison of the daily mean temperatures upstream and downstream of the Bryson project (Figure 4) indicated very little difference between the two sites. The similarity of upstream and downstream temperatures indicated that the short retention time and shallow depth of Ela Reservoir (Nantahala Power and Light, 2000) did not alter the mean temperature of the river. Examination of the 15-minute temperature measurements during the warmest period (Figure 5, 2 July – 2 August) revealed that Ela Reservoir minimized the ambient diel temperature fluctuations of the river. This ‘buffering’ of the diel temperature variability by the project was also evident by lower daily maximum temperatures observed downstream of the powerhouse (Figures 2 and 3). Also evident from the 15-minute data was the delay between the times of maximum and minimum temperatures observed downstream of the project within a given day (Figure 5). The time delay of maximum and minimum temperatures downstream of the project represents the travel time of the mass of water from the upstream site (short retention time of Ela Reservoir). The Oconaluftee River then enters the Tuckasegee, which is classified for warm water fish.

Lower Tuckasegee River

The daily average, minimum, and maximum temperatures calculated from the 15-minute temperature recordings from the Tuckasegee River at Whittier, river mile 19.2 (Figure 6) and at Bryson City, river mile 12.7 (Figure 7) exhibited the same seasonal pattern as temperatures for the Oconaluftee River (Figure 8). Again, similar to the Oconaluftee River, the lower Tuckasegee River had shorter periods of heating and cooling throughout the seasons, indicating rapid temperature responses to the prevailing meteorological conditions. Since the lower Tuckasegee River is not classified as trout waters, temperatures in the lower Tuckasegee did not exceed state water quality standards (29°C). Examination of the 15-minute temperature measurements during the warmest period (Figure 9) revealed the significant diel temperature cycles that occurred at both lower Tuckasegee sites. As mentioned in the previous section, Ela Lake tempered the diel temperature fluctuations downstream of the Bryson powerhouse. Since the cooler Oconaluftee River entered the Tuckasegee River at river mile 18.4, the temperatures at Bryson City reflected differences of temperature, flow, and subsequent mixing of the Tuckasegee and Oconaluftee Rivers.

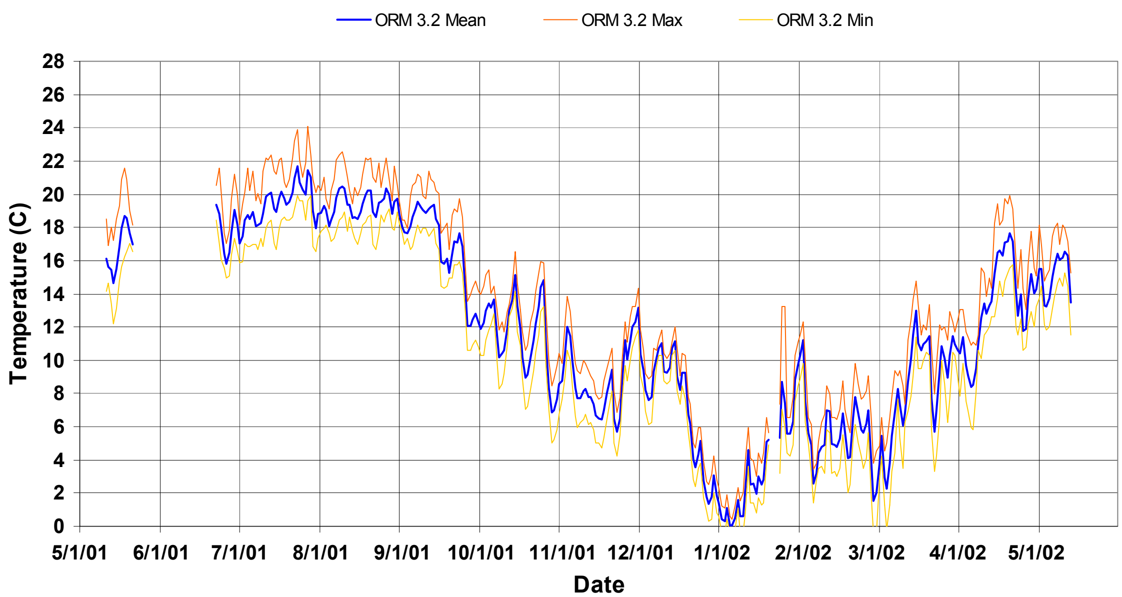

Figure 2. Mean, Minimum, and Maximum Daily Water Temperatures, Oconaluftee River - Upstream of Bryson Project at River Mile 3.2

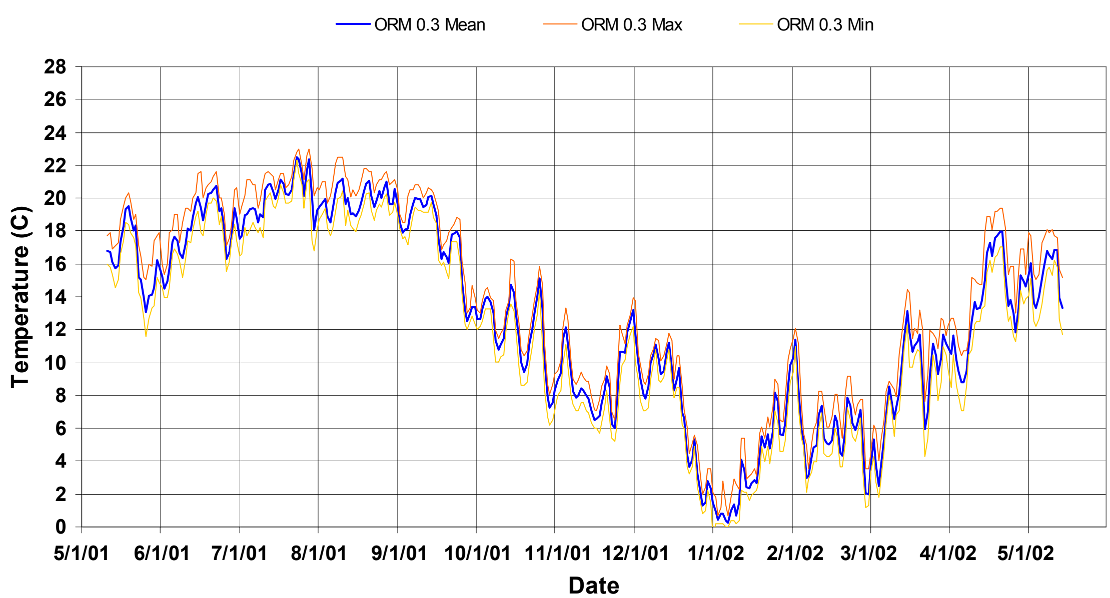

Figure 3. Mean, Minimum, and Maximum Daily Water Temperatures, Oconaluftee River - Downstream of Bryson Project at River Mile 0.3

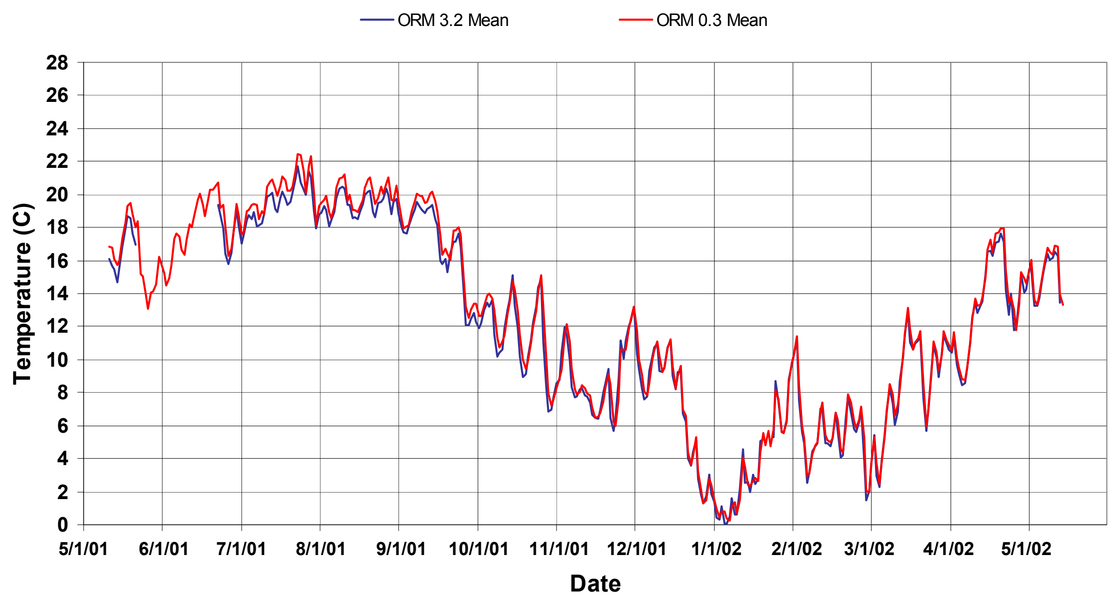

Figure 4. Comparison of the Mean Daily Water Temperatures, Oconaluftee River - Upstream and Downstream of Bryson Project (RM 3.2 and 0.3 respectively)

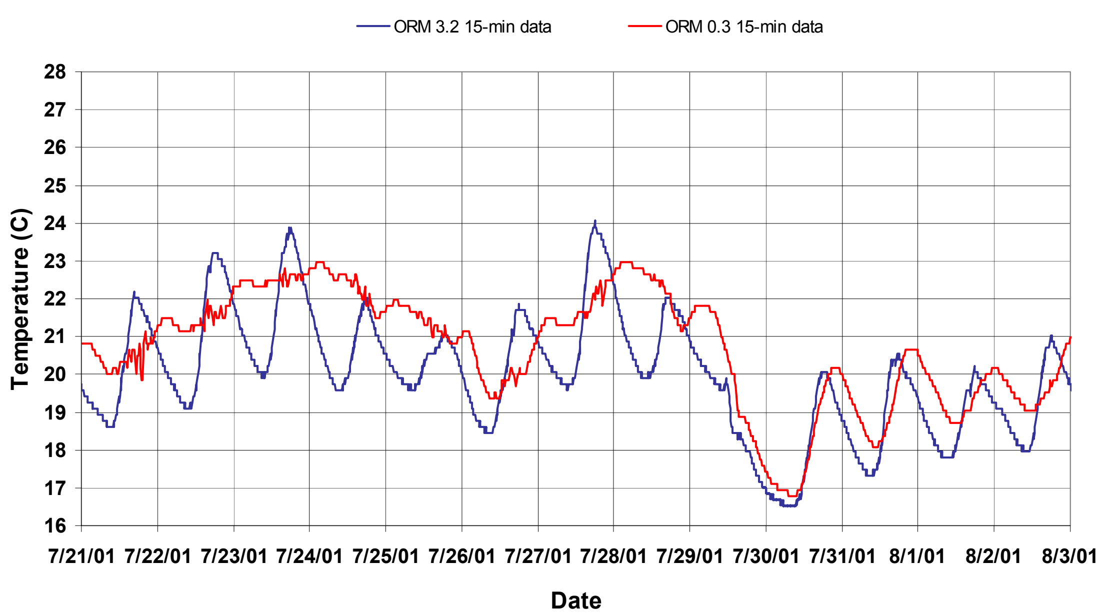

Figure 5. Comparison of 15 minute Water Temperatures, Oconaluftee River - Upstream and Downstream of Bryson Project (RM 3.2 and 0.3 respectively)

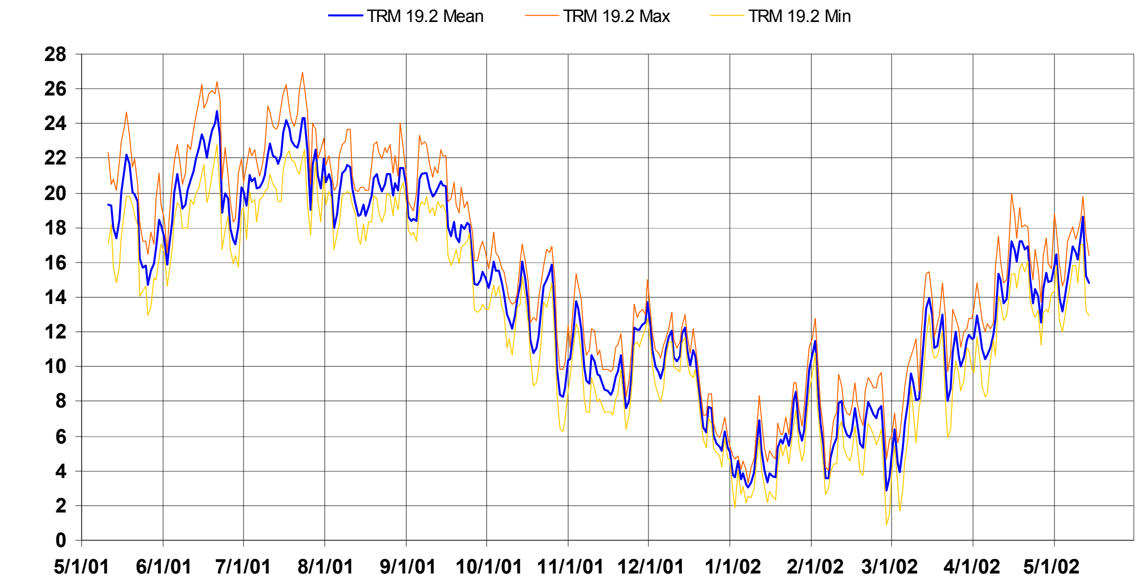

Figure 6. Mean, Minimum, and Maximum Daily Water Temperatures, Tuckasegee River - Upstream of the confluence of the Oconaluftee River - Whittier Site, River Mile 19.2

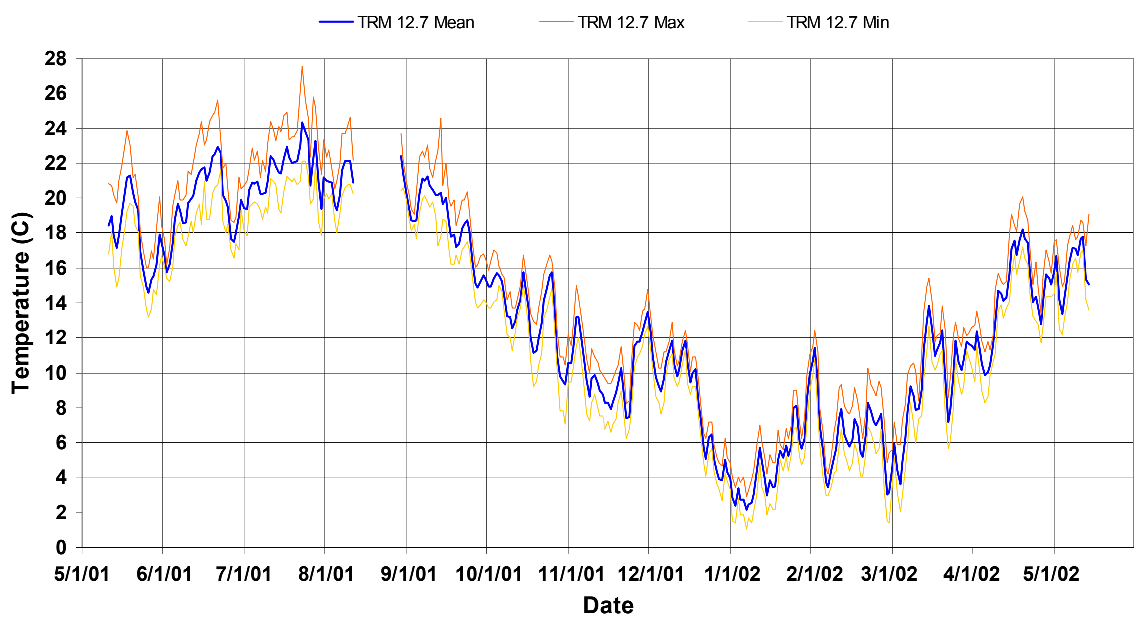

Figure 7. Mean, Minimum, and Maximum Daily Water Temperatures, Tuckasegee River - Downstream of the confluence of the Oconaluftee River - Bryson City Site, River Mile 12.7

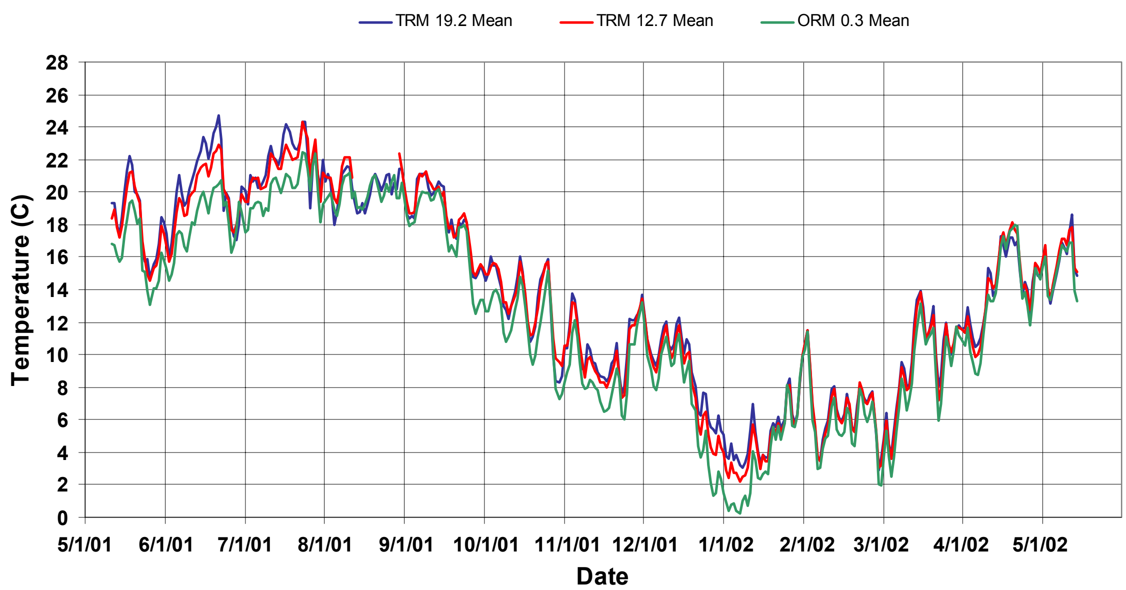

Figure 8. Comparison of the Mean Daily Water Temperatures, Tuckasegee River - Upstream and Downstream of the confluence with the Oconaluftee River (RM 19.2 and 12.7, respectively) and Mean Daily Water Temperature of the Oconaluftee River (RM 0.3)

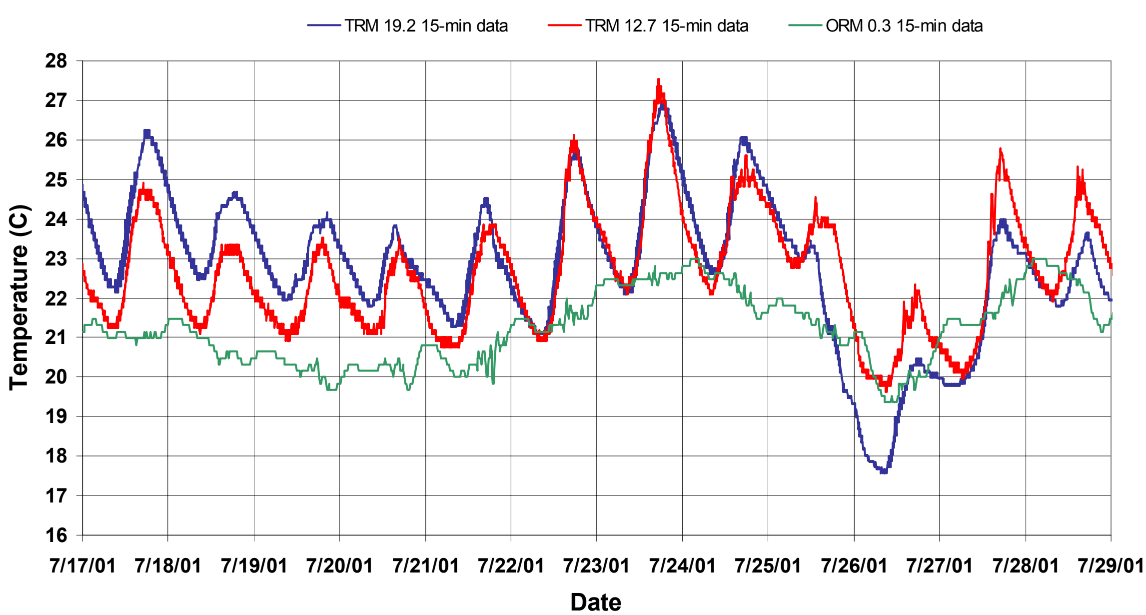

Figure 9. Comparison of the 15 minute Water Temperatures, Tuckasegee River - Upstream and Downstream of the confluence with the Oconaluftee River (RM 19.2 and 12.7, respectively) and 15 minute Water Temperature of the Oconaluftee River (RM 0.3)

Historical Water Temperature

Fifteen years of monthly 'grab' temperature data collected by the NCDENR-DWQ at the Oconaluftee River USGS gage (Figure 10) illustrate the variability of temperatures observed for any given month. These data show that the temperature of the river upstream from the Bryson project exceeded the state temperature standard, especially during dry and normal flow summers. In 1993, there was one measurement at 25°C. With the exception of one 21°C temperature recording in 1996, all of the temperatures collected during the summers with higher than normal flow were less than 20°C. It is significant to note that these data were obtained using grab samples at various times of day; hence, the actual maximum temperatures could have been higher.

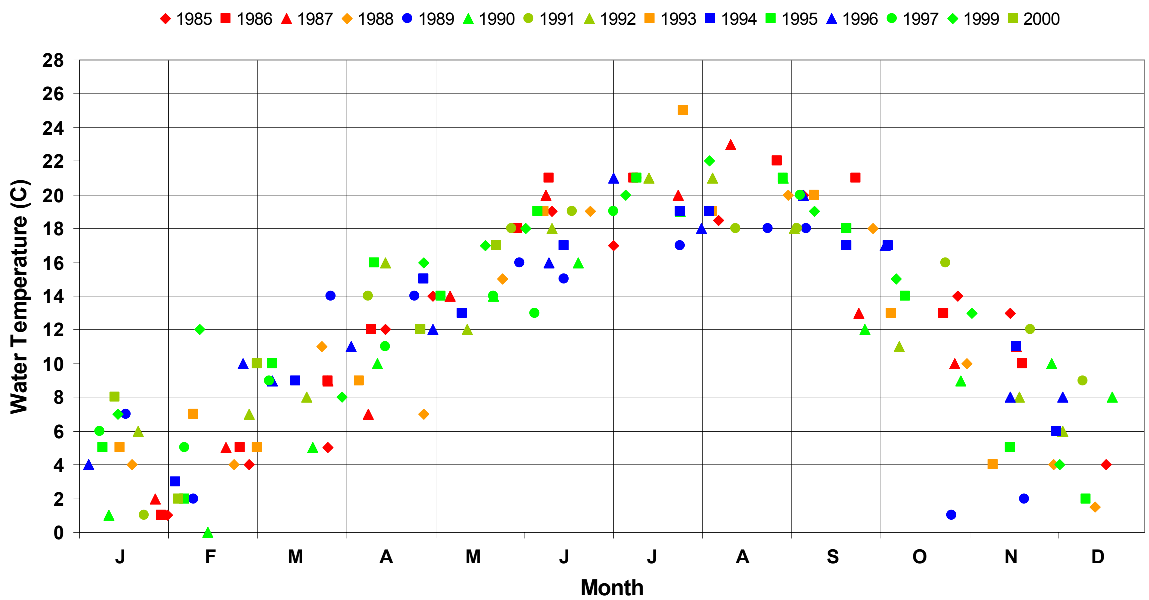

Figure 10. Monthly 'grab' Water Temperatures Collected by NCDENR-DWQ at RM 3.2 (USGS gage at Birdtown), Oconaluftee River (blue = summer flow > 436, green = 262 < summers flow > 436, and red = summers flow < 262)

The 25 years of temperature data collected by the NCDENR-DWQ from the Tuckasegee River at the Bryson City USGS gage (Figure 11) showed the same trend and variability as the temperature data collected from the Oconaluftee River. However, the summer temperatures were, on the average, 1-2°C warmer than temperatures measured from the Oconaluftee River, with the maximum recorded temperature of 26°C. The same pattern of higher temperatures recorded during the summers with low and normal flow and with cooler temperatures measured during the summers with high flow was also evident.

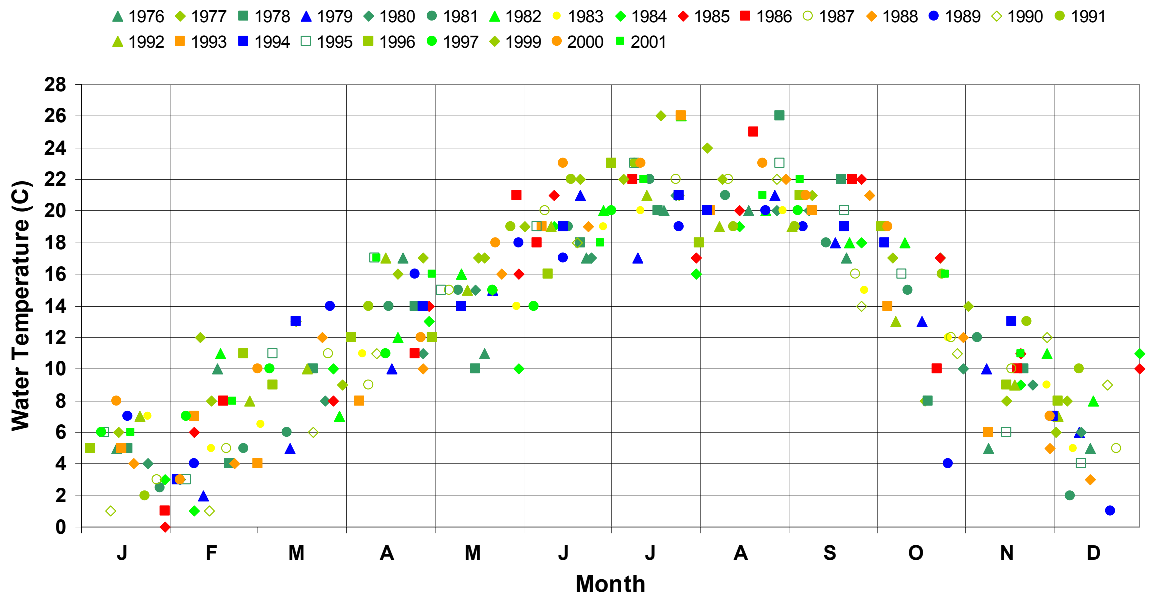

Figure 11. Monthly ‘grab’ Water Temperatures Collected by NCDENR-DWQ at RM 12.7 (USGS gage at Bryson City), Tuckasegee River (blue = summer flow > 1485, green = 891 < summer flow < 1485, and red = summer flow < 891)

Dissolved Oxygen

Dissolved Oxygen Deployments

The times of the measurement of dissolved oxygen monitoring at the Bryson 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.

Oconaluftee River

The dissolved oxygen concentrations measured at 5-minute intervals in the Oconaluftee River during August and September (Figures 12 and 13) were at least 2 - 3 mg/l greater than the 5 mg/l minimum standard for trout waters. The lowest recorded dissolved oxygen concentration was 7.2 mg/l for a brief period on September 19^{th}. Daily average dissolved oxygen concentrations were about 2 mg/l greater than the state standard of 6 mg/l oxygen.

The diel patterns of dissolved oxygen concentrations in the Oconaluftee River (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 upstream of Ela Reservoir exceeded 100% saturation, especially in September, indicating significant aquatic plant photosynthetic activity. Oxygen concentrations decreased during the afternoon and evening to a level less than saturation concentrations, again indicating consumption of oxygen associated with aquatic plants. During August, the oxygen concentrations downstream of the Bryson powerhouse showed similar diel patterns but with lower concentrations during the day. In September, concentrations were typically 1-3 mg/l lower than concentrations upstream of the reservoir. Fish and Wildlife Associates (Nantahala Power and Light, 2000) reported slightly reduced oxygen concentrations in the deeper areas of Ela Reservoir. These data, coupled with the slightly reduced oxygen concentrations, relative to saturation (1 -1.5 mg/l), downstream of the project , suggests that biological respiration rates in the reservoir reduced the oxygen concentrations while the water was in the reservoir. However, due to the very short retention times and the shallow depth of the reservoir, the September concentrations probably represent a maximum reduction of oxygen due to the reservoir.

Tuckasegee River

As observed in the Oconaluftee River, concentrations in the Tuckasegee River (Figures 14 and 15) were well above state water quality standards. Both lower Tuckasegee sites exhibited identical trends of diel oxygen changes. These daily patterns suggest the influence of aquatic plant metabolism on the diel changes of oxygen in the Tuckasegee River. The Oconaluftee River, with slightly reduced oxygen (relative to saturation) had very similar concentrations to the Tuckasegee River in August, and similar concentrations to those observed at the Whittier site in September.

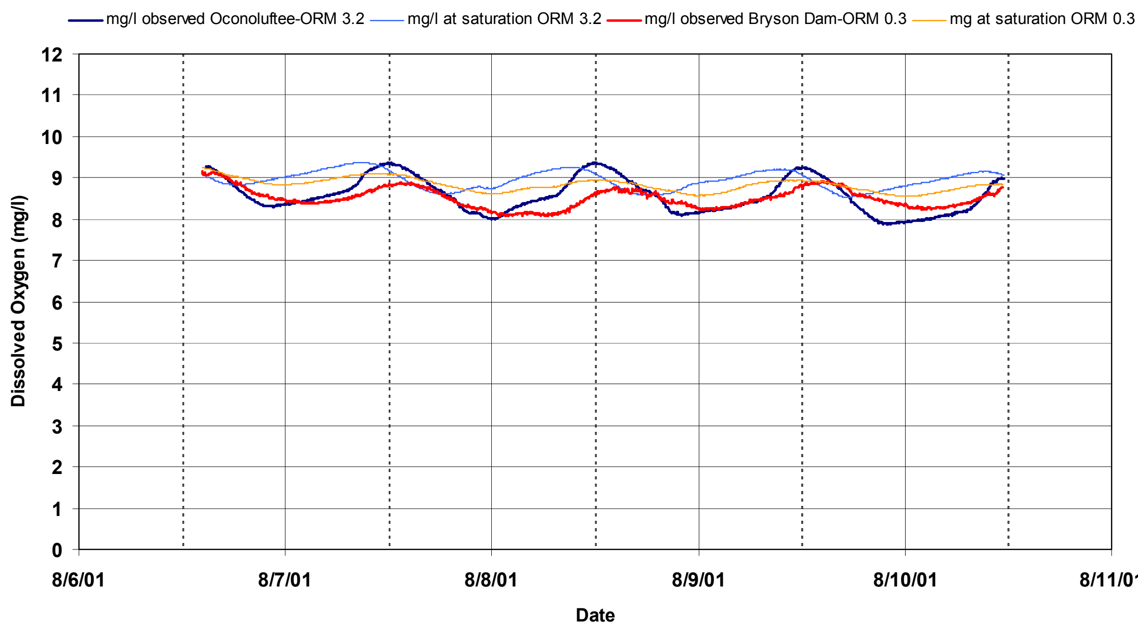

Figure 12. Comparison of the observed 5 minute Dissolved Oxygen Concentrations and Calculated Oxygen Saturation Concentrations, August 2001, Oconaluftee River - Upstream and Downstream of Bryson Project (RM 3.2 and 0.3 respectively)

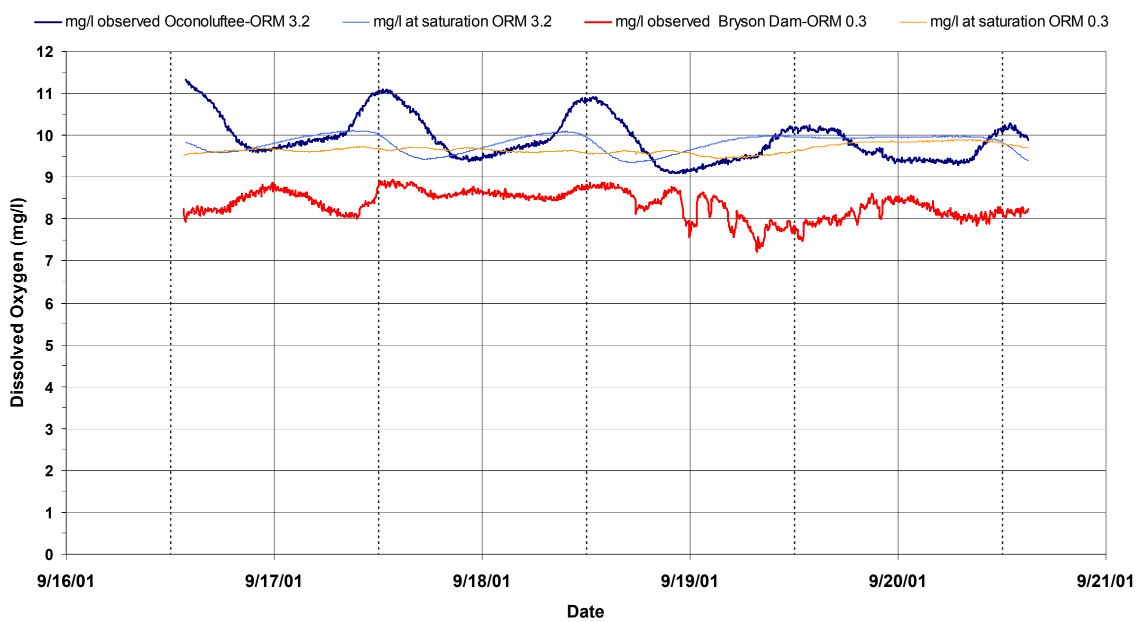

Figure 13. Comparison of the observed 5 minute Dissolved Oxygen Concentrations and Calculated Oxygen Saturation Concentrations, September 2001, Oconaluftee River - Upstream and Downstream of Bryson Project (RM 3.2 and 0.3 respectively)

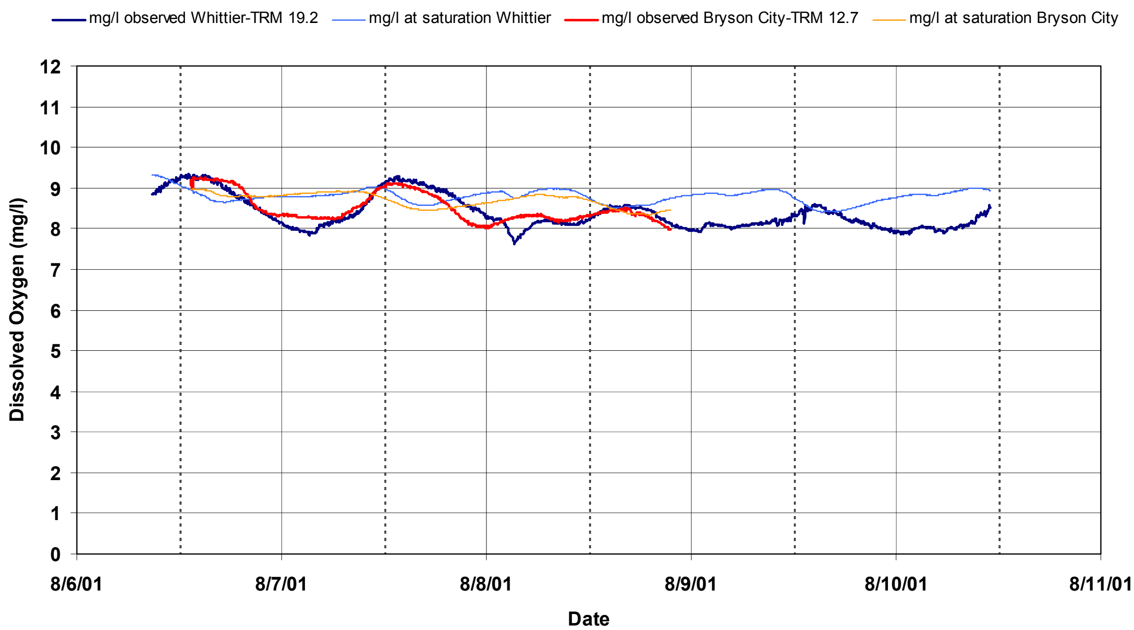

Figure 14. Comparison of the observed 5 minute Dissolved Oxygen Concentrations and Calculated Oxygen Saturation Concentrations, August 2001, Tuckasegee River - Upstream and Downstream of the Confluence of the Oconaluftee River (RM 19.2 and 12.7 respectively)

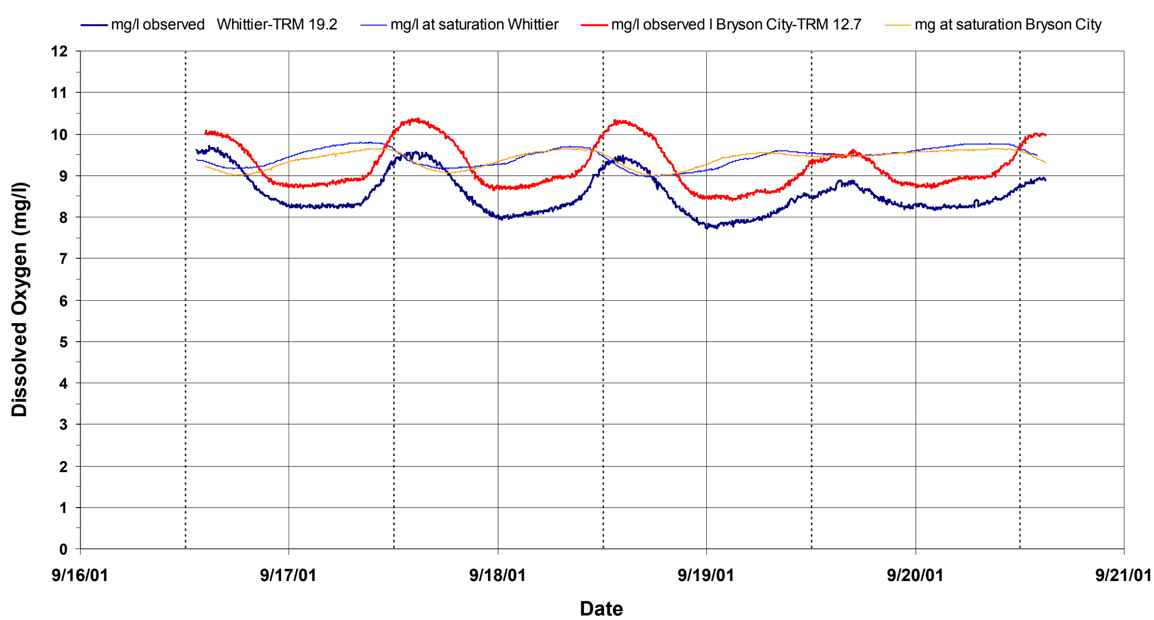

Figure 15. Comparison of the observed 5 minute Dissolved Oxygen Concentrations and Calculated Oxygen Saturation Concentrations, September 2001, Tuckasegee River - Upstream and Downstream of the Confluence of the Oconaluftee River (RM 19.2 and 12.7 respectively)

Historical Dissolved Oxygen Concentrations

The 15 years of monthly grab samples from the Oconaluftee River and the 25 years of monthly samples from the Tuckasegee River (Figures 16 and 17) indicate that both rivers consistently had oxygen concentrations greater than state water quality standards. Unlike the temperature data, summertime flow did not appear to influence the oxygen concentrations.

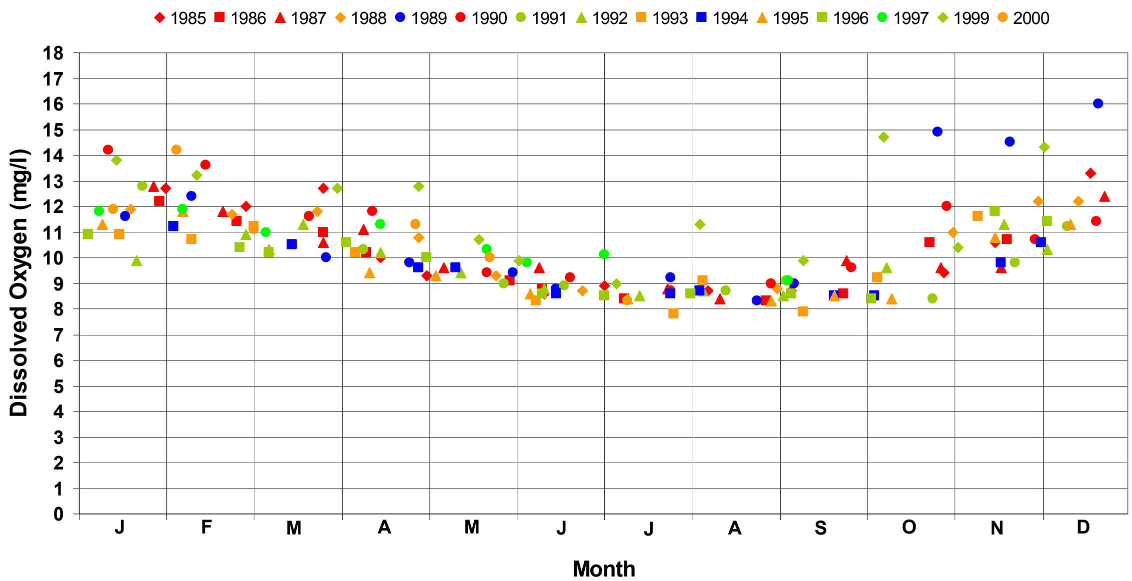

Figure 16. Monthly 'grab' Dissolved Oxygen Concentrations Collected by NCDENR-DWQ at RM 3.2 (USGS gage at Birdtown), Oconaluftee River (blue = summer flow > 436, green = 262 < summers flow > 436, and red = summers flow < 262)

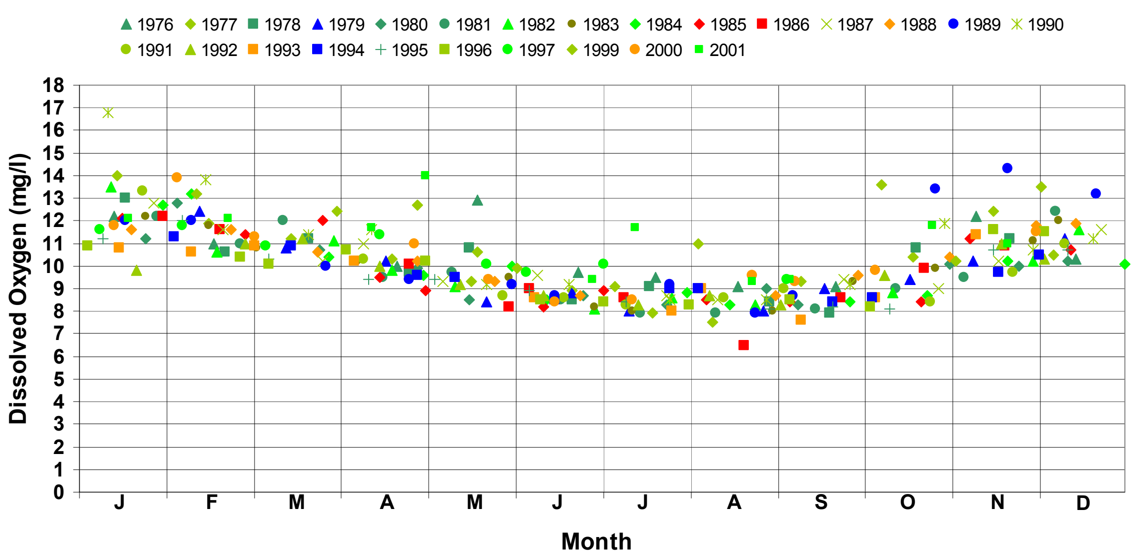

Figure 17. Monthly 'grab' Dissolved Oxygen Concentrations Collected by NCDENR-DWQ at RM 12.7 (USGS gage at Bryson City), Tuckasegee River (blue = summer flow > 1485, green = 891 < summer flow < 1485, and red = summer flow < 891)

CONCLUSIONS

Water temperatures in both the Oconaluftee and lower Tuckasegee Rivers responded rapidly to changing meteorological conditions as evidenced by similar daily, weekly, and seasonal changes of water temperature in both rivers. The local meteorological conditions created ambient river temperatures that periodically exceeded state water quality standards for trout waters (20ºC), but not for non-trout waters (29ºC). The Bryson project (Ela Reservoir) had little, if any, impact on water temperatures in the Oconaluftee River downstream of the project. Since water temperatures in the Oconaluftee River were cooler than the water in the Tuckasegee River and with the short distance of 0.3 miles to the confluence with the Tuckasegee River, the Oconaluftee River cooled the Tuckasegee downstream of the confluence. However, by the time the Tuckasegee water reached Bryson City, temperatures were similar to those observed upstream of the confluence with the Oconaluftee River.

Dissolved oxygen concentrations in both rivers 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 the two rivers. The influence of aquatic plant metabolism within Ela Reservoir resulted in slightly lower oxygen concentrations below the project during the September deployment compared to ambient concentrations in the Oconaluftee River. However, the oxygen concentrations released from Bryson powerhouse were similar to ambient concentrations in the Tuckasegee River. 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 Oconaluftee River (trout) and the Tuckasegee River (non-trout).

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