APPALACHIAN POWER COMPANY
CLAYTOR HYDROELECTRIC PROJECT NO. 793-018
INSTREAM FLOW NEEDS STUDY

Claytor IFN Study
Stream Temperature Model

Prepared for:

American Electric Power/Appalachian Power Company

Prepared by:

Thomas R. Payne & Associates
Fisheries Consultants
890 L Street
Arcata, California 95521

and

The Louis Berger Group, Inc.
75 Second Avenue, Suite 700
Needham, MA 02494

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INTRODUCTION

Appalachian Power Company (Appalachian) is making an application to the Federal Energy Regulatory Commission (FERC) for a new license for the Claytor Hydroelectric Project (No. 739-018), located on the New River in southwestern Virginia. Under the Integrated Licensing Process (ILP) selected for its application, Appalachian prepared and filed a Pre-Application Document (PAD) with FERC on January 6, 2006. As part of the licensing process, Appalachian has solicited input from stakeholder meetings, including governmental agencies and non-governmental organizations, to identify potential project-related issues.

The stakeholder input was used to develop the Claytor Project instream flow needs (IFN) study plan. The IFN study plan identified numerous issues which could affect aquatic species in the New River as a result of the Project, one of which is stream temperature.

The Stream Network Temperature Model (SNTEMP) was the model chosen for predicting water temperatures in the New River between Claytor Dam and Bluestone Reservoir. At its finest increment of assessment and prediction, this process-oriented temperature model utilizes mean daily input data (the mean value of the various requisite input variables over a 24 hour period) for model calibration. The required input data are daily stream flows and stream temperatures at various locations throughout the evaluated stream reach along with local daily climatological data (air temperature, relative humidity, wind speed, and solar radiation). Along with these variable data, also required are fixed measurements of topographic shading and stream geometry. This model has the benefit of being peer-reviewed, published, and widely applied. SNTEMP incorporates (1) a complete solar model that includes both topographic and riparian vegetation shade; (2) a meteorological correction model to account for the change in air temperature, relative humidity, and atmospheric pressure as a function of elevation; (3) a complete set of heat flux components to account for all significant heat sources; (4) a heat transport model to determine longitudinal water temperature changes; (5) regression models to smooth or complete data gaps by known water temperature data sets; (6) a flow mixing model at tributary junctions; and (7) calibration equations to help eliminate bias and reduce errors at calibration nodes (Theurer et al, 1984).

The user-friendly computer program STRMTEMP, version 1.0.4 (TRPA 2005) was used to complete the temperature analysis. This program is based upon the SNTEMP program, but has added features which include improved reports and graphs of the program results.

Following calibration and validation of the constructed model (based upon two years of field data), the Claytor SNTEMP model should serve as a modeling tool capable of predicting downstream temperatures in the New River at various locations under a variety of alternative future flow regimes. As such, the model may be used as an assessment tool for determining low flow threshold impact levels on aquatic habitat.

BACKGROUND

The Claytor Project is an existing conventional hydroelectric project located on the New River, Pulaski County, Virginia. The project has four generating units with a combined hydraulic capacity of 10,000 cfs and a generating capacity of 75 MW. The project is operated on a weekly cycle as a peaking facility from October 16 through April 14. Historical hydro unit outflow releases are normally in the range of 750-8,000 cfs. Daily reservoir fluctuations are typically less than one foot, with weekly fluctuations of 1-2 feet. The reservoir is drawn down five feet in the late fall or early winter to facilitate lake residence maintenance and repairs.

Under a cooperative agreement with the Virginia Department of Game and Inland Fisheries, Appalachian currently operates the Project to maintain stable reservoir elevations at or above 1,844 feet from April 15 through June 15 to protect shallow water spawning habitat in the reservoir. From April 15 through October 15, Appalachian voluntarily operates the project to maintain more constant downstream flows to enhance recreation activities (primarily rafting and kayaking) by limiting peaking. During this period the reservoir elevation is maintained between 1,845 and 1,846 feet, unless power system emergencies or heavy inflow supersede.

The Claytor Project is operated to provide a minimum average daily flow of 750 cfs. Certification (401) for water quality requires that the release from the impoundment be equal to or greater than the 7 day-10-year return frequency drought flow. When the flow rate is less than the 7 day-10-year drought flow, project release may not be less than the flow rate in the New River above the impoundment. The City of Radford operates a 1.0 megawatt hydroelectric project on the Little River, a tributary to the New River immediately downstream to Claytor Dam. This run-of-river operation peaks at 400 cfs and inflow to the New River is apparent at the Radford gage, particularly during low flow conditions. The minimum flow established for the Little River is 25 cfs.

STUDY AREA

The geographic scope of the instream flow evaluation extends from Claytor Dam near Radford downstream to the head of Bluestone Reservoir, a distance of approximately 59 miles (Figure 1). Three major sources of tributary inflow supplement the mainstem flow at 0.6 miles (Little River), 36.5 miles (Walker Creek), and at 49.7 miles (Wolf Creek) downstream of Claytor Dam.

HYDROLOGY AND WATER TEMPERATURE

Mainstem and tributary flows and temperatures were obtained from a number of sources. New River flow data downstream of Claytor Dam was measured at USGS gauges at Radford (Gauge No. 03171000) and Glen Lyn (Gauge No. 03176500). Levels of tributary inflow into the New River were provided by USGS for the Little River at Greysontown (Gauge No. 03170000), Walker Creek at Bane (Gauge No. 03173000), and Wolf Creek near the Narrows (Gauge No. 03175500). Numerous (16) stream temperature recorders were

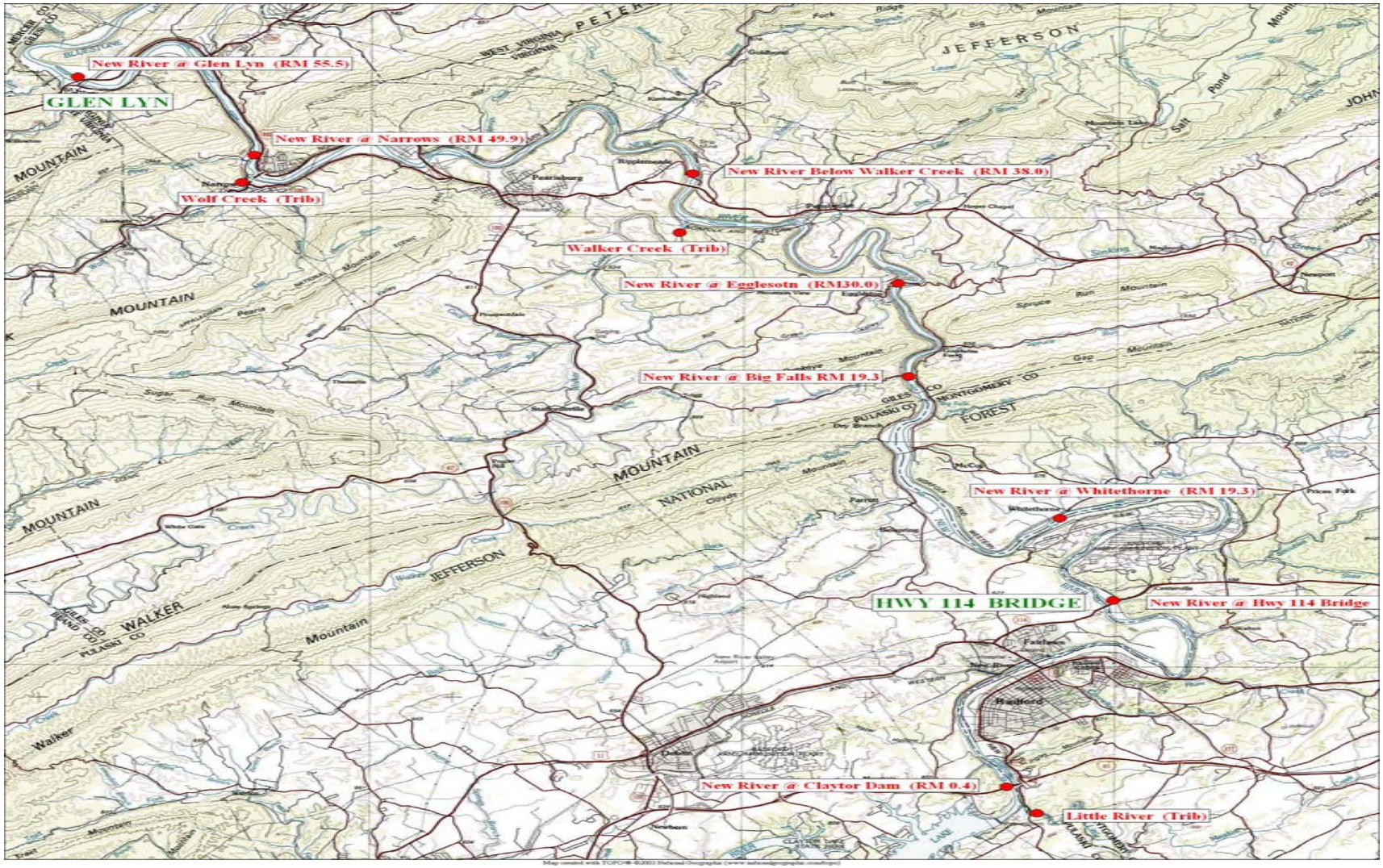

Figure 1. New River stream temperature probes (in red) and USGS gauged flow locations (in green) for the Claytor Hydroelectric Project stream temperature study.

placed throughout the modeled reach, on the mainstem New River and near the confluences on the tributaries, some with reduncancy (Table 1.).

Table 1. Claytor Hydroelectric Project daily mean water temperature data stations.

Location	RM	Dates
New R downstream of Claytor dam	**0.4**	**5/18/07 – 9/22/08**
Little River	**Trib**	**5/18/07 – 9/22/08**
New R Route 114 bridge area	**10.6**	**5/18/07 – 9/22/08**
New R Route 114 bridge area DS of #3 (duplicate)	**10.6**	**5/18/07 – 9/22/08**
New R Whitethorne	**19.3**	**5/18/07 – 9/22/08**
New R Whitethorne (duplicate)	**19.3**	**5/18/07 – 9/22/08**
New R BigFalls DS of RR crossing	**26.0**	**5/18/07 – 9/22/08**
New R Eggelston below bridge	**30.0**	**5/18/07 – 9/22/08**
New R Eggelston below bridge DS of #12 (duplicate)	**30.0**	**5/18/07 – 9/22/08**
Walker Creek downstream of Bridge	**Trib**	**5/18/07 – 9/22/08**
New R below Walker Creek DS of 460 Bridge	**38.0**	**5/18/07 – 9/22/08**
New R Narrows	**49.9**	**5/18/07 – 9/22/08**
New R Narrows upstream of #8 (duplicate)	**49.9**	**5/18/07 – 9/22/08**
Wolf Creek near Narrows Town Park	**Trib**	**5/18/07 – 9/22/08**
New R Glen Lyn upstream of Route 460B	**55.5**	**5/18/07 – 9/22/08**
New R Glen Lyn upstream of Route 460B DS of #5 (duplicate)	**55.5**	**5/18/07 – 9/22/08**

The SNTEMP model requires in addition to temperature, the level of stream flow at any calibration/validation nodes. With only two locations of known flow on New River in the study reach below Claytor Dam (USGS gauges at Radford and Glen Lyn), only the temperature data collected at the Route 114 Bridge and at Glen Lyn were used in calibration/validation nodes (this assumes minimal accretion between Radford gauge and Route 114 Bridge).

Development of an accurate temperature model for rivers and streams such as the New River involve acquiring as much real, measured data as might be available for calibration. Hogan et al. (1973) found that analysis of data for a period of two years leads to the same general distribution of equilibrium temperatures as does a ten year period. While gage data was available for a longer period, only two seasons of stream temperature data were available for construction, calibration and validation of the entire model.

All stream temperatures for New River and its three major tributaries serving as input in the construction of the Claytor SNTEMP model appear in Appendix A, while all input stream flow levels appear in Appendix B.

STREAM GEOMETRY

Stream geometry and topographic shading measurements were made using the National Geographic's Mid-Atlantic USA mapping program TOPO!. For distances, locations, and elevations of significant structures and general river geometry, direct measurements were made within the program TOPO! with the aid of the program's software tools. For stream topographic shading, portions of the river were segmented based upon prevailing azimuth within a reach of stream, and measurements of rise over run (topographic altitudes) were made every half mile to the dominate shade-producing topographic features. These values are summarized in Table 2.

Table 2. New River stream geometry and topographic input data for the Claytor SNTEMP model.

Distance upstream of Bluestone Reservoir (kilometers)	Stream width (meters)	Topographic shading		Stream reach orientation azimuth (radians)	Nodal latitude (radians)	Nodal elevation (meters)
		Left bank slope (radians)	Right bank slope (radians)			
115.9	159.00	0.1691	0.0997	-0.0524	0.6471	526.4
108.7	137.00	0.1941	0.0838	1.0472	0.6481	524.6
105.1	118.00	0.3104	0.0410	-0.9599	0.6483	523.0
102.5	145.00	0.0781	0.2618	-0.0873	0.6481	522.7
99.8	129.00	0.1559	0.1865	-0.6981	0.6485	520.0
94.2	145.00	0.2006	0.0394	1.1868	0.6489	516.9
89.7	129.00	0.0499	0.1646	-0.2269	0.6492	514.1
88.1	188.00	0.0979	0.1836	1.1519	0.6494	511.1
80.8	209.00	0.1943	0.2138	-0.2269	0.6490	509.0
62.8	118.00	0.2960	0.2141	0.5236	0.6512	487.1
60.7	123.00	0.3732	0.1697	-0.3491	0.6509	485.9
58.0	138.00	0.2390	0.2546	-0.8203	0.6513	484.0
46.2	121.00	0.2286	0.1888	1.2217	0.6521	481.0
34.3	177.00	0.2072	0.2397	-0.3665	0.6516	464.5
27.9	152.00	0.3449	0.2398	1.4137	0.6525	459.0
22.2	134.00	0.2088	0.3645	0.8901	0.6525	447.1
17.2	109.00	0.2891	0.2201	-1.5359	0.6529	442.0
15.0	159.00	0.2616	0.2224	-0.0698	0.6530	441.0
2.8	142.00	0.2286	0.2820	1.3265	0.6545	431.9
0.0					0.6547	427.9

METEOROLOGY

Meteorological stations were established that collected data measuring air temperature and relative humidity: below Claytor Dam, at Big Falls, and at Glen Lyn. Mean daily values were generated for these variables for most of the period of measurement from 18 May 2007 to 22 September 2008. The weather station located near the project area at Dublin, Virginia was used as an information source for wind speed data, and for short periods when the three established met stations were not collecting air temperature data. Mean daily values of solar radiation were available from measurements collected at Bluefield State College in Bluefield, WV, north of the New River study reach. When Bluefield State College solar radiation values were missing or suspect, mean daily values of solar radiation were also taken from measurements collected at Oak Ridge National Laboratories. Mean daily measurements of air temperature, wind speed, relative humidity, and solar radiation used in the Claytor SNTEMP model appear in Appendix C and D.

MODEL CALIBRATION

Calibration of the temperature model is the process by which certain parameters are adjusted to allow the model to more accurately predict observed water temperatures. Any differences in conditions could affect the ability of the model to reproduce observed water temperatures and warrant calibration adjustments. These calibrations should be within reasonable limits, as defined in the documentation for the models (Bartholow 1989).

The input data to these parameters are modified globally (the entire input data set of the specified parameter) by the application of a constant and coefficient modifier to each daily input value. The global calibration factors were used in the computer program to modify the meteorological parameters according to the general form of:

$$Y = a_0 + a_1 y$$

where:

Y is the modified meteorological parameter
y is the original input meteorological parameter
a_0 is the calibration constant factor
a_1 is the calibration coefficient factor

Adjustments are often needed to correct for differences in physical conditions between the water surface where temperature change occurs and the sites of data collection. For instance, air temperature data serving as input to the model was collected at the upper, middle, and lower portions of the New River study reach and averaged. Depending upon the meteorological station site locations (distance to river, distance above water surface, etc.), the air temperature in the microclimate immediately above the water surface may or not be well represented.

The Claytor Project Temperature Model was constructed and first calibrated using data from 228 days of year 2007 (18th May through 31st December). Evaluation and testing of the four meteorological parameters led to a calibration that was ultimately accomplished through an iterative process of varying the global calibration modification parameter constant and coefficient for air temperature. This process resulted in a selected constant of 0.50 and a coefficient equal to 0.96, minimally adjusting for air temperature differences between the river surface and mean of the values generated from the three meteorological data collection stations located throughout the modeled reach. The effect this calibration would have on input temperatures would be to slightly raise air temperatures below 12.5°C, and to slightly lower air temperatures above 12.5°C. When globally applied to the air temperature data within the model, resulting predicted river temperatures more closely matched observed temperatures.

The goal in calibration is to simultaneously maximize the R^2 values while minimizing the mean error and probable errors. The comparisons of the year 2007 predicted and the observed stream temperatures at Route 114 Bridge and Glen Lyn resulted in correlation coefficients (R^2) of greater than 0.94, mean error of prediction less than 1°C, and probable error of prediction less than 1.3°C (Table 3).

Table 3. Claytor Project SNTEMP mean daily stream temperature model quality control calibration statistics at two locations for 2007 (18 May through 31 December), validation statistics for 2008 (28 January through 22 September) including correlation coefficient (R^2) of the predicted versus the observed mean daily stream temperature, mean error of the model-predicted mean daily stream temperature, and the probable error or mean of the absolute values of the error of model-predicted mean daily stream temperature.

Nodal Location	Correlation Coefficient	Mean Error	Probable Error
Route 114 Bridge 2007	**0.984**	**-0.05**	**0.57**
Route 114 Bridge 2008	**0.991**	**-0.10**	**0.51**
Glen Lyn 2007	**0.942**	**-0.96**	**1.23**
Glen Lyn 2008	**0.960**	**0.85**	**1.09**

Another name for the R^2 is also expressed as Root Mean Square Error (RSME) and as such is an index of error as follows (taken from Bartholow 1989):

$$RSME = ((sum\ (Pi - Oi)^2\ )/n\ )^{0.5}$$

where: Pi = prediction (temperature) at time/space i
Oi = observed (temperature) value at time/space i
N = number samples

The mean error is derived by averaging of the errors of temperature prediction while the probable error is the mean of the absolute values of the observed minus the predicted temperatures. While it is desirable for a model to have resulting R^2 values of 1.00 (perfect correlation) as possible, a value of 0.90 or greater is acceptable. The mean error should be less than +/-0.5^{o}C, and the maximum error under 1.5^{o}C.

Figures 2 and 3 are scatter plots of the year 2007 predicted versus the observed stream temperatures at Route 114 Bridge and Glen Lyn, respectively. These graphs show the more accurate temperature prediction at the upstream node (Route 144 Bridge) over that of the Glen Lyn location. In the Glen Lyn simulation, a wider scatter of points and several outliers suggest a lower accuracy of temperature prediction, especially when predicting lower temperatures (winter conditions).

The graphs of predicted and observed mean daily stream temperature at Route 114 Bridge and at Glen Lyn for 2007 appear in Figures 4 and 5, respectively. For the Route 114 Bridge location, the daily predicted temperatures (solid blue line) closely follow the observed temperatures (red dots), except for a lag in time of a day. The same simulation pattern is observed at Glen Lyn, but the daily error is more exaggerated. Again, the observed temperatures occur about a day after they are predicted.

MODEL VALIDATION

The global calibration for air temperature was applied to the Claytor model containing 238 days of year 2008 data (28th January through 22nd September). The comparisons of the year 2008 predicted and the observed stream temperatures at Route 114 Bridge and Glen Lyn resulted in correlation coefficients (R^2) of greater than 0.96, mean errors of prediction less than 1^{o}C, and probable errors of prediction less than 1.1^{o}C (Table 3).

Figures 6 and 7 are scatter plots of the year 2008 predicted versus the observed stream temperatures at Route 114 Bridge and Glen Lyn, respectively. Again, these graphs suggest higher accuracy of temperature prediction at the upstream node (Route 144 Bridge) over that of the Glen Lyn location. For the same locations between years, the 2008 predictions appear more accurate than the 2007.

The graphs of predicted and observed mean daily stream temperature at Route 114 Bridge and at Glen Lyn for 2008 appear in Figures 8 and 9, respectively. For the Route 114 Bridge location, the daily predicted temperatures closely follow the observed temperatures, without an obvious lag in time. The same simulation pattern is observed at Glen Lyn, with the prediction error more exaggerated; again, without an obvious lag in time.

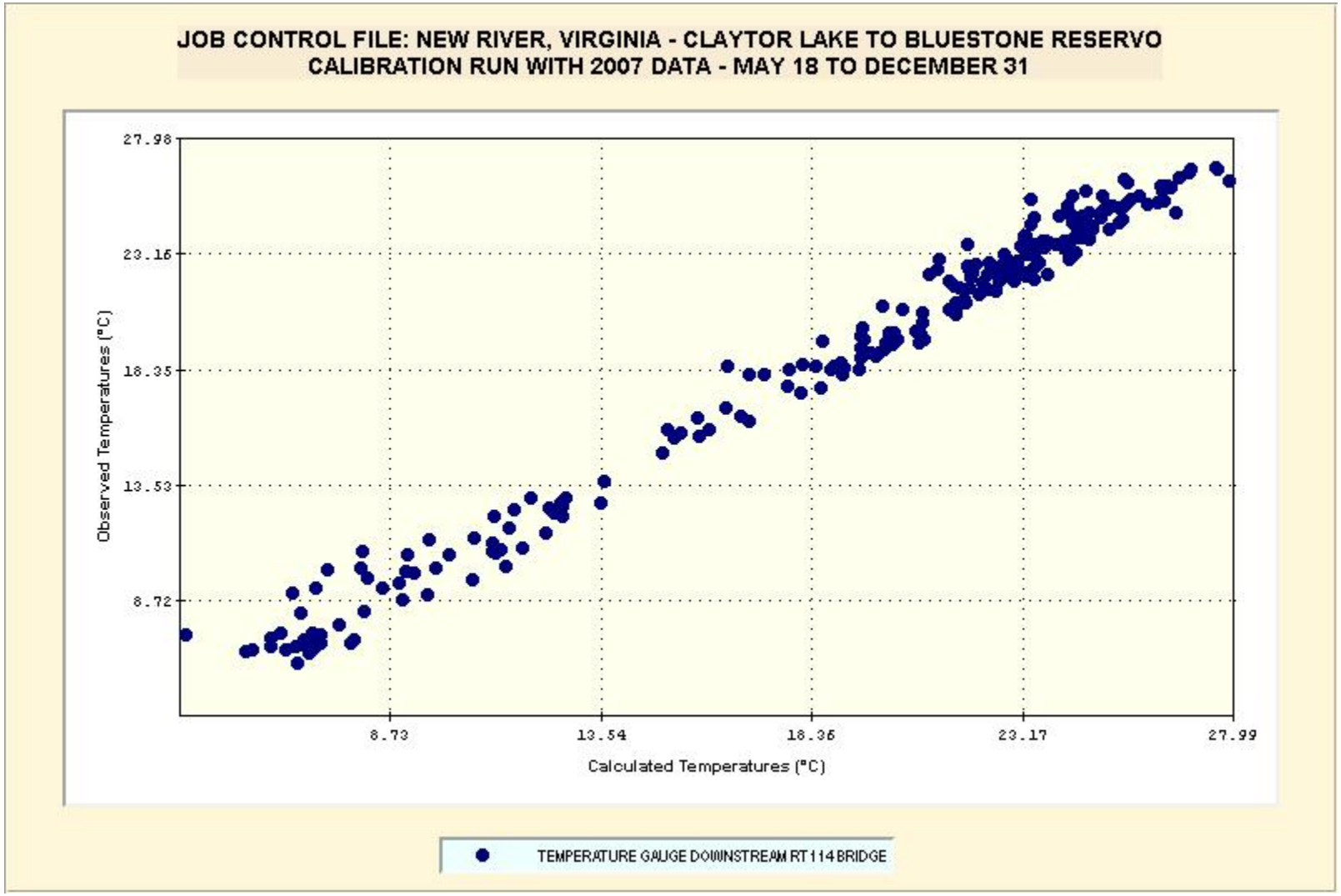

Figure 2. Scatter plot of the year 2007 predicted versus the observed stream temperatures at Route 114 Bridge.

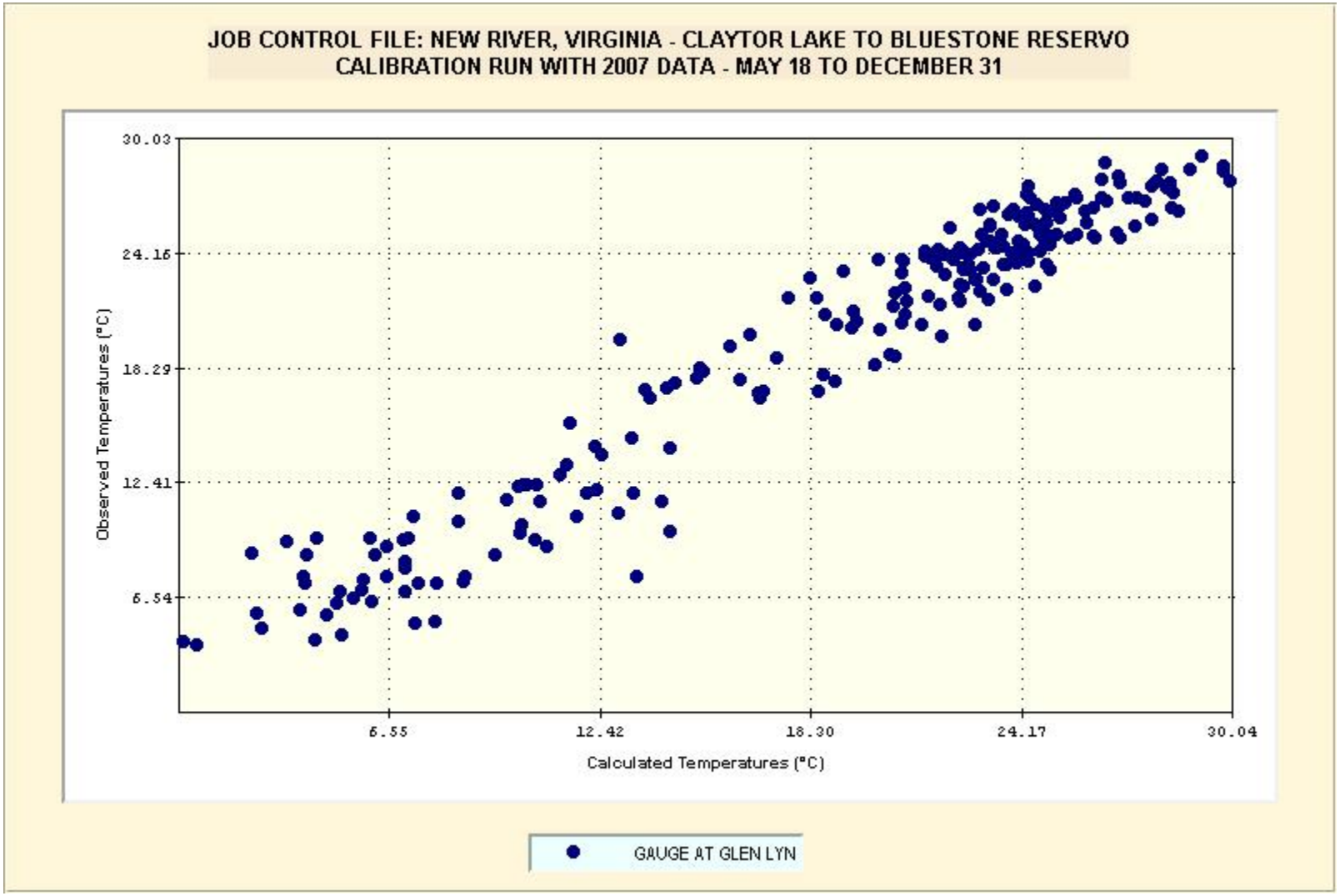

Figure 3. Scatter plot of the year 2007 predicted versus the observed stream temperatures at Glen Lyn.

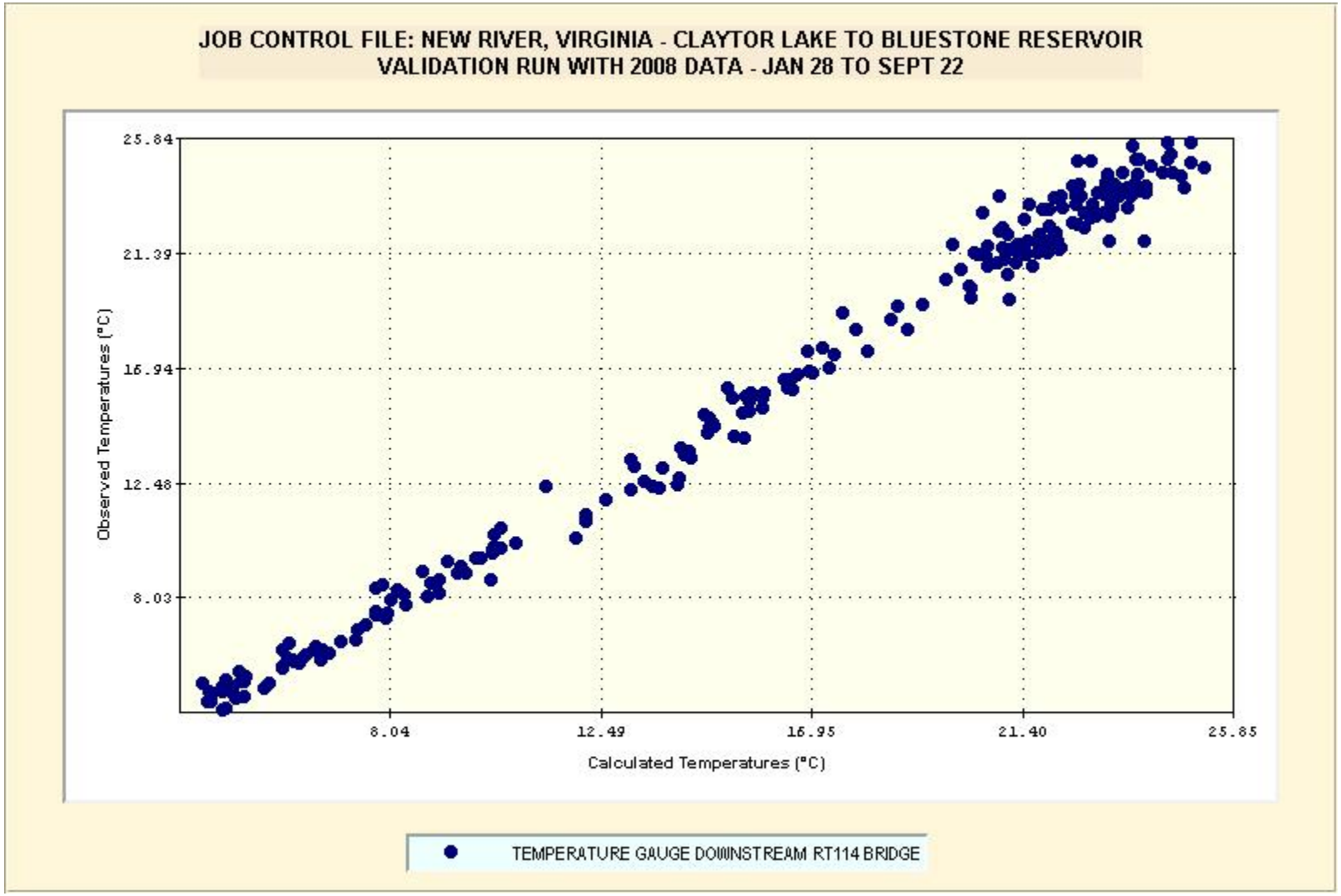

Figure 4. Scatter plot of the year 2008 predicted versus the observed stream temperatures at Route 114 Bridge.

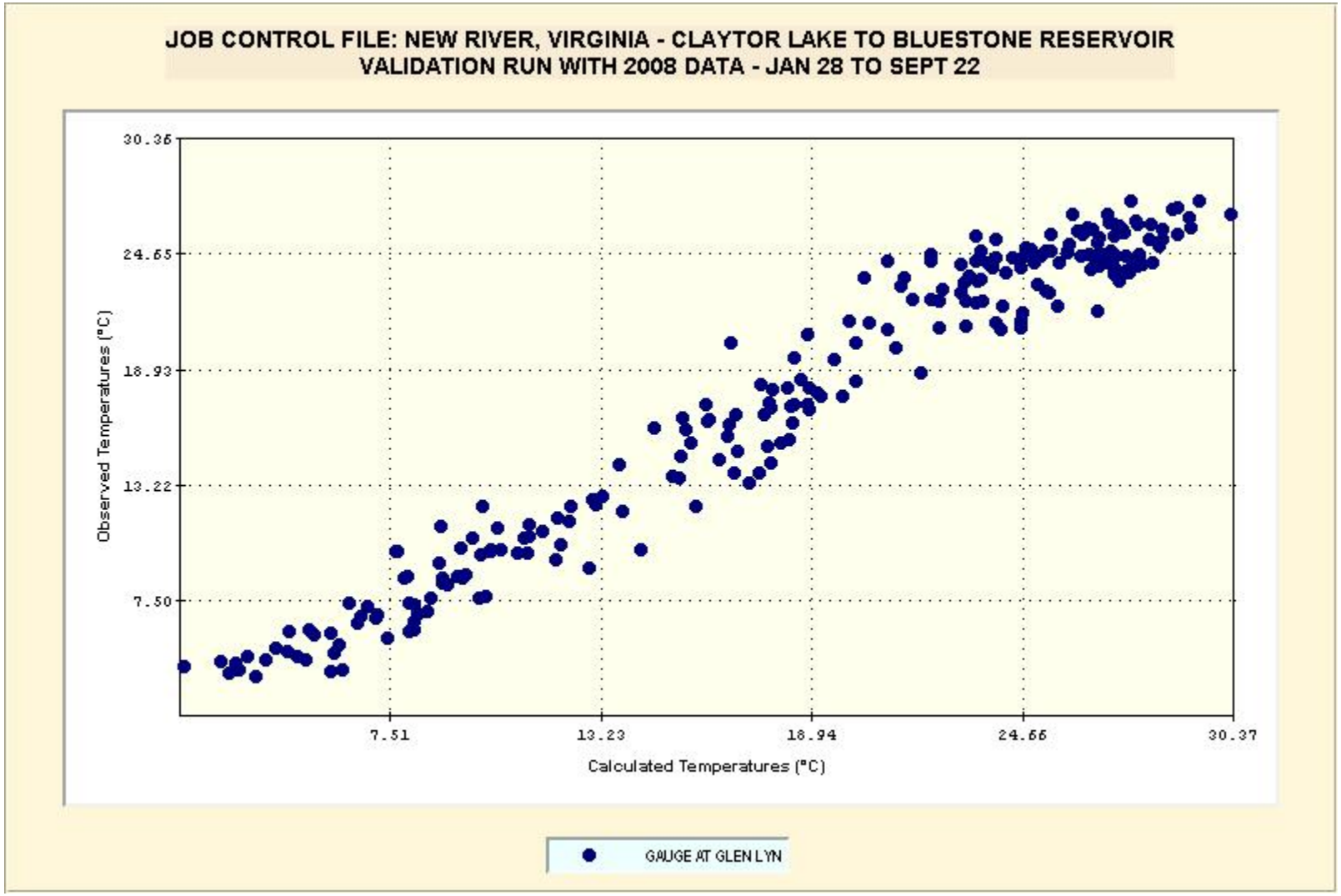

Figure 5. Scatter plot of the year 2008 predicted versus the observed stream temperatures at Glen Lyn.

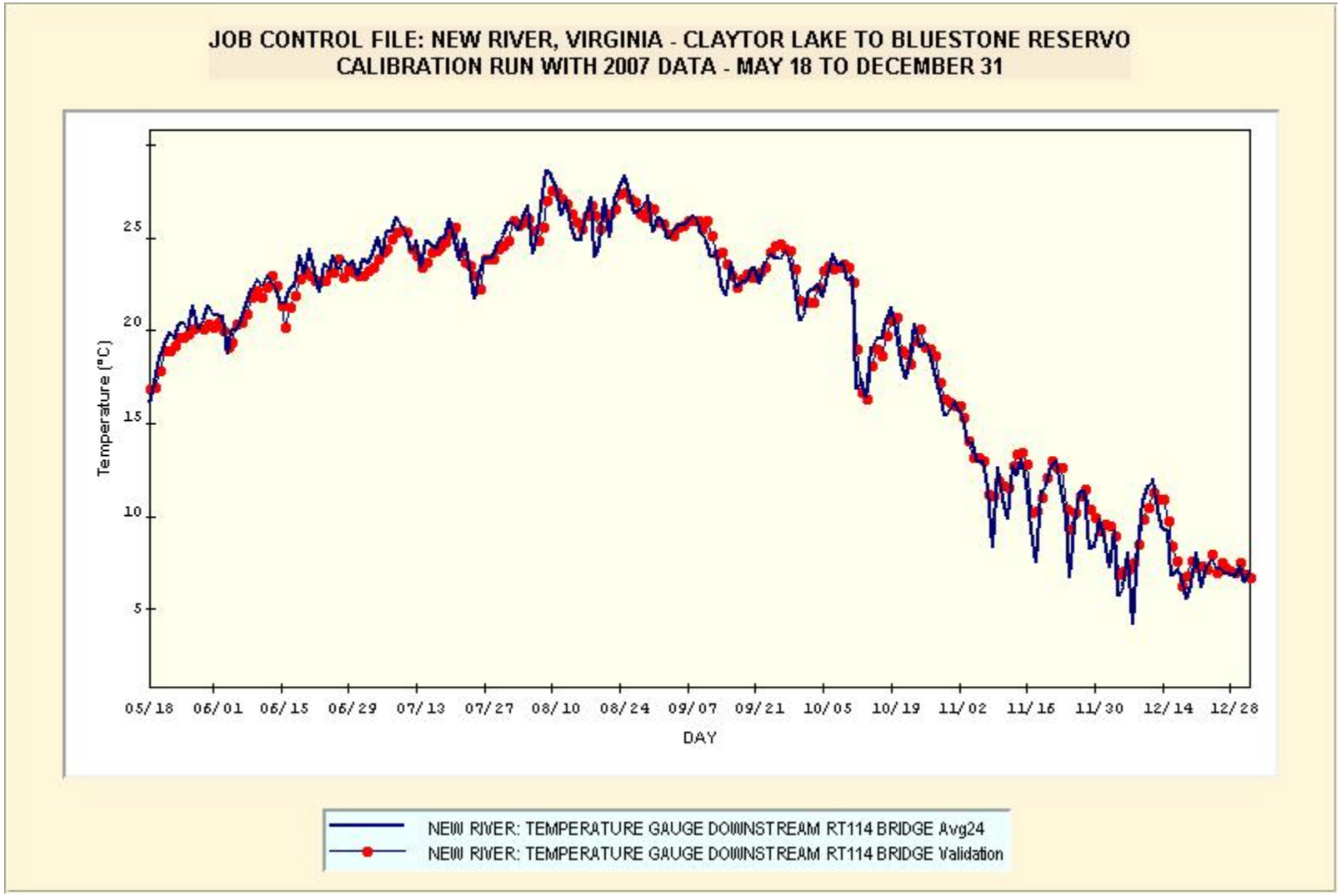

Figure 6. Claytor SNTEMP - predicted and observed stream temperatures (^{o}C) for the year 2007 at Route 114 Bridge.

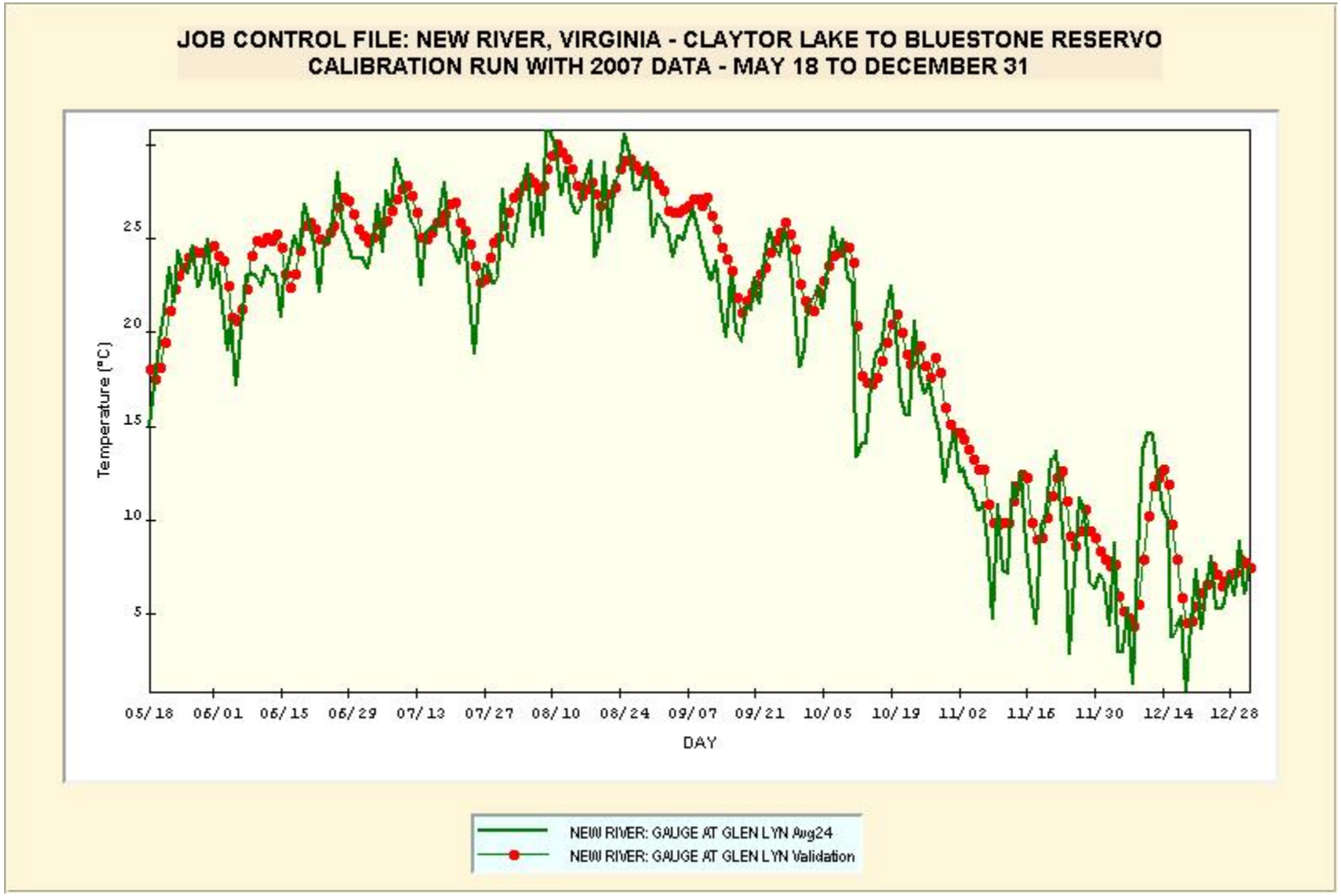

Figure 7. Claytor SNTEMP - predicted and observed stream temperatures (^{o}C) for the year 2007 at Glen Lyn.

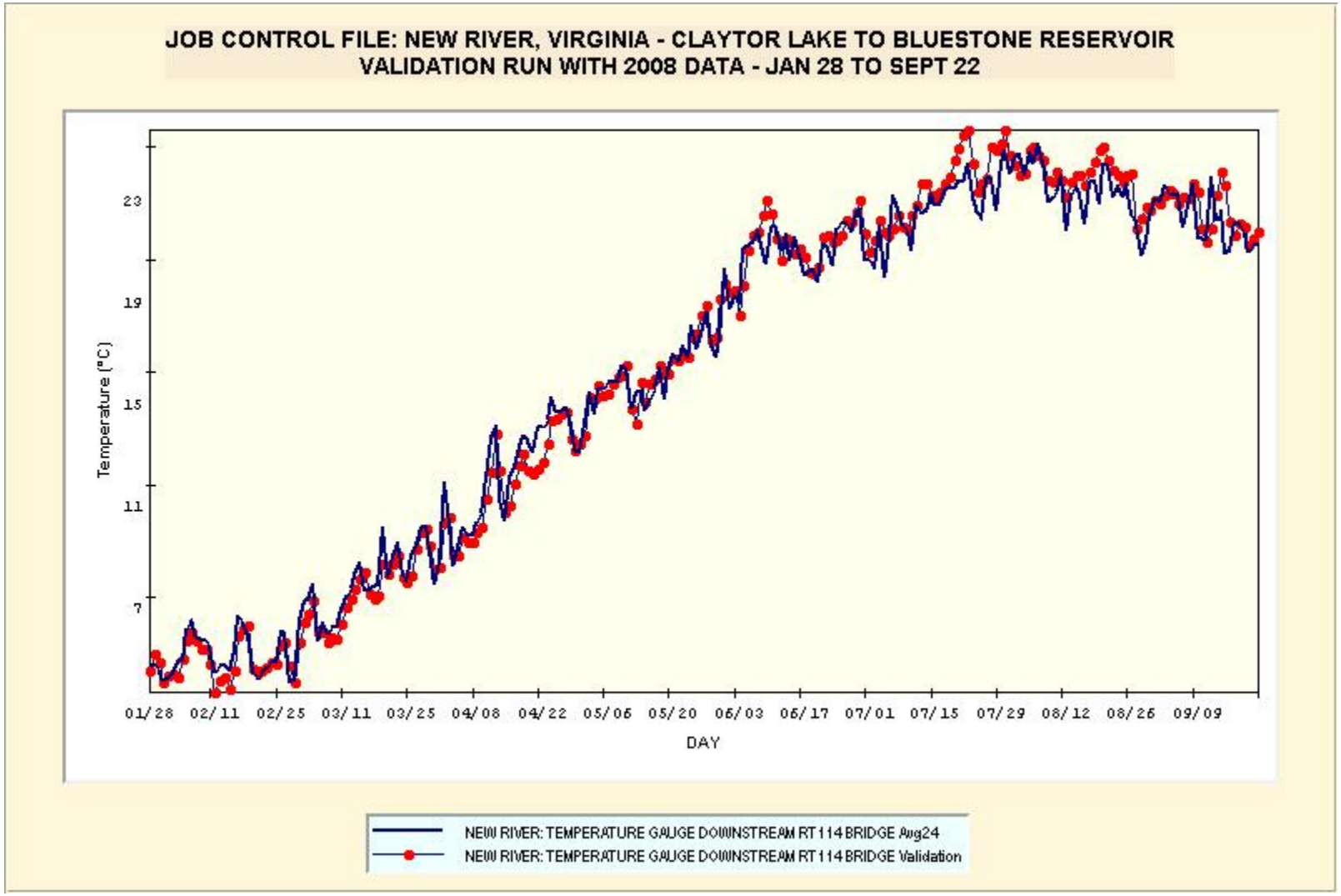

Figure 8. Claytor SNTEMP - predicted and observed stream temperatures (^{o}C) for the year 2008 at Route 114 Bridge.

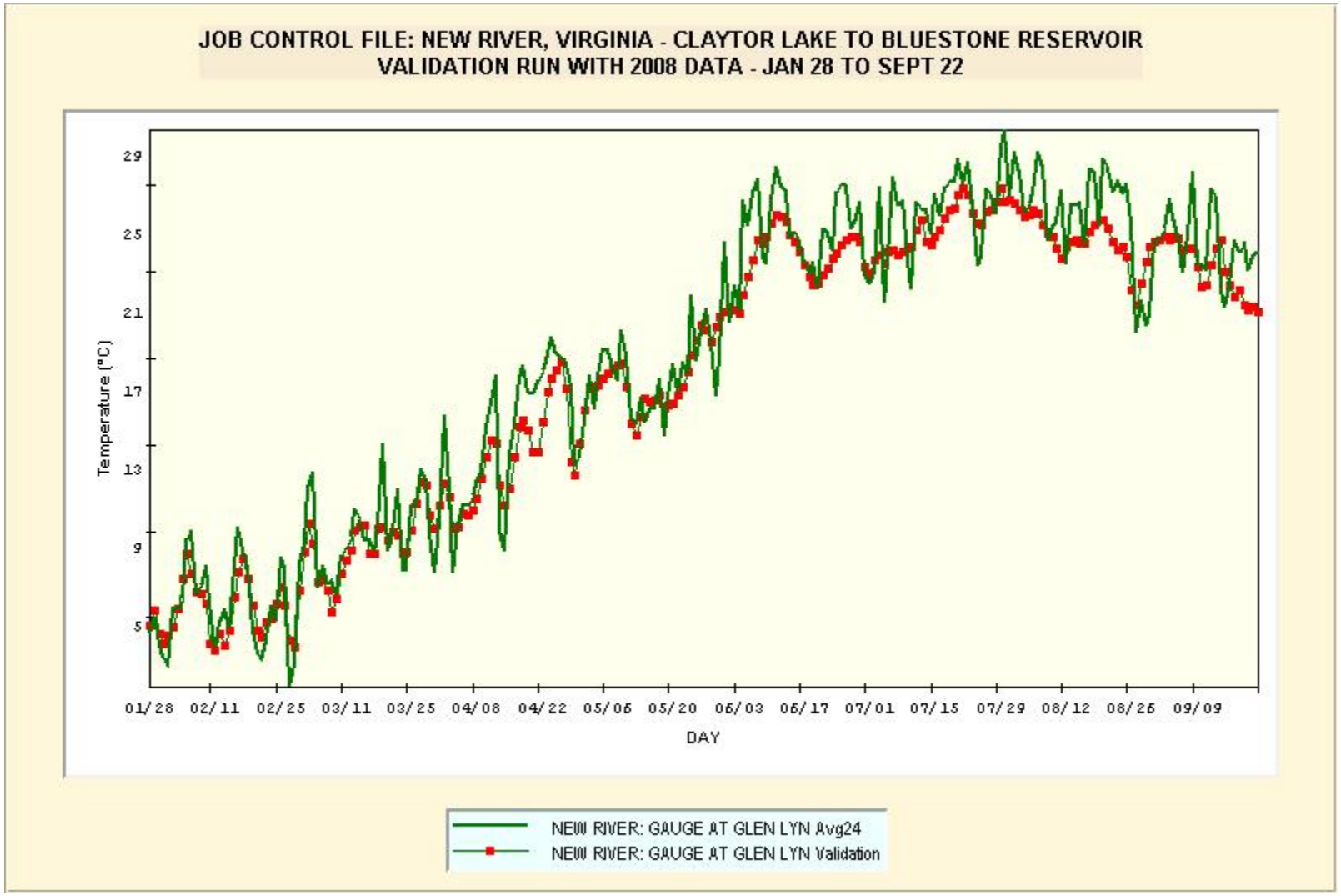

Figure 9. Claytor SNTEMP - predicted and observed stream temperatures (^{o}C) for the year 2008 at Glen Lyn.

CONCLUSION

Following calibration and validation of the constructed model (based upon two years of field data), the Claytor SNTEMP model should serve as a modeling tool capable of predicting downstream temperatures in the New River at various locations under a variety of alternative future flow regimes. The present model is not without weaknesses, however, and could have been strengthened by the collection of on-site solar radiation data. The spotty availability and questionable reliability of the Bluefield site solar radiation data made the model more difficult to calibrate and makes it appear to be less robust than it may actually be. Travel time of the flow throughout the reach may also affect the predictive capability of the model. Under low flow conditions the model-predicted response in stream temperature at a downstream node to a change in meteorological conditions may not be observed until the following day.

These things aside, the model as is should function adequately as an assessment tool for determining low flow threshold impact levels on aquatic habitat downstream of Claytor Dam under various hydrological and meteorological conditions.

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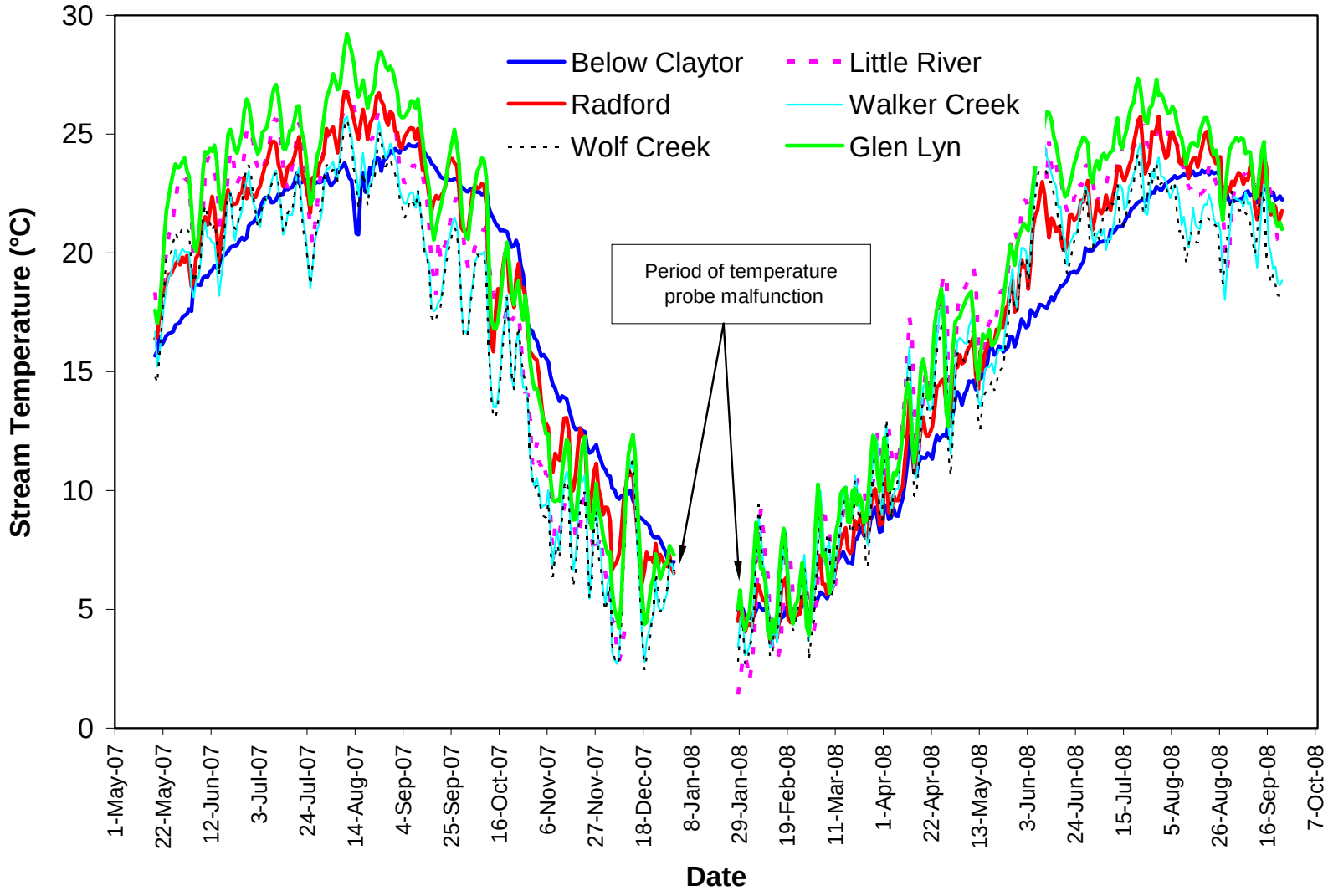
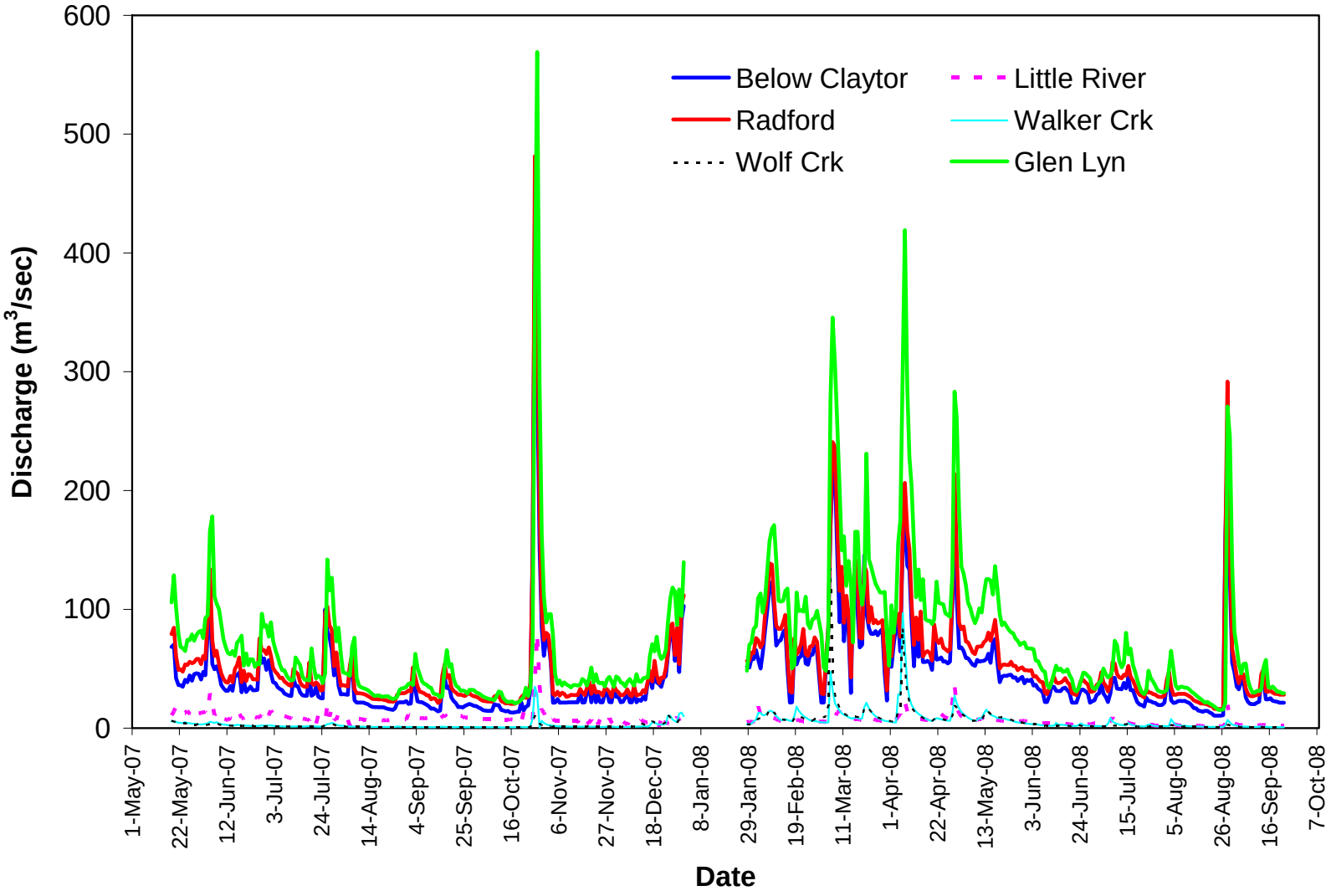
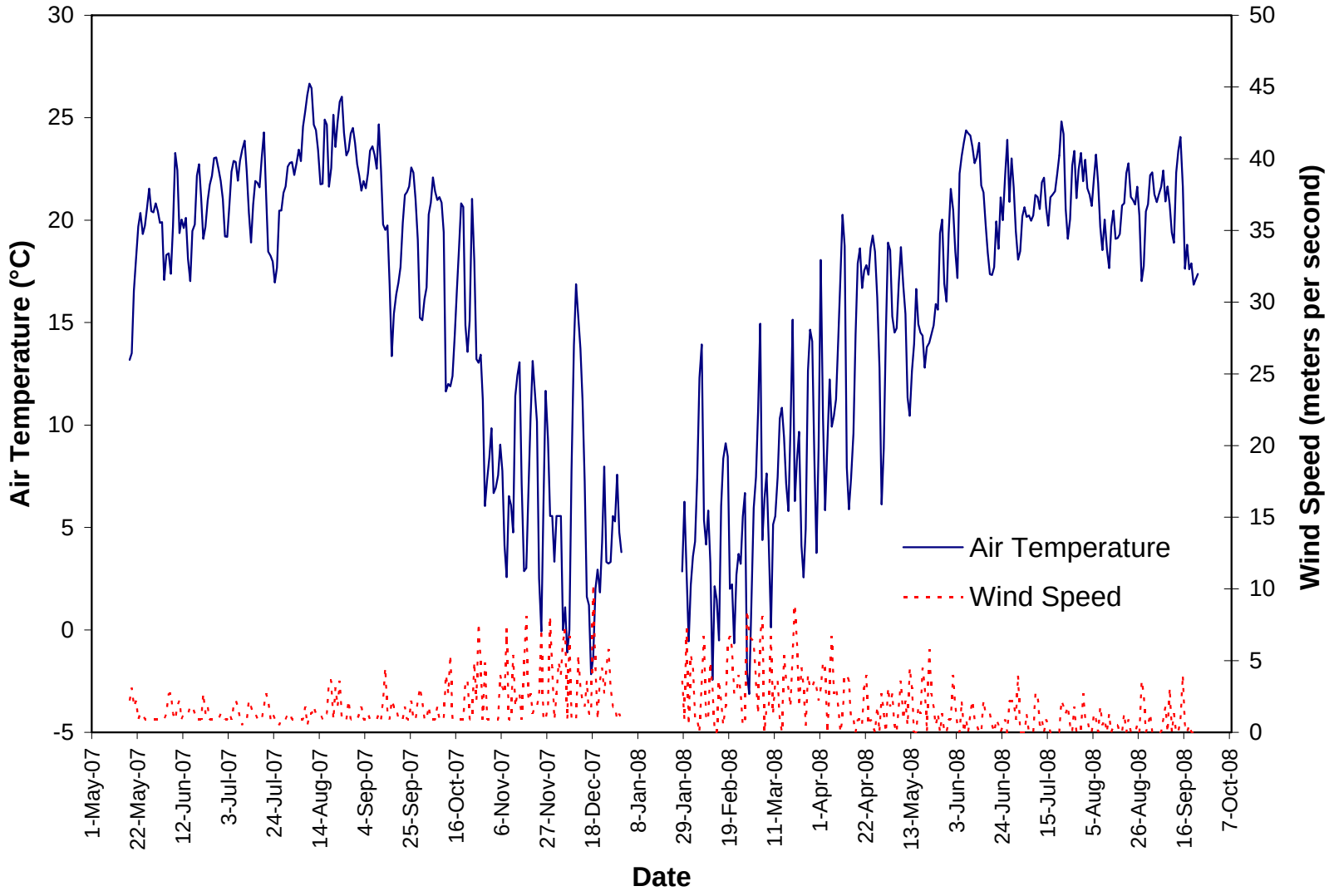
Appendices



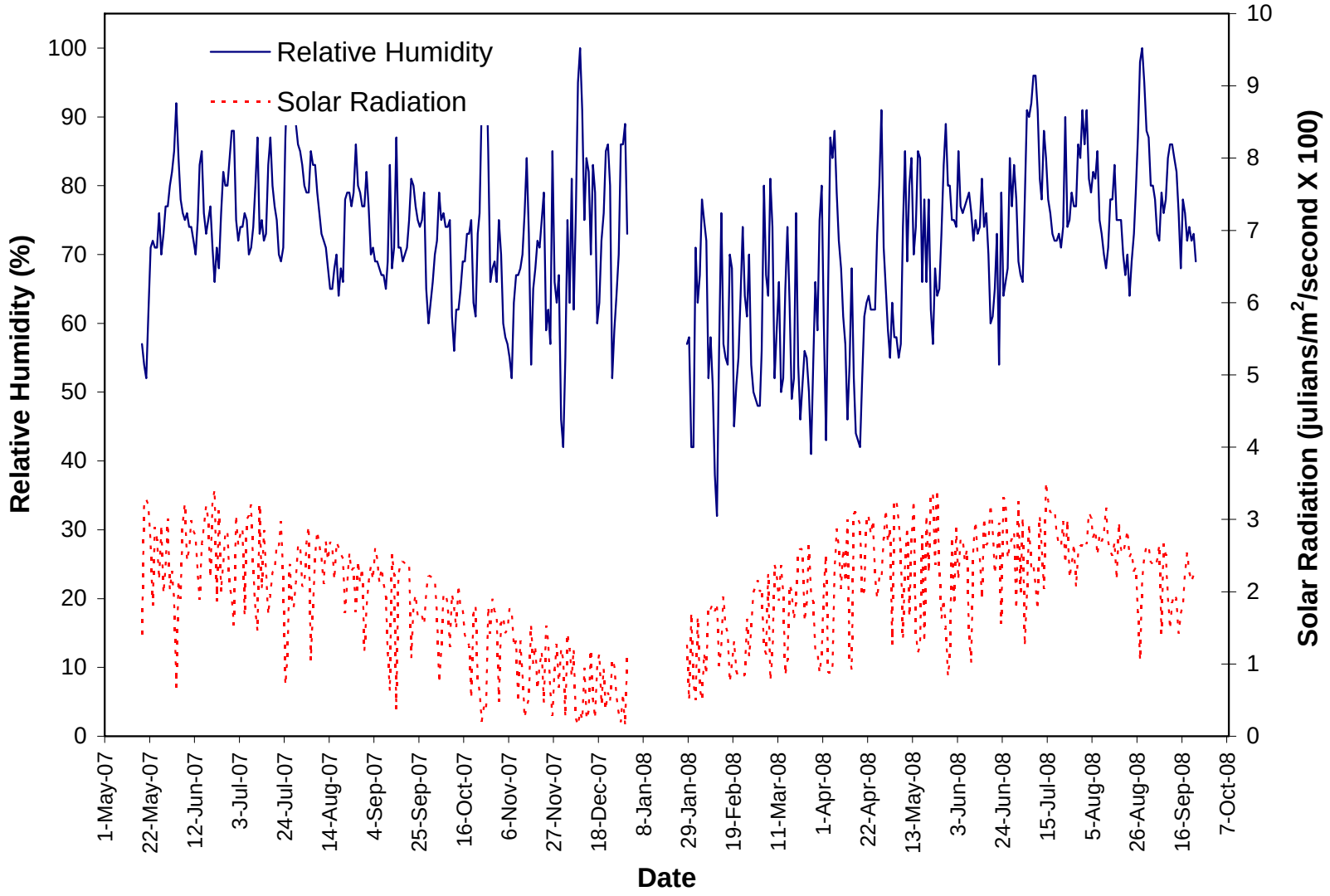
Appendix A. New River and tributary inflow water temperatures (^{o}C) used in the Claytor SNTEMP model, 18 May 2007 to 22 September 2008. Note missing data for 1-27 January 2008 due to temperature probe malfunction.



Appendix B. New River discharge and tributary inflows (m^3/sec) used in the Claytor SNTEMP model, 18 May 2007 to 22 September 2008.



Appendix C. Mean daily measurements of air temperature (^{o}C) and wind speed (m/sec) used in the Claytor SNTEMP model, 18 May 2007 to 22 September 2008.



Appendix D. Mean daily measurements of percent relative humidity and solar radiation (julians/m^2/sec x 100) used in the Claytor SNTEMP model, 18 May 2007 to 22 September 2008.