PPRP-DC-1

PPRP

A TEMPERATURE SIMULATION MODEL OF THE YOUGHIOGHENY RIVER FROM DEEP CREEK STATION TO SANG RUN

JUNE 1997

MARYLAND POWER PLANT
RESEARCH PROGRAM

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John R. Griffin
Secretary
Maryland Department of Natural Resources

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A TEMPERATURE SIMULATION MODEL OF THE YOUGHIOGHENY RIVER FROM DEEP CREEK STATION TO SANG RUN

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June 1997

ACKNOWLEDGMENTS

The author wishes to thank Dr. Mark Dortch of the Corps of Engineers Waterways Experiment Station for reviewing a draft of this report and providing useful comments, and two anonymous reviewers who commented on a draft version of this report which was subsequently published in The Environmental Professional (1997, Vol. 19, pp 209-220). All comments were carefully considered in preparing this final report.

FOREWORD

This final report, “A Temperature Simulation Model of the Youghiogheny River from Deep Creek Station to Sang Run,” was prepared by Stephen P. Schreiner of Versar, Inc., at the request of Rich McLean of the Power Plant Research Program (PPRP), Maryland Department of Natural Resources (MDNR). This report documents work done under task DC-3 of PPRP Contract PR91-047-001(91) and (92).

ABSTRACT

Deep Creek Lake Hydroelectric Station discharges into the Youghiogheny River (MD) in a peaking mode, resulting in rapid and dramatic changes in flow and temperature in the river. During low flow periods in summer, cold water releases from the project can provide a benefit to the trout fishery in the river by moderating otherwise unfavorable low flows and high temperatures. We developed a temperature model of the river using CE-QUAL-RIV1 to evaluate the effectiveness of various release scenarios for maintaining water temperature below 25°C, a critical value for brown trout. Temperatures were recorded continuously at 10-30 minute intervals for several summers at various locations in the river to provide data for model calibration and verification. The model was modified to include benthic conduction and shading subroutines to improve simulation results. Model simulations and test releases included both full and partial generation releases of 1-3 hours in duration at mid-day and during several continuous low flow releases. Results were then used to estimate the relative cost of various release scenarios to the utility and other users of river flows. Model results were also used in determining a means of triggering releases when required, based on daily meteorological forecasts, flows, and temperature conditions in the river.

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1.0 INTRODUCTION

1.1 PURPOSE

Pennsylvania Electric Company (Penelec) owns and operates Deep Creek Lake and Hydroelectric Station for power generation. As part of permitting activities for the Deep Creek facility, the Power Plant Research Program (PPRP) within the Maryland Department of Natural Resources (MDNR) developed recommendations for operation of the facility to provide various environmental and recreation enhancements. One of the goals of the MDNR is to use cool water releases from the project to enhance the temperature habitat for trout during low flow conditions in the summer months. In support of that goal, PPRP sponsored a study to develop a temperature model of the Youghiogheny River downstream of the Deep Creek Station discharge to simulate possible operating scenarios for the project. The temperature model provides a means of evaluating various release scenarios to achieve a desired temperature in the river. These scenarios can then be used to quantify the relative costs of temperature enhancement to the utility and other users of river flows.

1.2 STUDY AREA

The river reach of interest extends from the Deep Creek Station tailrace, 0.4 miles (0.6 km) upstream of Hoyes Run, downstream to the Sang Run bridge, 3.6 miles (5.8 km) downstream of the tailrace (Figure 1-1). This section of the river is relatively flat and wide compared to the narrower, deeper and more shaded sections upstream and downstream. Consequently, temperatures in this flat section tend to reach more severe levels than in the other reaches (Figure 1-2). Since it is immediately downstream of the project, this section would receive the most benefit from release of cold water from the project. There would, however, continue to be some benefit to fish habitat in the reach further downstream.

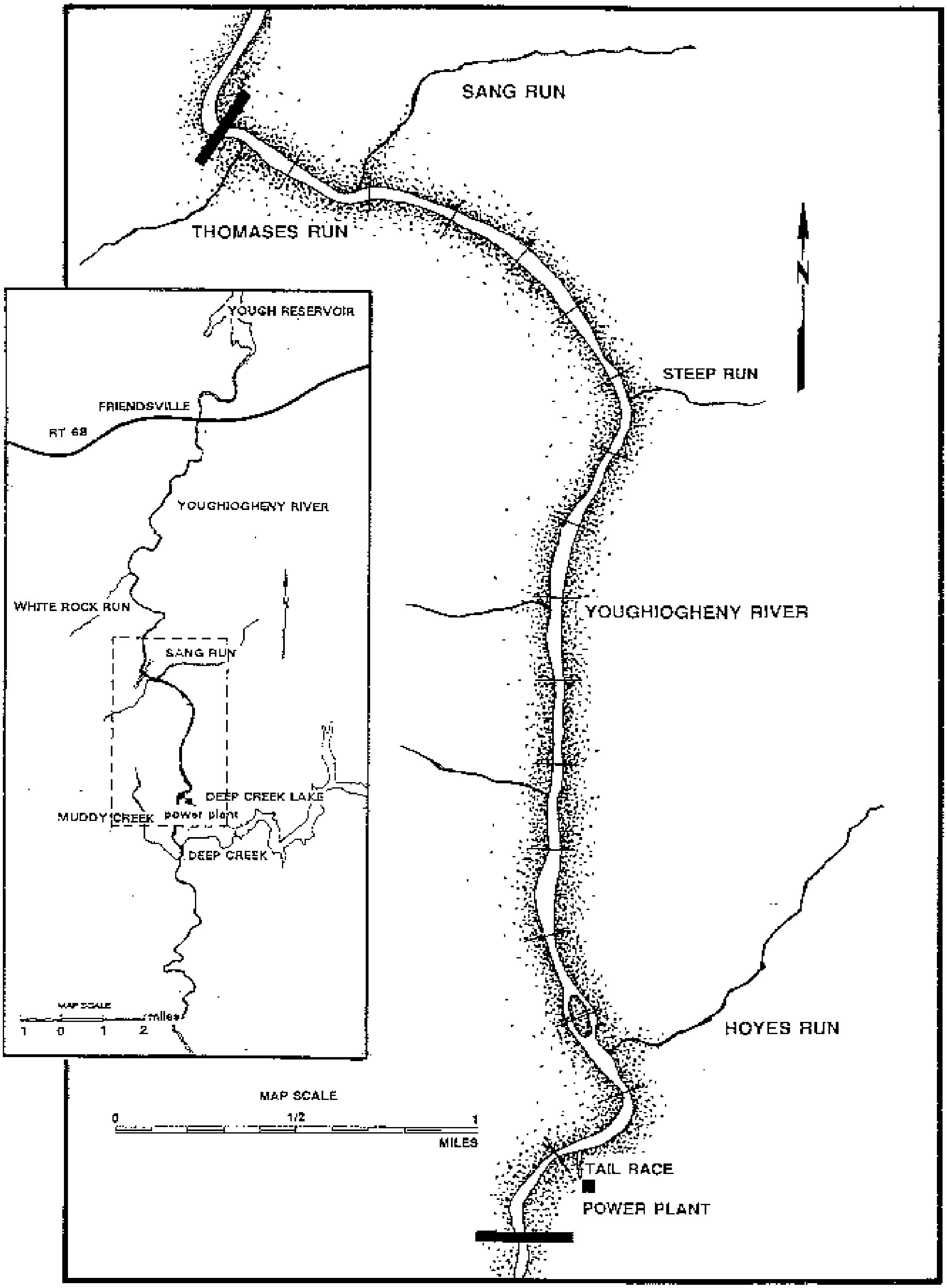

Figure 1-1. YOUGH-RIV1 segmentation of the Youghiogheny River from Deep Creek Station (labeled power plant) to Sang Run, with inset showing river from north of Oakland, MD to Friendsville. Mainstem segment is indicated by heavy lines; lighter lines indicate model nodes.

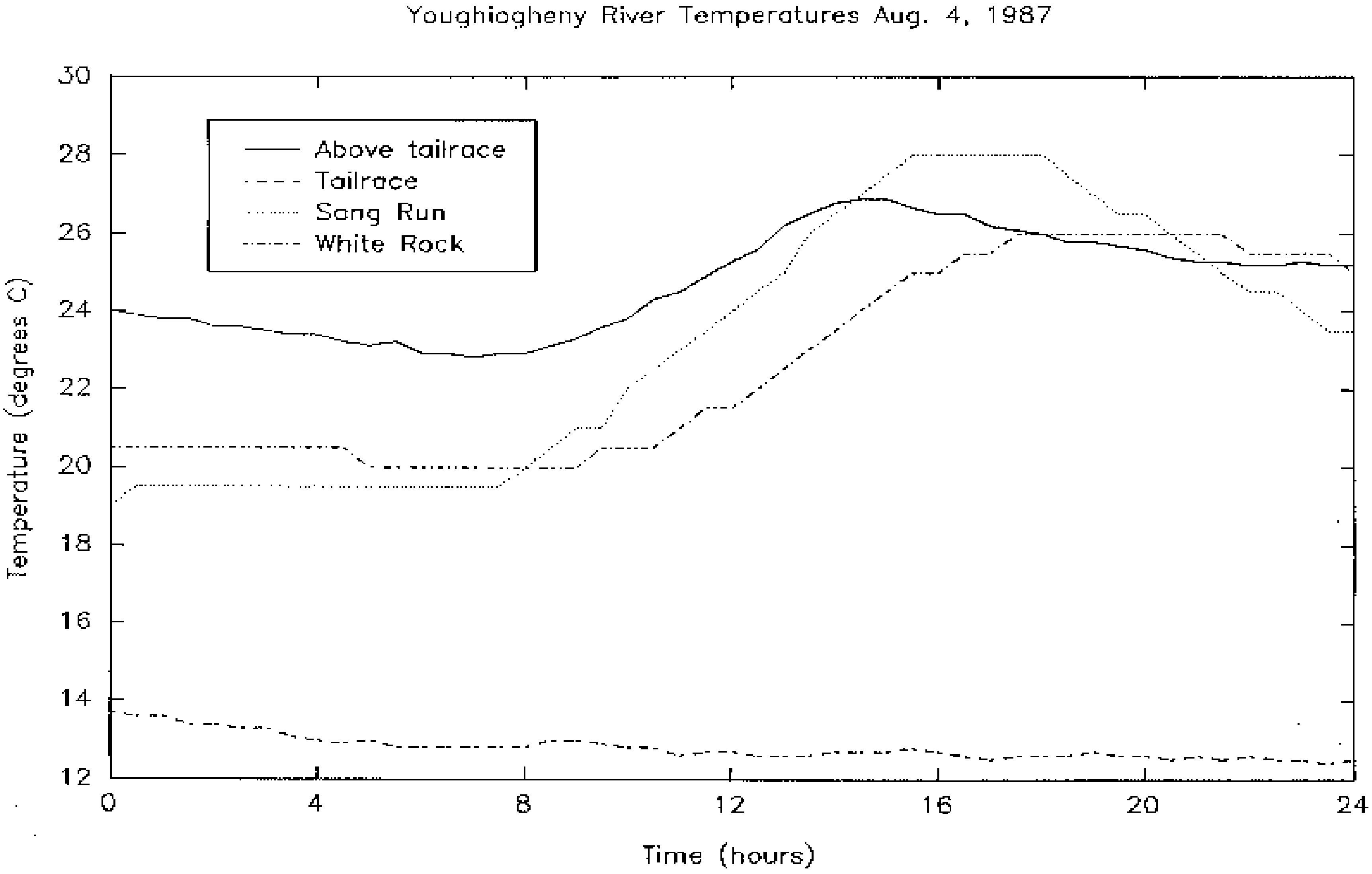

Figure 1-2. Youghiogheny river temperatures on August 4, 1987, illustrating variable heating and cooling patterns in various portions of the river during low baseflow, non-generating periods. The White Rock location is 7 miles downstream from the Sang Run bridge. Other locations are described in the text.

1.3 TEMPERATURE MODEL REQUIREMENTS

A temperature model of the Youghiogheny River for the section of interest outlined above must be able to simulate dynamic flow conditions in which a baseflow of less than 25 cfs (0.71 m^3/sec) may increase to greater than 640 cfs (18.1 m^3/sec) in a matter of a few minutes due to project releases. These releases are typically 2-3 hours in duration during summer low flow conditions and usually occur during daylight hours on weekdays. The diurnal temperature range may be as great as 10°C during baseflow (no release) conditions; a generation release may result in 16°C water being released into ambient river water which may be 27°C or warmer at mid-day during summer low-flow conditions.

When temperature modeling of the Youghiogheny River was originally discussed in 1989, an empirical approach was proposed. Temperature data collected by MDNR fisheries for evaluating fish habitat in the river in 1987 and 1988 were to be used along with air temperature records to build a regression type model to predict river temperature from air temperature. Upstream and release river flows were to be included using a mass-balance approach. However, the 1987 and 1988 data was incomplete for this purpose and in particular, the upstream temperature monitors had been placed in locations where they were affected by the generation releases and leakage flows from the project. Also, the nearest air temperature records were from Oakland, Maryland, and only daily min/max temperatures were available. Thus, this data was not suitable for an empirical modeling approach. Collection of appropriate local air and river temperature data in 1989 specifically for modeling purposes was then proposed. However, 1989 and again in 1990, conditions were atypically wet and cool, and the data were not suitable for the conditions for which the model would need to simulate. In early 1991, it was decided that a simulation modeling approach would be required so that the existing 1987 and 1988 data could be used to build and calibrate a suitable model in time to develop and evaluate recommendations prior to the 1991 relicensing submission deadline.

Due to the dynamically changing flow conditions, steady-state models such as the EPA's QUAL2E (Brown and Barnwell 1987) or the Fish and Wildlife Services' SNTEMP (Theurer et al. 1984) are not suitable models, although they could be used for assessing the use of minimum flows for controlling temperature during non-generation periods. The Corps of Engineers has developed a suitable one-dimensional dynamic flow model called CE-QUAL-RIV1 (Environmental

Laboratory 1990); although it is more difficult to set up and calibrate than the steady-state models, it was chosen due to its ability to simulate large flow fluctuations.

1.4 RIV1 MODEL DESCRIPTION

CE-QUAL-RIV1 (RIV1) is a dynamic, one-dimensional (longitudinal) riverine water quality model suitable for use when flows change substantially within a day or from day to day. RIV1 consists of two submodels, for hydrodynamics (RIV1H) and water quality (RIV1Q), each of which are calibrated and run separately. RIV1H simulates river geometry and flow characteristics and its output is then read by RIV1Q, the water quality model. Temperature simulation algorithms (as well as other water quality constituents not being considered here) are implemented in RIV1Q. To develop a model specific to the Youghiogheny River, it was necessary to parameterize the RIV1 framework to the specific section of interest as well as the specific types of flow and temperature conditions of interest.

In general, the basic RIV1 model requires the following input data:

- initial flow and temperature conditions in the river;
- upstream flow and temperature for the mainstem and tailrace discharge throughout the simulation period;
- river cross-section geometry, consisting of:
    - width
    - elevation
    - roughness factor;
- downstream boundary condition (e.g., a stage:discharge relationship); and
- meteorological data to simulate heat flux at the site.

Due to the rapidly changing temperature conditions in the river which occur on a daily basis, at least hourly meteorological data are required to drive the heatflux computation portion of the model. Potential limitations of the basic RIV1 model (1990 version used here) for the Youghiogheny River are as follows:

- it contains no topographic or vegetative shading component, processes which may alter the timing and reduce the amount of direct solar radiation reaching the river;
- it has no benthic heat conduction component, a process which may buffer both heating and cooling processes occurring in a shallow river such as this one;
- cross-section geometry is limited: available data were measured at a minimum flow of 73 cfs (2.1 m^3/sec); worst case low flow conditions may be less than 20 cfs (0.57 m^3/sec);
- hydraulic travel time information from the tailrace to Sang Run is available only for 60 cfs (1.7 m^3/sec) and 173 cfs (4.9 m^3/sec); flows need to be simulated from <25 (0.71 m^3/sec) to >600 cfs (17.0 m^3/sec); and
- available meteorological data is not site-specific.

In spite of these limitations, RIV1 provided the most suitable framework for a Youghiogheny River temperature model. In models of this type, calibration should be performed using a measured dataset to compare model predictions while adjusting the appropriate parameters to obtain the best fit to available observed data. To evaluate the calibrated model, it should then be tested or verified against one or more independent datasets without further parameter adjustment. The calibration and verification steps performed for YOUGH-RIV1 are described below for each submodel. (Note: input and output for RIV1 requires use of English units of measurement; SI equivalents for key parameters in the text of this report are given in parenthesis.)

2.0 MODEL CALIBRATION AND VERIFICATION

2.1 THE HYDRAULIC MODEL

2.1.1 Hydraulic Geometry

A model of the Youghiogheny River section of interest needs to include two main segments, one for the river mainstem from just above the tailrace downstream to the Sang Run bridge (Figure 1-1), and another for the tailrace itself, which discharges to the eastern side of the mainstem. Each reach can be divided into a number of nodes, the length of which are determined by degree of detail required, the hydraulic geometry data available, and type of flow conditions to be simulated.

The mainstem segment of the Youghiogheny River model consists of 17 equally spaced nodes and the tailrace segment consists of 2 nodes, with the second tailrace node connected to the second mainstem node, as shown in Figure 1-1. Elevations for each node (Table 2-1) were obtained from USGS topographic maps. The number of mainstem nodes was chosen in order to make use of as many of the measured transects available from an IFIM model of the river prepared by Penelec (1991). The number of nodes was also chosen to provide sufficient spatial and temporal detail for comparison with the available calibration data, without creating a large computational burden.

RIV1H can represent the following cross-section types: rectangular, triangular, trapezoidal, parabolic, and ellipsoidal. Based on the available transect information, a trapezoidal representation was chosen for this simulation, as it provides for a minimum width and a flow-variable width above the minimum. Coefficients for trapezoidal sections in the model input file are used to represent the minimum width (C1) and the average side slope (C2). These values were estimated from the measured cross-sections using the data collected at 73 cfs (2.1 m^3/sec) and 680 cfs (19.3 m^3/sec) (Dyok, Foster-Wheeler Environmental Corp., pers. comm.). For nodes between the measured values, the data were interpolated (Table 2-2). The model uses these coefficients to calculate a width for each node depending on the flow at each time step. Predicted widths and depths for each node at an upstream baseflow of 20 cfs (0.57 m^3/sec) and at a maximum flow of 680 cfs (19.3 m^3/sec) are shown in Table 2-2.

Table 2-1. Youghiogheny River and YOUGH-RIV1 model hydraulic geometry from Deep Creek Station tailrace to Sang Run

Node #	Elevation (Ft. MSL)	Ebasco Transect	Tailrace Distance (miles)	Ebasco Width (feet) @ 73 cfs	Ebasco Width (feet) @ 680 cfs	C1 min (feet)	C2 Slope	Adj. Slope
Segment 1: Mainstem Youghiogheny River								
1	2030	-	-0.11	-	-	119	61.2	-
2	2022	1	0.11	176	232	119	61.2	-
3	2017	3	0.33	123	140	101	10.5	-
4	2013	4	0.55	223	266	171	44.4	35.0
5	2009	-	0.77	-	-	182	15.9	-
6	2005	-	0.99	-	-	188	9.70	-
7	2001	-	1.21	-	-	183	6.97	-
8	2000	-	1.43	-	-	182	5.44	-
9	1999	-	1.64	-	-	180	4.47	-
10	1998	-	1.86	-	-	177	3.78	-
11	1997	5	2.08	182	188	175	3.28	-
12	1996	6	2.30	119	203	40	60.5	27.0
13	1995	-	2.52	-	-	70	21.6	-
14	1994	-	2.74	-	-	88	13.2	-
15	1993	-	2.96	-	-	94	9.46	-
16	1992	7	3.18	121	129	103	7.39	-
17	1991	8	3.40	185	202	152	15.9	-
Segment 2: Tailrace								
1	2022	-	0.0	-	-	150	-	-
2	2022	-	0.0	-	-	150	-	-

The tailrace segment of the model was divided into 2 nodes, each 150 ft (45.7 m) wide and 1000 ft (305 m) long. The actual tailrace is only about 50 ft (15.2 m) wide by 450 ft (137 m) long but due to model instability during rapidly changing flows, the length and width was increased to the larger values. To compensate for the greater residence time in the model tailrace as compared with the actual tailrace, generation flows in the model were released 15 minutes earlier than actually occurred.

Table 2-2. YOUGH-RIV1 cross-section geometry and Manning's coefficients

Node #	**Ebasco Transect**	**Model Width 20 cfs (feet)**	**Model Width @ 680 cfs (feet)**	**Model Depth @ 20 cfs (feet)**	**Model Depth @ 680 cfs (feet)**	**AX (intercept)**	**DNDH (slope)**
1	-	155	-	0.29	-	.09849	.03922
2	1	154	258	0.28	1.13	.10467	.05000
3	3	114	139	0.61	1.83	.11793	.04348
4	4	190	254	0.23	1.19	.10411	.05556
5	-	196	230	0.45	1.51	.11235	.04878
6	-	193	209	0.25	1.08	.10391	.06061
7	-	190	211	0.50	1.99	.10633	.03419
8	-	187	204	0.48	2.01	.10611	.03390
9	-	185	198	0.52	2.04	.10667	.03333
10	-	180	193	0.46	2.11	.10385	.03101
11	5	180	192	0.69	2.48	.11636	.03306
12	6	90	187	1.00	2.73	.13363	.03774
13	-	106	184	0.82	2.65	.11967	.03252
14	-	107	157	0.73	2.63	.11564	.03101
15	-	109	144	0.78	2.62	.11592	.03125
16	7	112	138	0.59	2.38	.10990	.03053
17	8	173	211	0.67	1.87	.11756	.04211

2.1.2 Boundary Conditions

An upstream boundary condition of flow was used for both the mainstem and tailrace segments of the model. Upstream flows were calculated from the daily average flows measured at the USGS gage near Oakland, MD (station 03075500), 10 miles (16 km) upstream from the project tailrace. The equation used to convert the Oakland gage reading to a flow just upstream of the tailrace was obtained from Penelec (1991):

$$Qt = 0.8 * [2.3 * Qo^{0.957}] \qquad (1)$$

where Qt = tailrace flow in cfs (.0283 m^3/sec)

Qo = Oakland flow in cfs.

This equation was obtained by a log regression of the Oakland flows against the Friendsville flows (USGS station 03076500) for low flow time periods (< 100 cfs (2.83 m^3/sec) at Oakland) when the Deep Creek Station was not operating. The flow predicted for Friendsville (in brackets in equation 1) was then prorated by a factor based on the drainage area ratio of 0.8.

The tailrace boundary flow was set to 7 cfs[1] (0.2 m^3/sec) during non-operating periods, to represent the estimated leakage flow through the wicket gates (Penelec 1991). Operating records were used for the flows released during operation, typically 630 cfs (17.8 m^3/sec) for 2-turbine operation.

A stage-discharge rating curve was used as the downstream boundary condition for the mainstem:

$$Q = 93.81 * H^{3.11} \tag{2}$$

where Q = flow in cfs (0.028 m^3/sec) and H = stage in feet (0.3048 m). This relationship was computed from the observed stage-discharge values as shown in Table 2-3.

Table 2-3. Stage-discharge values for the gage at Sang Run bridge used as the downstream boundary condition for the YOUGH-RIV1 model

Stage (H in feet) ("new" gage at Sang)	**Flow (Q in cfs)**	**Predicted Stage**
0.8	48*	0.79
1.5	380#	1.57
1.9	660$	1.87
2.0	770$	1.97

Data sources:
* observed on 13 August 1990
\# Grove et al. 1986
$ Graefe et al. 1989

---

[1] This leakage flow was subsequently estimated to be 9 cfs.

2.1.3 Calibration Period

As part of a fisheries study conducted by MDNR, half-hourly temperature measurements were available for some summer months in 1987 and 1988, a period of hot, low flow conditions for the Youghiogheny River. Locations for which these data were collected included stations above the Deep Creek Station tailrace, within the tailrace (1987 only), 0.4 miles (0.6 km) downstream near Hoyes Run, and 3.6 miles (5.8 km) downstream near Sang Run. Data were also available for a shorter time period near Steep Run, approximately 2.4 miles downstream. Based on the available data, the model calibration period was chosen to be the 48-hours from July 22 to 23, 1987 (Figure 2-1). These dates were chosen because they contained the most severe river temperature measurements available; in addition, the first day had no generation release, while the second day had a 2-hour release commencing at 1400 hours. (All times are specified in local standard time [ST], consistent with the convention used in RIV1). The hydraulic model was set up to run the actual measured flows for the period, with a baseflow of 37 cfs (1.05 m^3/sec) above the tailrace, and with the addition of 7 cfs (0.2 m^3/sec) leakage flow from the tailrace during non-generating periods. A generation flow of 630 cfs (17.8 m^3/sec) was added for 2 hours on the second day commencing at 1400 hours ST. Initially, 7.5 minute timesteps were used for all flow ranges to provide sufficient temporal detail without undue computational burden. However, due to model instability at higher flows, a 15-minute timestep was used for baseflow time periods and 3-minute timesteps were used during generation flow periods. The dataset used as input to the hydraulic model is shown in Table 2-4.

2.1.4 Roughness Factor

The river bottom roughness is an important calibration factor in correctly setting the hydraulic travel time in the model. It is particularly important for a shallow river with widely varying flows such as occurs in the Youghiogheny. RIV1H can represent a linearly varying Manning's N for each cross-section depth. The equation relating N to depth is N = AX -DNDH*H where H is the value for depth at a particular node, AX is the intercept value and DNDH is the slope. In order to calibrate AX and DNDH values for each node, the value of N for the baseflow of 60 cfs was varied until the travel time matched that measured during a dye

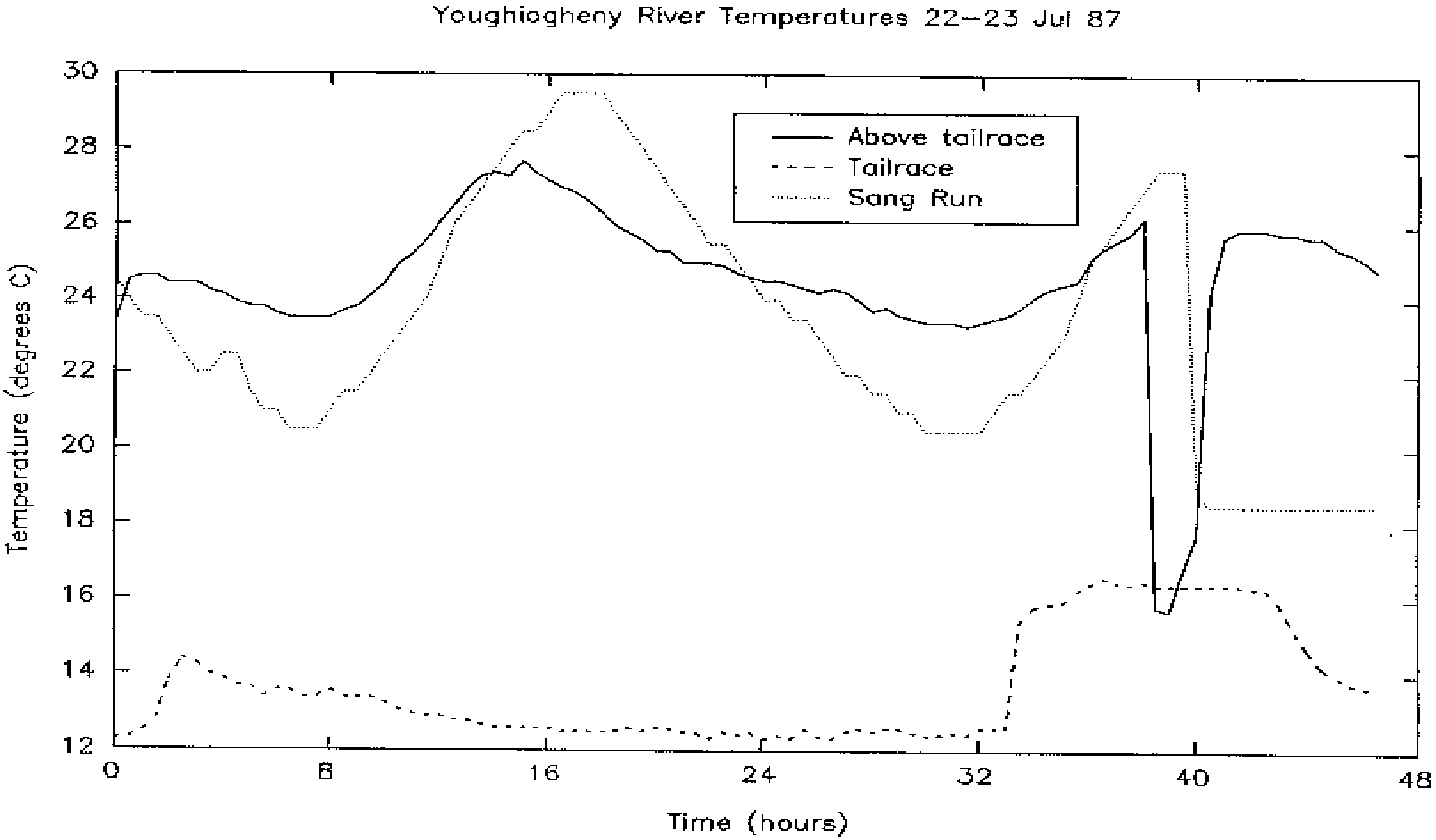

Figure 2-1. Youghiogheny River temperature on July 22 and 23, 1987, for stations above the Deep Creek Station tailrace, within the tailrace, and just above the Sang Run bridge. Temperatures above the tailrace and in the tailrace were used as upstream boundary conditions for the YOUGH-RIV1 model calibration, except during generation release when above tailrace measurements were affected by the releases due to a backwater effect as shown above. Upstream temperatures during this time estimated by interpolation between unaffected times for modeling purposes. The Sang Run data were used to judge calibration success of the model.

Table 2-4. Input dataset for the YOUGH-RIV1 hydraulic model. Dataset format described in Environmental Laboratory (1990).

```
 YOUGH RIVER MODEL-JUL87 CAL; N=.04-.08;2-HR GEN @630CFS;37 CFS BASE, 3-15 STEP
19, 256, 2
&CONST BETA=1.0, GR=32.17, RMILE0=0.0, THETA=1.00, TOLER=0.20,
 IPRINT=4 &END
1 MAINSTEM YOUGHIOGHENY - TAIL TO SANG     17      Q     37.R .32147  .23226
1158.    37.  0.39    0. 2030.  119.61.2     2.0   .09    0..09849.03922
1158.    40.  0.39    0. 2022.  119.61.2     2.0   .09    0..10467.05000
1158.    44.  0.74    0. 2017.  101.10.5     2.0   .09    0..11793.04348
1158.    44.  0.35    0. 2013.  171.35.0     2.0   .09    0..10411.05556
1158.    44.  0.56    0. 2009.  182.15.9     2.0   .09    0..11235.04878
1158.    44.  0.32    0. 2005.  188.9.70     2.0   .09    0..10391.06061
1158.    44.  0.64    0. 2001.  183.6.97     2.0   .09    0..10633.03419
1158.    44.  0.63    0. 2000.  182.5.44     2.0   .09    0..10611.03390
1158.    44.  0.66    0. 1999.  180.4.47     2.0   .09    0..10667.03333
1158.    44.  0.61    0. 1998.  177.3.78     2.0   .09    0..10385.03101
1158.    44.  0.90    0. 1997.  175.3.28     2.0   .09    0..11636.03306
1158.    44.  1.21    0. 1996.   40.27.0     2.0   .09    0..13363.03774
1158.    44.  1.03    0. 1995.   70.21.6     2.0   .09    0..11967.03252
1158.    44.  0.94    0. 1994.   88.13.2     2.0   .09    0..11564.03101
1158.    44.  0.96    0. 1993.   94.9.46     2.0   .09    0..11592.03125
1158.    44.  0.80    0. 1992.  103.7.39     2.0   .09    0..10990.03053
1158.    44.  0.79    0. 1991.  152.15.9     2.0   .09    0..11756.04211
2 TAILRACE - TRIB TO MAINSTEM               2  1  2Q        H           90.
1000.    07.  0.42    0. 2022.  150.    0.    0.   .02    0.   .0     .0
1000.    07.  0.41    0. 2022.  150.    0.    0.   .02    0.   .0     .0
+2/
         4
       151       191       231       256
      900.        7.
      180.      630.
      180.        7.
      900.        7.
COMMENT: JULY 87 HYDRAULIC MODEL CALIBRATION, BEST MANN. N, TRAPEZOIDAL SECTIONS
```

study conducted by Dyok (Foster-Wheeler Environmental Corp. pers. comm.). Final values for AX and DNDH were set to yield an N value of 0.04 for generation flows (~670 cfs [19.3 m^3/sec]) and to yield an N value of 0.08 for the baseflow of 60 cfs (2.1 m^3/sec). No direct time of travel information was available for generation flows occurring during a low baseflow period, so the high flow N value could not be directly calibrated. Travel time can be inferred from the response of temperature sensors in the river near Sang Run, although a flow response could precede a temperature response by an unknown period of time. The value of 0.04 was chosen as a minimum value which was consistent with values between 0.026 and 0.069 calculated for a flow of 700 cfs (19.8 m^3/sec) by Dyok (Foster-Wheeler Environmental Corp., pers. comm.). This value was as low as the model could be reliably run without the occurrence of numerical instability.

2.2 THE TEMPERATURE MODEL

RIV1Q predicts the net heat transfer occurring in the river according to the following equation:

$$Hn = Hs + Hl - He - Hb \pm Hc \tag{3}$$

where Hn = net heat transfer, $\frac{\text{heat energy}}{\text{area * time}}$

Hs = net short-wave radiation,

Hl = net long-wave radiation,

He = net loss due to evaporation,

Hb = net loss due to back radiation, and

Hc = heat conduction across the air-water interface.

A change in temperature is then calculated from the net heat transfer:

$$\Delta T = \frac{Hn}{p * Cp * H}$$

where ΔT = rate of temperature change, °/time,

p = specific mass of water, mass/volume,

Cp = specific heat of water, $\frac{\text{heat energy}}{\text{mass} * \text{degree}}$, and

H = hydraulic depth (x-s area/width).

The algorithms used to compute the heatflux values are the same as those used in the QUAL2E model and are described in detail in Brown and Barnwell (1987). The computations depend on water temperature, time of year and day, site location (latitude, longitude, and elevation), and local meteorological data.

2.2.1 Meteorological Data

Ideally, site-specific meteorological data should be used to provide the most accurate simulation. The closest station to the site with suitable data was Morgantown, West Virginia, which is 30 miles (48 km) WNW of the site and at elevation 1300 ft (396 m) vs. about 2000 ft (610 m) for the site. Hourly data from the Morgantown station consisted of cloud cover percent, wind speed, dry bulb temperature, dew point temperature, and atmospheric pressure. The initial dataset used for the selected calibration period is presented in Table 2-5.

2.2.2 Boundary Conditions for Temperature

Mainstem upstream boundary conditions for temperature were obtained from measurements made at half-hour intervals upstream from the tailrace (see Figure 2-1). This station was affected by releases during project operation due to a backwater affect, so upstream temperatures during these times were estimated by interpolation of data points measured between the influence of the operating period. Initial temperatures for each node were set to the same value as the initial boundary condition temperature. Tailrace boundary conditions for temperature were set to values as measured in the tailrace (see Figure 2-1). Heatflux processes were turned off in the tailrace, as measured values were available at frequent intervals.

2.2.3 Dispersion Coefficient

The horizontal dispersion coefficient determines the longitudinal spread of a constituent carried with the water flow. With respect to temperature, it may affect the sharpness of temperature peaks over time. To calibrate this value, the dye study data used for the roughness factor calibration (section 2.1.4) were used. A conservative tracer was used in the model

Table 2-5. Meteorological input dataset for the RIV1Q model. Dataset format described in Environmental Laboratory (1990).

```
          203
         0.07
        39.35    80.25    75.00
   48
    3       7      11      15      19      23      27      31      35      39
   43      47      51      55      59      63      67      71      75      79
   83      87      91      95      99     103     107     111     115     119
  123     127     131     135     139     143     147     151     155     175
  195     215     235     239     243     247     251     256
    1       0       0      74      72   28.88
    2       0       0      72      71   28.88
    3       0       0      70      69   28.88
    4       0       0      69      69   28.89
    5       0       0      67      67   28.89
    6     0.2       0      66      66   28.90
    7     0.4       0      66      66   28.90
    8     0.3       0      71      69   28.91
    9     0.2     5.8      75      70   28.92
   10     0.1     5.8      79      69   28.92
   11     0.3     5.8      83      70   28.92
   12     0.3     3.5      84      69   28.91
   13     0.2     5.8      88      68   28.90
   14     0.3     6.9      88      68   28.88
   15     0.3     5.8      90      66   28.86
   16     0.2     9.2      91      66   28.85
   17     0.2     5.8      90      64   28.83
   18     0.2     4.6      89      66   28.82
   19     0.1     5.8      88      67   28.81
   20     0.1       0      86      68   28.81
   21     0.1     4.6      80      69   28.81
   22     0.0     4.6      77      71   28.82
   23     0.0       0      75      70   28.82
   24     0.0       0      73      70   28.82
   25     0.0       0      72      69   28.82
   26     0.0       0      70      68   28.83
   27     0.0       0      70      67   28.83
   28     0.0       0      70      67   28.82
   29     0.0       0      69      67   28.82
   30     0.0       0      67      66   28.82
   31     0.0       0      69      67   28.84
   32     0.0       0      71      68   28.85
   33     0.0     4.6      75      69   28.85
   34     0.0     4.6      82      69   28.84
   35     0.0     6.9      85      69   28.84
   36     0.1     5.8      88      69   28.84
   37     0.4       0      91      68   28.83
   38     0.4     5.8      90      67   28.81
   39     0.4     4.6      90      65   28.80
   40     0.5     5.8      93      65   28.78
   41     0.3     5.8      93      65   28.77
   42     0.4     5.8      91      67   28.76
   43     0.6     5.8      89      67   28.75
   44     0.6     6.9      87      68   28.76
   45     0.6       0      83      70   28.76
   46     0.6     4.6      79      70   28.77
   47     0.8       0      76      71   28.79
   48     0.7       0      75      71   28.80
   49     0.7       0      74      70   28.81
HOUR    CLOUD    WIND     AIR     DEW  PRESSURE
        COVER    SPEED    TEMP   POINT  (" Hg)
        FRACT.   KNOTS    (F)    (F)
```

to compare the shape of the arrival of the measured dye cloud at Sang Run with that simulated by the model. A dispersion coefficient of 25 seemed to provide the closest fit with observed data for the ascending part of the measured curve (Figure 2-2). The strong "tailing" effect of the measured dye suggests side channel storage somewhere in the reach or lateral differences in dye dispersion. The input dataset to RIV1Q containing initial conditions, boundary conditions, and the dispersion coefficients is listed in Table 2-6.

2.2.4 Initial Calibration Results

The RIV1Q model was run with the calibrated RIV1H results using the input datasets discussed above. To evaluate the model results, the simulation data for node 17 were compared graphically to the temperature data recorded at Sang Run for the same time period. The root mean squared (RMS) calibration error was also computed to assess the difference in model predictions vs. observed values (Thomann 1982):

$$\text{RMS error} = \text{SQRT}\ [(\text{sum}(\ (\text{Tic} - \text{Tim})\ **\ 2)\ )/\text{n},\ \text{i}=1,\text{n}] \qquad (5)$$

where Tic = computed temperature at the ith time
Tim = measured temperature at the ith time
n = number of measurements

This value provides an estimate of the average difference between the simulated temperature and the measured temperature.

Results revealed that the model overpredicted the maximum daily temperatures at Sang Run by over 5°C (Figure 2-3 - dashed line); the RMS calibration error was 5.1. The timing of the maximum and minimum temperatures also occurred slightly earlier in the simulation as compared with the measured values. The values of the daily minimum temperature were within about 1°C during non-operating periods on both days of the calibration period. These results indicate that too much heating occurred in the model during the day, probably due to excess short-wave radiation being incorporated into the water column. Since the daily minimum temperatures were approximately correct, other factors in the heatflux equation are probably reasonably well-represented.

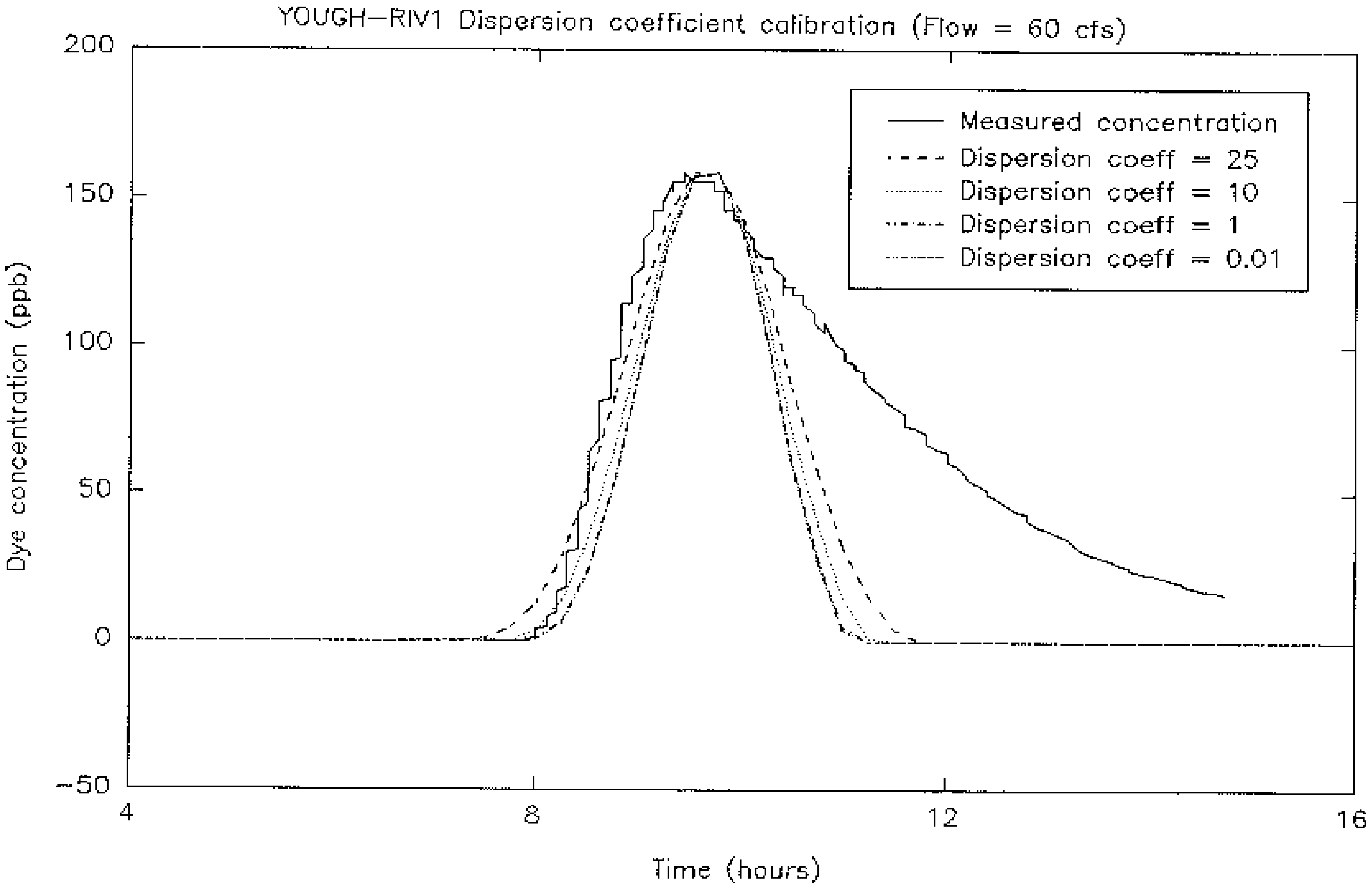

Figure 2-2. YOUGH-RIV1 model dispersion coefficient calibration. Measured dye concentrations at Sang Run during a baseflow period of 60 cfs are compared with model predictions of dye concentration using various values of the dispersion coefficient.

Table 2-6. Input dataset for the RIV1Q water quality model. If the value for CVSLAB is set to zero, the benthic conduction subroutine will not be used. If the value of shflag is set to zero, the shading subroutine will not be used. Other parameters are as described in Environmental Laboratory (1990).

```
YOUGH RIVER MODEL - RIV1Q CALIBRATION: 24H NOGEN; 2H GEN AT 1000; 22-23 JUL 87
 1 MAINSTEM YOUGH - TAILRACE TO SANG
 &CONST ATB=.0, DAWN=7.0, IPLOT=1, IPRINT=4, ITEM=0, KEXT=0.5,
  START=0.0, SUNSET=21.0, CVSLAB=0.68, ZSLAB=50., TDKSLB=0.01,
  shflag=1 &END
24.5
25.
24.5
25.
24.5
25.
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25.
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24.5
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24.5
25.
24.5
25.
24.5
25.
24.5
25.
 2 TAILRACE - POWERHOUSE TO MAINSTEM
 &CONST &END
12.5
100.
12.5
100.
+1,+2/
      48
       4       8      12      16      20      24      28      32      36      40
      44      48      52      56      60      64      68      72      76      80
      84      88      92      96     100     104     108     112     116     120
     124     128     132     136     140     144     148     152     156     176
     196     216     236     240     244     248     252     256
    24.5
    24.6
    24.4
    24.4
```

Table 2-6. Continued

```
    24.1
    23.8
    23.6
    23.5
    23.5
    23.8
    24.4
    25.2
    26.1
    27.0
    27.4
    27.7
    27.2
    26.9
    26.3
    25.8
    25.3
    25.0
    25.0
    24.7
    24.5
    24.4
    24.2
    24.2
    23.7
    23.6
    23.4
    23.4
    23.4
    23.6
    24.1
    24.4
    25.1
    25.6
    26.2
    26.3
    26.3
    26.1
    25.9
    25.8
    25.7
    25.4
    25.1
    25.2
      48
       4         8        12        16        20        24        28        32        36        40
      44        48        52        56        60        64        68        72        76        80
      84        88        92        96       100       104       108       112       116       120
     124       128       132       136       140       144       148       152       156       176
     196       216       236       240       244       248       252       256
    12.3
    12.5
    13.8
    14.3
    13.9
    13.7
    13.6
    13.4
    13.6
```

Table 2-6. Continued

13.4
13.3
13.0
12.9
12.8
12.6
12.6
12.6
12.5
12.5
12.6
12.6
12.5
12.3
12.4
12.3
12.3
12.4
12.5
12.5
12.6
12.4
12.5
12.6
12.6
15.8
15.9
16.4
16.5
16.5
16.4
16.4
16.4
16.3
15.9
14.7
14.0
13.7
13.6

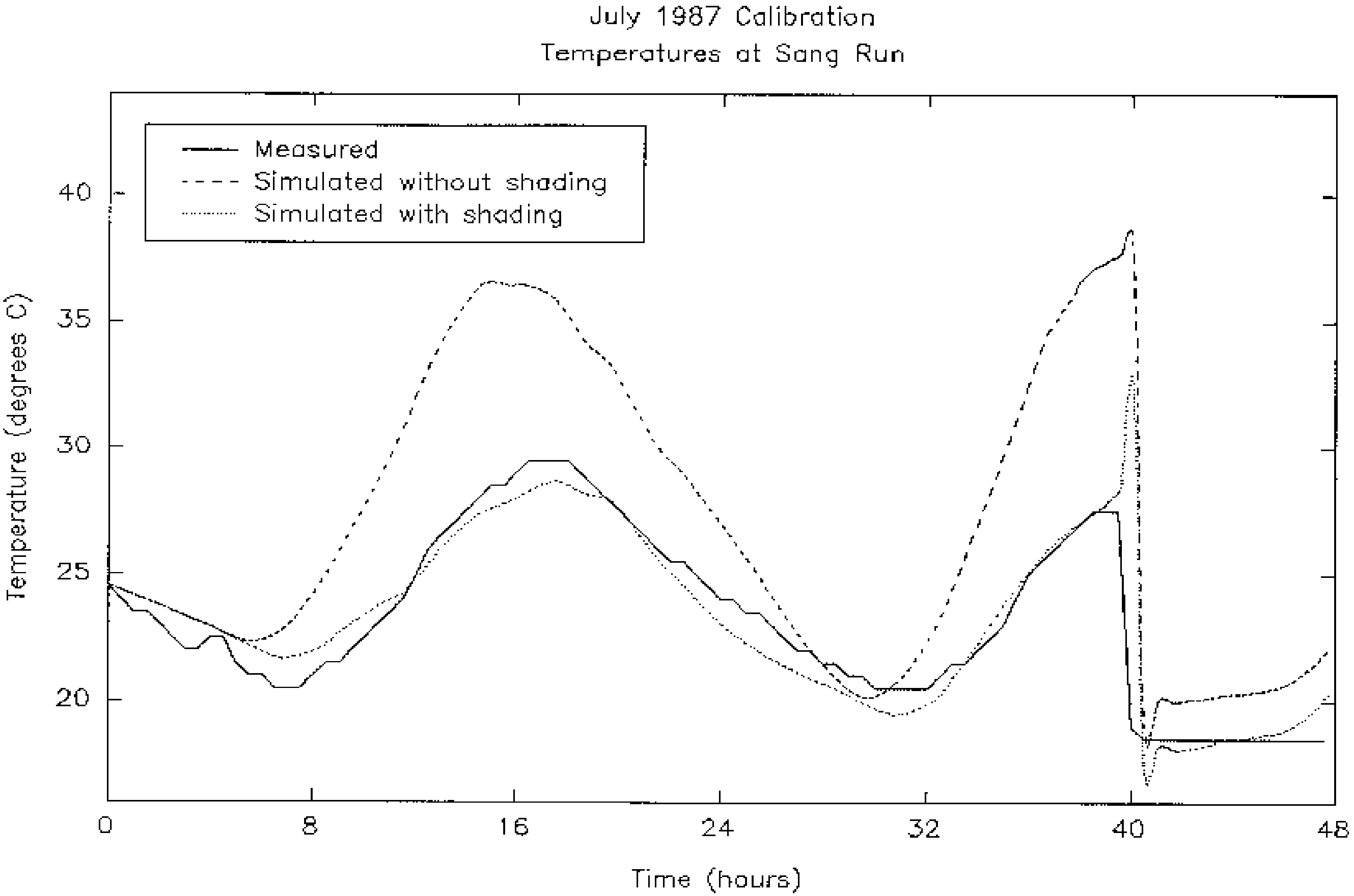

Figure 2-3. YOUGH-RIV1 model calibration comparing measured temperatures at Sang Run and simulated temperatures with and without a shading subroutine

2.2.5 Shading

The basic RIV1Q algorithms do not include simulation of shading due to local topography or vegetation, which are likely important factors influencing the timing and amount of incoming short-wave radiation. A shading algorithm is available in the SNTEMP model (Theurer et al. 1984) and was incorporated into a subroutine for the YOUGH-RIV1 model (Appendix A-1). Supplemental input data for this algorithm include reach azimuth, (angle of the river with respect to a north/south line), topographic altitude angle, vegetation density, height, and diameter, and vegetation offset (distance from stream edge). Reach azimuth and topographic angles were estimated for each node from USGS 15' topographic sheets of the river and surrounding area. Vegetation parameters were estimated for the entire mainstem segment from photographs of various locations within this section of the river. Sensitivity analyses showed that the reach azimuth and topographic altitudes affected model results to a much greater extent than did the vegetation parameters, within reasonably expected values of each. The dataset containing the shading parameters is shown in Table 2-7.

Model results of using the shading subroutine were much closer to observed values (Figure 2-3 - dotted line), with an RMS error value of 1.6. However, there remain large but short-term (less than 1 hour) high and low temperature spikes in the simulated temperature at about 40 hours into the simulation. These spikes occur when the generation flow released on the 2nd day of the calibration period at 1400 hours ST (38 hours into the simulation) reaches Sang Run (node 17). Since measurements were made at half-hour intervals, and the model uses 3 minute timesteps during the release period, some of this phenomenon could have been missed by the field measurements, although they are probably due to numerical instability in the model.

Table 2-7. Input parameters for the YOUGH-RIV1 shading subroutine module. The main segment is listed first, with values for each node within each segment. Parameter names and units of measurement are listed at the bottom of the input file.

```
 1
   0.19     .24     .27    1.      1.     30.     30.    150.    150.      5.      5.      1.
   1.05     .27     .36    1.      1.     30.     30.    150.    150.      5.      5.      1.
   0.14     .25     .26    1.      1.     30.     30.    150.    150.      5.      5.      1.
  -0.51     .12     .28    1.      1.     30.     30.    150.    150.      5.      5.      1.
  -0.4      .42     .26    1.      1.     30.     30.    150.    150.      5.      5.       .5
   0.05     .3      .4     1.      1.     30.     30.    150.    150.      5.      5.       .5
   0.       .27     .38    1.      1.     30.     30.    150.    150.      5.      5.       .5
   0.       .3      .38    1.      1.     30.     30.    150.    150.      5.      5.       .5
  -0.07     .27     .38    1.      1.     30.     30.    150.    150.      5.      5.      1.
   0.03     .27     .24    1.      1.     30.     30.    150.    150.      5.      5.      1.
   0.35     .28     .33    1.      1.     30.     30.    150.    150.      5.      5.      1.
   0.44     .27     .26    1.      1.     30.     30.    150.    150.      5.      5.      1.
  -0.3      .26     .25    1.      1.     30.     30.    150.    150.      5.      5.      1.
  -0.54     .21     .3     1.      1.     30.     30.    150.    150.      5.      5.      1.
  -0.8      .17     .3     1.      1.     30.     30.    150.    150.      5.      5.      1.
  -1.13     .15     .26    1.      1.     30.     30.    150.    150.      5.      5.      1.
  -1.36     .11     .19    1.      1.     30.     30.    150.    150.      5.      5.      1.
 2
   0.       .15     .19    1.      1.     30.     30.    150.    150.      5.      5.      1.
   0.       .15     .19    1.      1.     30.     30.    150.    150.      5.      5.      1.

reach  | east | west | east | west | east | west | east | west | east | west | add'l
azimth | topo angle  | veg density |veg diameter | veg height  | dist fr edge| empir
radians|  (radians)  |  0. - 1.    |   (feet)    |   (feet)    |   (feet)    | fctor
1234567|234567|234567|234567|234567|234567|234567|234567|234567|234567|234567|234567
```

2.2.6 Streambed Conduction

Streambed or benthic conduction may also be an important physical process affecting temperature in the Youghiogheny River which is not simulated by RIV1Q. This process could slow down the rate of heating and cooling in the river since some of the heat transferred to the river water could also enter and be stored in the river bed where it could later be released back to the water column during cooler periods. This energy storage process could be particularly important if cold water released from the project entered the river at mid-day during a time when the baseflow river water and bed was quite warm. Streambed conduction could add additional heat to the colder release water than would otherwise be expected. Conversely, once the river bed is cooled by the release water, the water in the river will heat up more slowly after the end of a release.

A streambed conduction algorithm presented by Jobson (1977) was incorporated into a subroutine for RIV1Q (Appendix A-2). This procedure is suitable for a dynamic temperature model and does not require temperature measurements in the river bed. It does require terms for thermal diffusivity and heat storage capacity of the bed material and suggested values are provided by the author for several types of riverine systems. Summarizing from Jobson (1977), the bed is considered to be a homogenous medium insulated on the lower face and with the upper face always having a temperature equal to that of the overlying water. The heatflux into or out of the bed is then determined as a function of the water temperature history. The thermal diffusivity (TDKSLB), heat storage capacity (CVSLAB), and thickness (ZSLAB) of the bed material are the only required parameters.

Initial values for these parameters were selected from a range of typical values in Jobson (1977) and a sensitivity analysis was performed to determine values which provided the best fit to the calibration data (Figure 2-4). The best parameter values were when TDKSLB = 0.68 cm^2/sec, CVSLAB = 0.01 cal/cm^3*deg, and ZSLAB = 50 cm. The RMS calibration error value decreased to 1.5. Although this was only a slight improvement during steady-state conditions, spike values which occurred during the release period were reduced by 1 to 2 degrees C. However, peak temperature for the first 24-hour period was nearly 2 degrees too low and a 4 degree temperature spike still occurred just prior to the arrival of the cool release water at node 17.

2.2.7 Final Calibration

Additional factors that could affect the prediction accuracy include the use of non-local meteorological data and error due to insufficient details of the physical geometry. Perhaps the major heatflux parameter (other than short-wave radiation as influenced by shading) that could be affected by the use of non-local data is the rate of evaporation. This factor is calculated based on the difference between the dry-bulb air temperature and the dew-point temperature. It is reasonable to assume that humidity levels at a river in a primarily wooded area to be somewhat higher than in an open, non-wooded area such as near Morgantown airport where the meteorological data were collected. Therefore, evaporation rates might be somewhat lower at the river than the rates calculated from dew-point temperatures at Morgantown airport. To account for this possible difference, the dew-point temperatures obtained from Morgantown

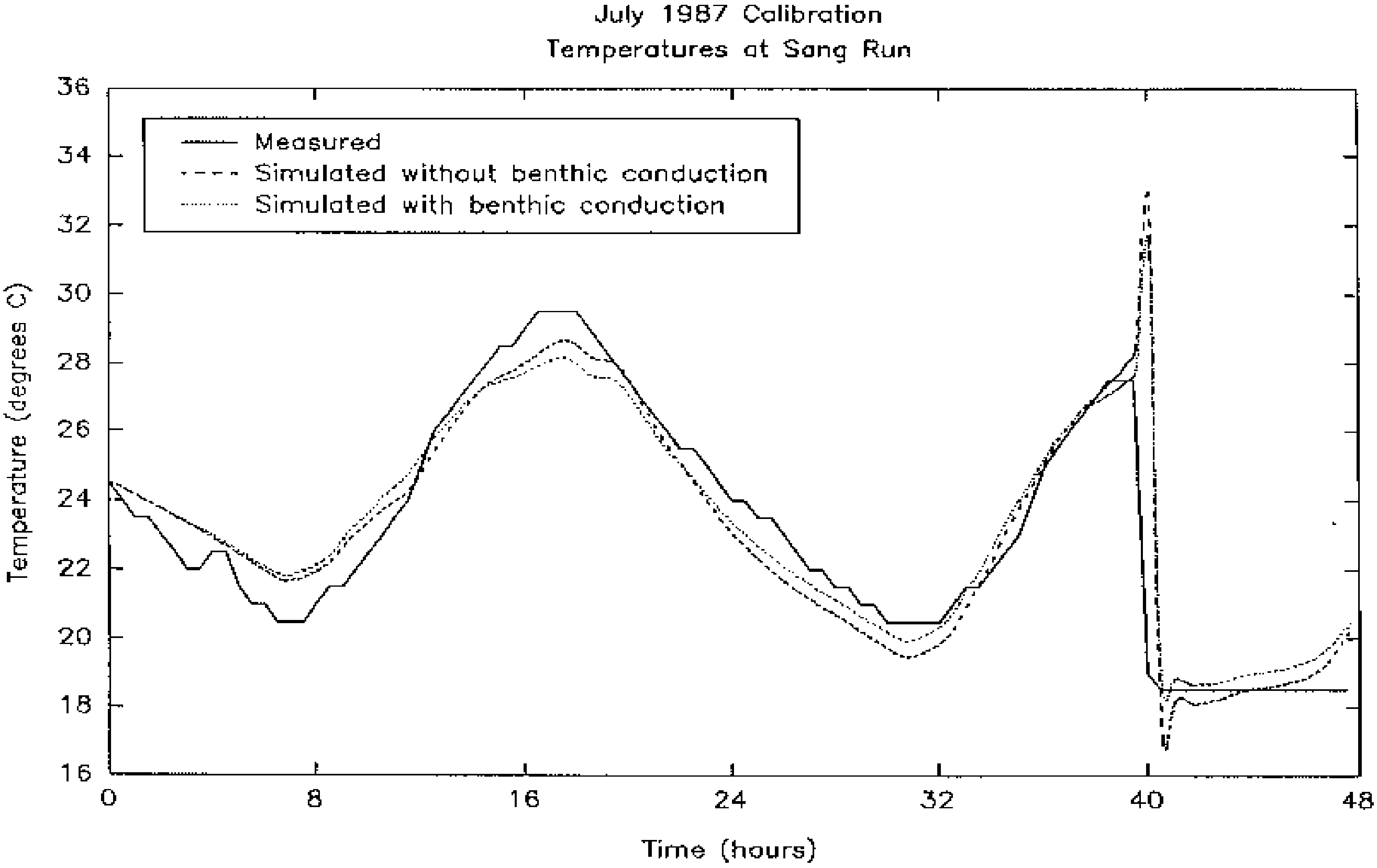

Figure 2-4. YOUGH-RIV1 model calibration comparing temperatures at Sang Run and simulated temperatures with a shading subroutine and with and without benthic conduction.

were adjusted so that the difference between the dry-bulb and dew-point temperature was reduced by various percentages from 10 to 50%. The best value appeared to be a 25% reduction in this temperature difference (Figure 2-5). This value is consistent with Bartholow (1991) who found that relative humidity levels had to be increased by 20% over recorded values to account for humidity near the river. Steady-state prediction values were improved but the overall RMS error increased slightly for node 17 because the spike value following release was increased slightly, probably due to increased upstream temperatures.

Temperatures at some upstream nodes were 3 to 4°C higher than at node 17. Although the only location for which measured data was available for the calibration set was at node 17, these higher upstream temperatures were likely not realistic. The reason for this difference is not clear but may be due to inaccurate estimates of river width, increasing the amount of short-wave radiation which could enter the river. To compensate for this effect in the absence of more precise field information, total short-wave radiation entering the middle of the mainstem segment was reduced by various percentages to obtain the best fit with observed data. The best values were obtained by reducing the short-wave radiation entering nodes 5-8 by 50% at each time step (Figure 2-6).

The best calibration for the YOUGH-RIV1 model is shown in Figure 2-7; Root Mean Square (RMS) calibration errors for the various improvements made to the basic model are shown in Table 2-8. Temperature predictions for various nodes of the river are shown in Figure 2-8.

Table 2-8. Root Mean Square (RMS) Error Estimates for the YOUGH-RIV1 model calibration factors using the July 22-23, 1987 dataset. Features were added successively. RMS values without spike were determined by excluding temperatures at approximately 40 hours elapsed time.

Calibration Feature	Total RMS	RMS Without Spike
Basic Model	5.10	4.73
Add Shading Subrouting	1.62	0.78
Add Benthic Conduction	1.54	0.82
Adjust Dew-point Temperature	1.56	0.71
Adjust Shading Factors	1.37	0.75

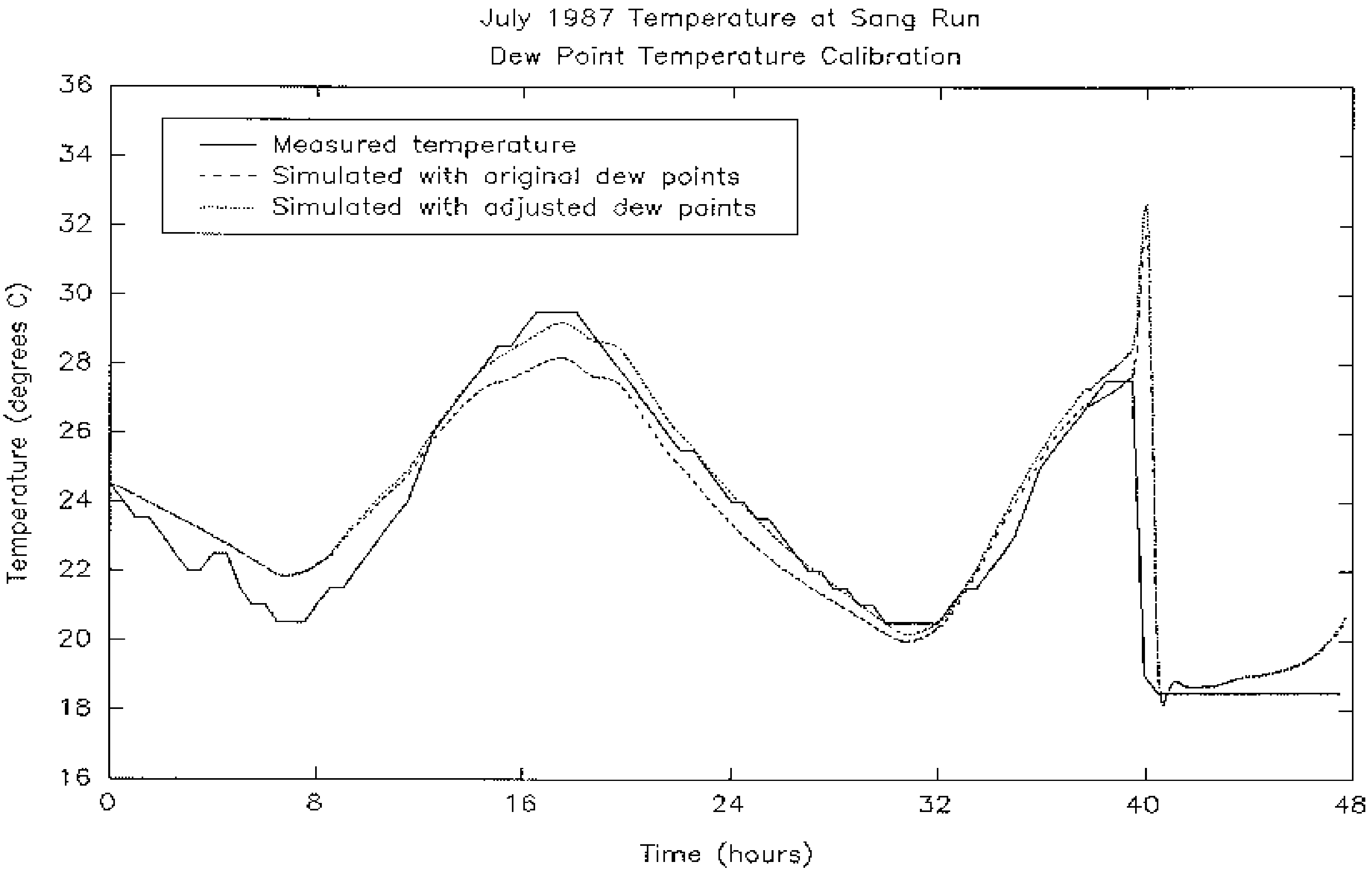

Figure 2-5. YOUGH-RIV1 model calibration comparing temperatures at Sang Run and simulated temperatures with shading and benthic conduction subroutines and with original and adjusted dew point temperatures. The difference in dew point and dry bulb temperatures (measured at Morgantown Airport) were adjusted to 75% of their original values for each hourly interval.

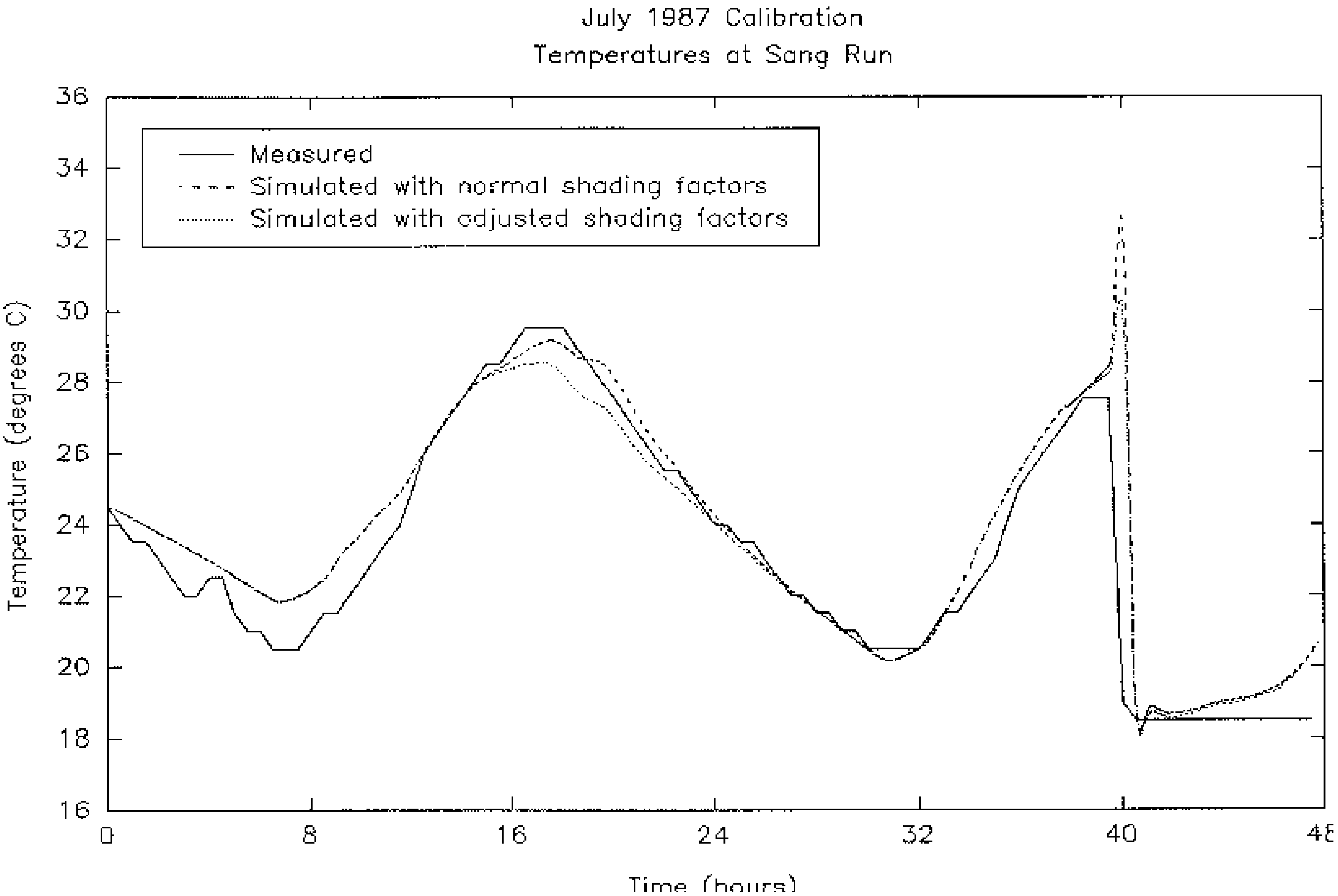

Figure 2-6. YOUGH-RIV1 model calibration comparing temperatures at Sang Run and simulated temperatures with shading and benthic conduction subroutines, adjusted dew point temperatures and with original and adjusted shading factors.

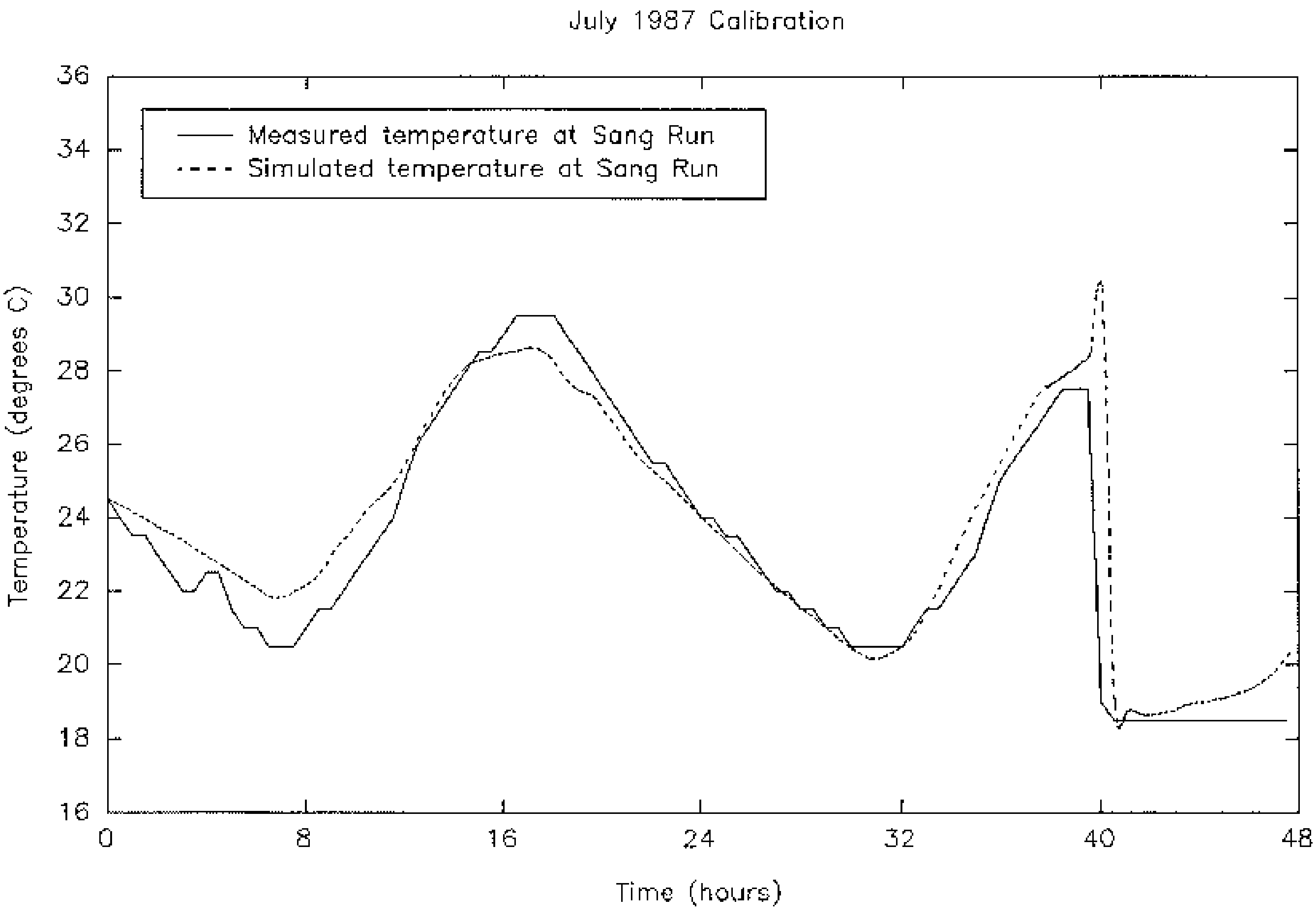

Figure 2-7. Final YOUGH-RIV1 model calibration comparing measured and simulated temperatures at Sang Run

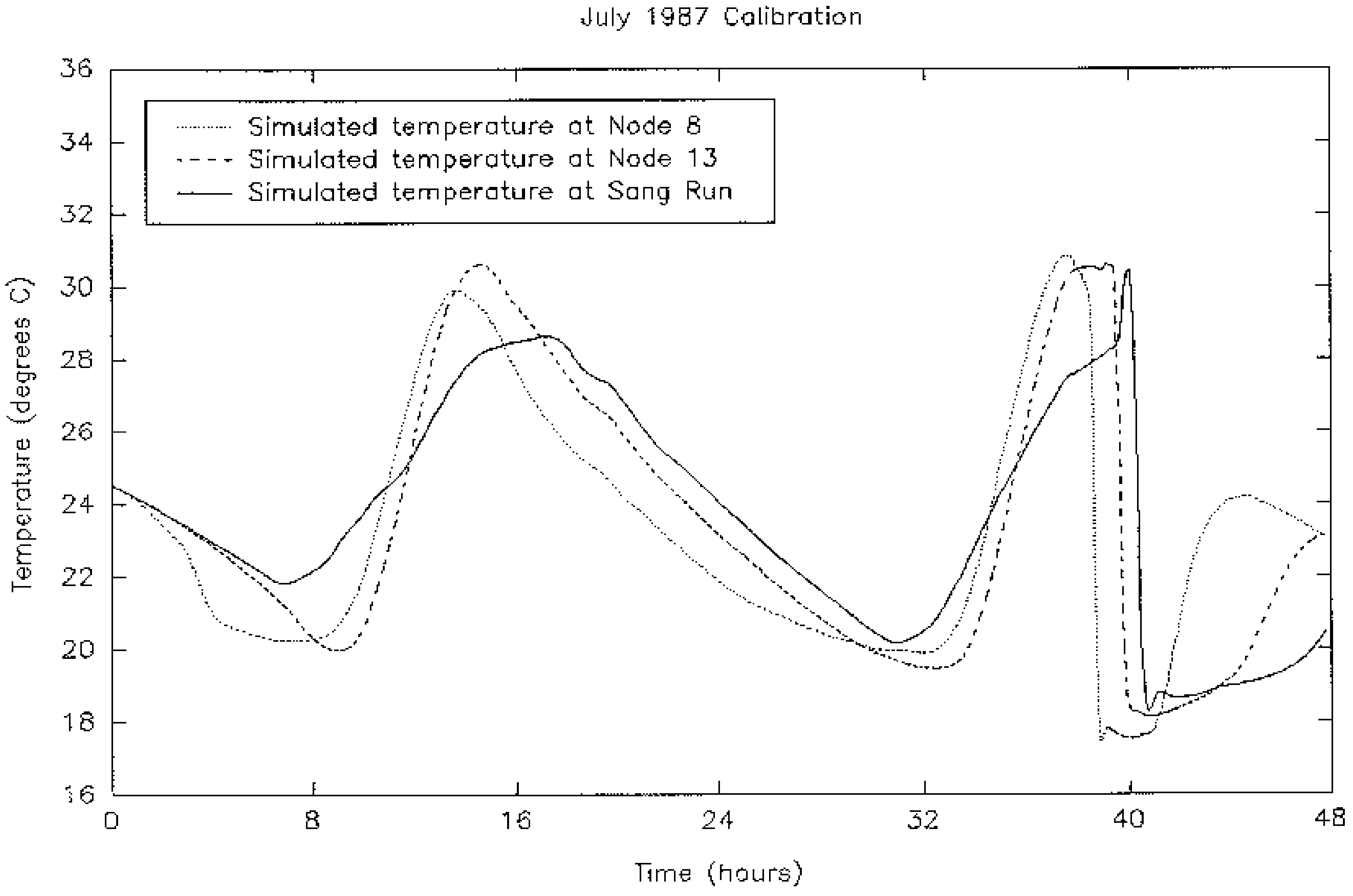

Figure 2-8. Final YOUGH-RIV1 model calibration temperatures for node 8 (1.4 miles downstream of tailrace), node 13 (2.4 miles downstream of tailrace), and node 17 (Sang Run, 3.6b miles downstream of the tailrace)

Components of the heatflux calculations, shading factors, and river temperature for the calibration period for nodes 8 and 17 are illustrated in Figures 2-9 and 2-10, respectively. Two major points are illustrated in these figures. First, short-wave radiation (direct solar radiation entering the river) is the component of the heatflux computations which changes most during the diurnal cycle. Evaporation is the component with the second largest diurnal fluctuation. Streambed conduction is primarily important during rapid changes in temperature; such a change occurs as a result of a generation release of a large volume of cold water at mid-day. Second, the shape of the change in the shading factor curve during the day is quite different for different nodes of the river, being affected primarily by the orientation of the river with respect to the sun and the local topography.

2.2.8 Model Verification

Temperature data collected in 1991 were used to check model predictions against an independent dataset. July 25-26, 1991 was a time period of low flows and relatively warm conditions. The first day of this period had no project operation and a baseflow of approximately 25 cfs. The second day of this period contained a two-turbine release of 2 hours commencing at 1000 hours ST. The same model parameters and factors used with the calibration dataset were used with the verification dataset. Only the meteorological dataset and the baseflow values for the verification time period were changed. Results for each of 3 nodes at which measured data were available for comparison are shown in Figures 2-11 through 2-13. RMS error values for these nodes are listed in Table 2-9. They are somewhat higher than for the calibration set at least partially due to a release which occurred prior to the simulation period (for 17 minutes commencing at 2005 ST on July 24). This release cooled the river below expected values which were not included in the simulation initialized with upstream boundary condition temperature values. Peak temperature values for the first day of the verification simulation are quite close for nodes 8 and 13 but about 2°C cooler for node 17 at Sang Run. The reason for these differences is unknown. The response at each node following the project release is reasonably close in timing of the temperature drop and minimum value but the response following the return to baseflow seems to be somewhat higher and more rapid in the simulation than was actually measured. This suggests that the model is either transporting water too rapidly from the system following the release, or that the river bed acts as a greater buffer than is actually being simulated. Overall results suggest

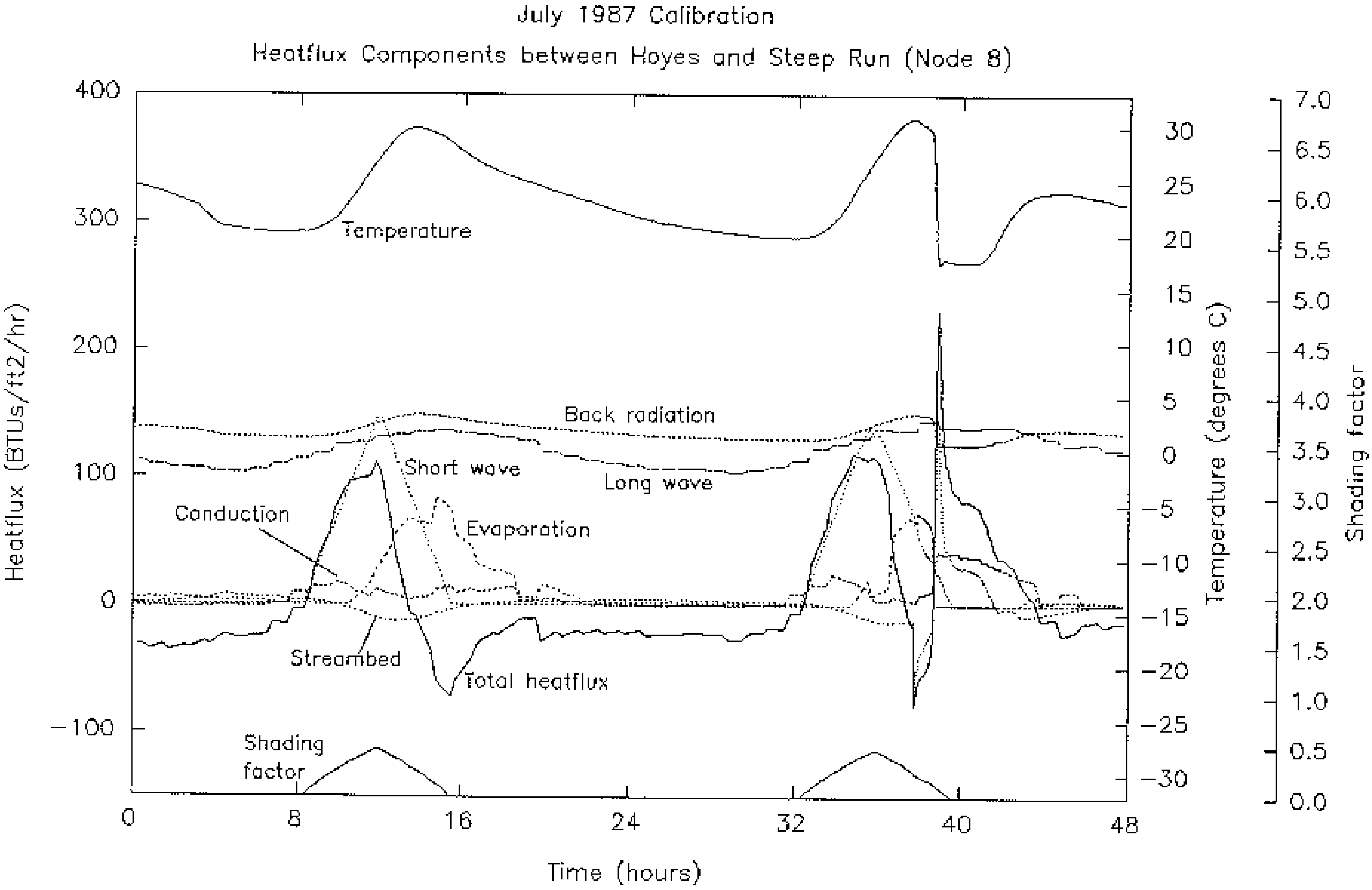

Figure 2-9. Final YOUGH-RIV1 model calibration for node 8, showing heatflux components, water temperature, and shading factors. Reach azimuth is 0 radians or 0 degrees with respect to a north/south line; east and west topographic angles are 0.3 and 0.38 radians (17 and 22 degrees), respectively.

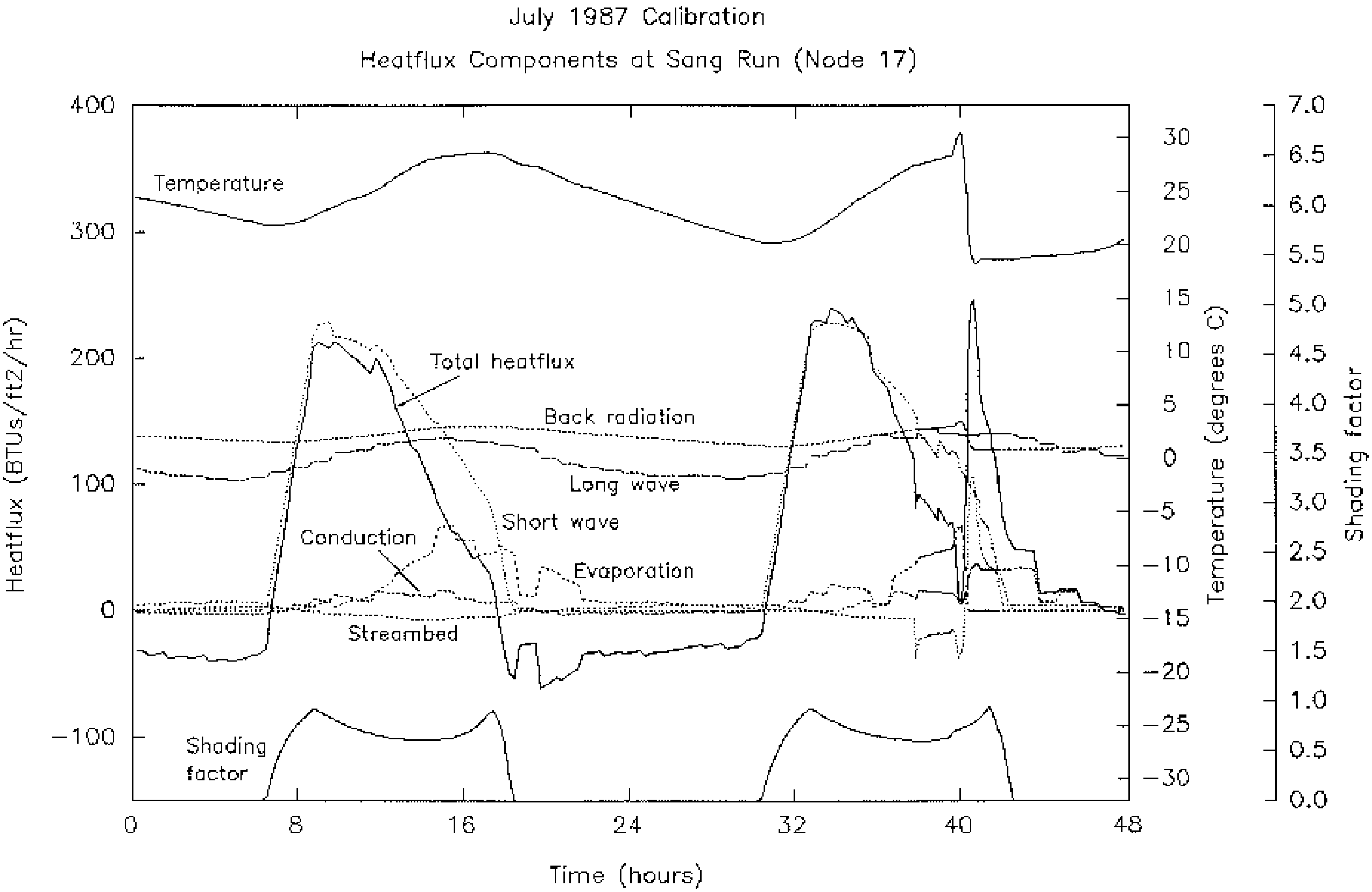

Figure 2-10. Final YOUGH-RIV1 model calibration for node 17, showing heatflux components, water temperature, and shading factors. Reach azimuth is -1.36 radians or 78 degrees west of north; east and west topographic angles are .11 and .19 radians (6 and 11 degrees), respectively.

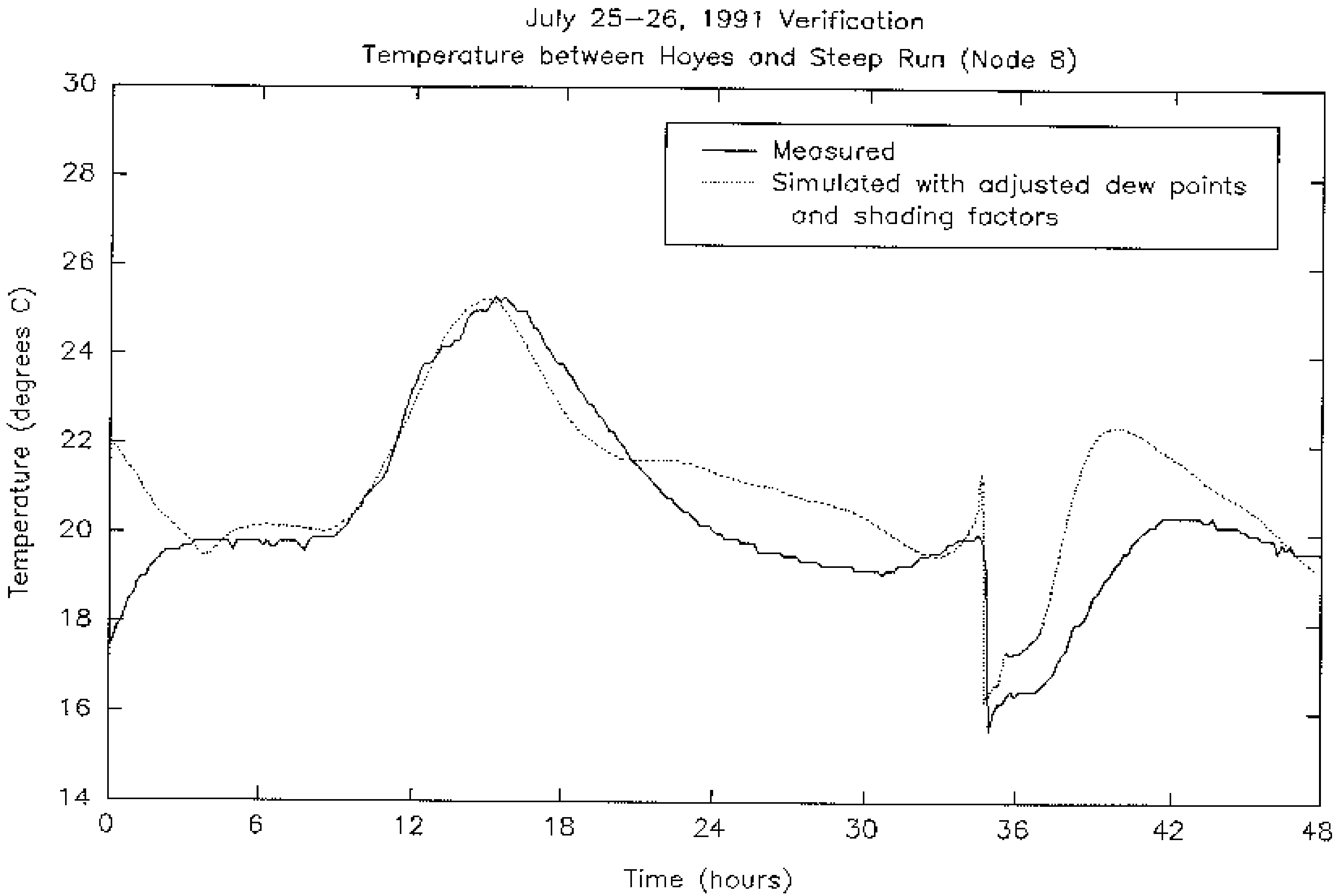

Figure 2-11. YOUGH-RIV1 model verification on July 25-26, 1991, comparing measured and simulated temperataures at node 8 (1.4 miles downstream from the tailrace).

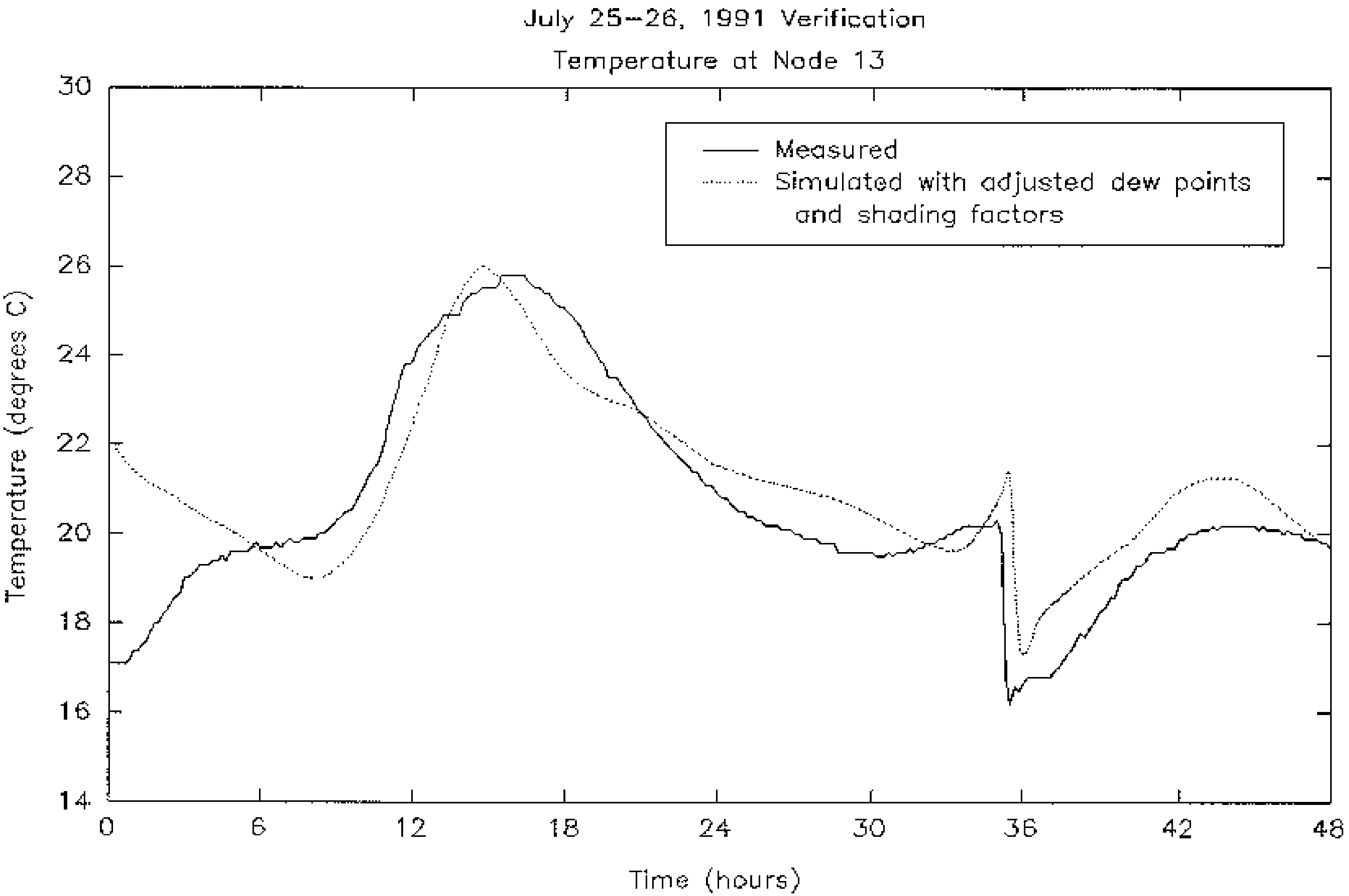

Figure 2-12. YOUGH-RIV1 model verification on July 25-26, 1991, comparing measured and simulated temperatures at node 13 (2.4 miles downstream from the tailrace).

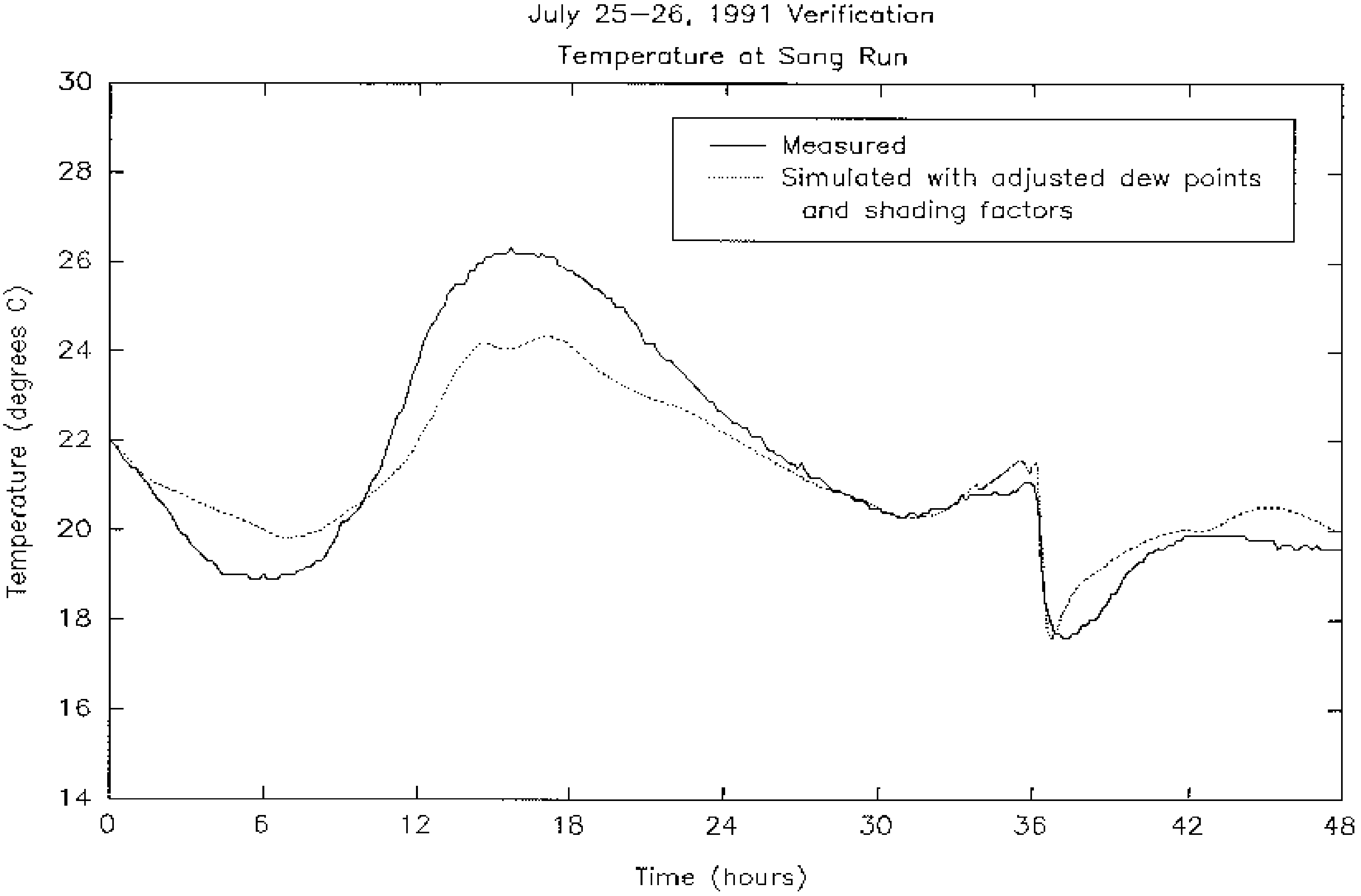

Figure 2-13. YOUGH-RIV1 model verification on July 25-26, 1991, comparing measured and simulated temperatures at node 17 (Sang Run, 3.6 miles downstream from the tailrace).

that the model will produce environmentally conservative predictions for a worst-case temperature prediction, i.e., the model will predict slightly more water to be required to achieve a desired temperature goal than may actually be the case. Further improvements to the model would require more detailed cross-section geometry, canopy data and hydraulic travel time measurements over an appropriate range of flows.

Table 2-9. Root Mean Square (RMS) Error Estimates for the YOUGH-RIV1 model verification dataset (July 25-26, 1991) for nodes at which measured data were available

Node	RMS Error
8	1.28
13	1.39
17	0.99

3.0 SIMULATIONS OF ALTERNATIVE RELEASE SCENARIOS

In their draft relicense application, Penelec proposed a 40 cfs minimum flow for physical habitat enhancement and use of generation releases for enhancement of habitat temperature when necessary. Since two turbines are available, each with approximately 315 cfs capacity, a one or a two-turbine release for temperature control is feasible. However, white-water recreation interests require a two-turbine release during low-flow periods to provide for sufficient flow. Preliminary recommendations by MDNR on Penelec's draft license application were for a minimum flow of 60 cfs at all times and use of additional low level (probably non-power generating) flows for temperature enhancement when necessary during summer months.

To evaluate the flow required to provide temperature enhancement, the same time period used for the calibration run was used to simulate various release scenarios. These simulations should be representative of requirements under worst-case flow and temperature conditions. Mainstem upstream boundary conditions for temperature were the same as for the calibration period. Tailrace boundary conditions for temperature were set to 13.5°C for low flow (<100 cfs) additions and 16.5°C for generation release flow additions. These values are reasonably representative of these release conditions for mid-July. The values would be a degree C or so lower earlier in the summer and a degree C or so higher later in the summer.

Figures 3-1 and 3-2 illustrate simulation results at Sang Run and node 13 for the July 22-23, 1987 dataset using various low-flow additions. The 7 cfs leakage-only flow represents existing conditions when the project is not operating; results for the first 24-hours of the simulation for this release scenario are identical to the calibration results. The constant 1 cfs scenario represents a result with the presence of a minimal leakage flow. Other low-flow release scenarios included: 1) a constant 40 cfs continuously (for a total river flow of 77 cfs continuously downstream of the tailrace); 2) 70 cfs for 10 hours starting at 0700 ST (107 cfs in the river during the release period, 44 cfs otherwise); and 3) 100 cfs for 10 hour starting at 0700 ST (137 cfs during the release period and 44 cfs otherwise). These results indicate that 100 cfs for 10 hours would be required for this worst-case condition to maintain river

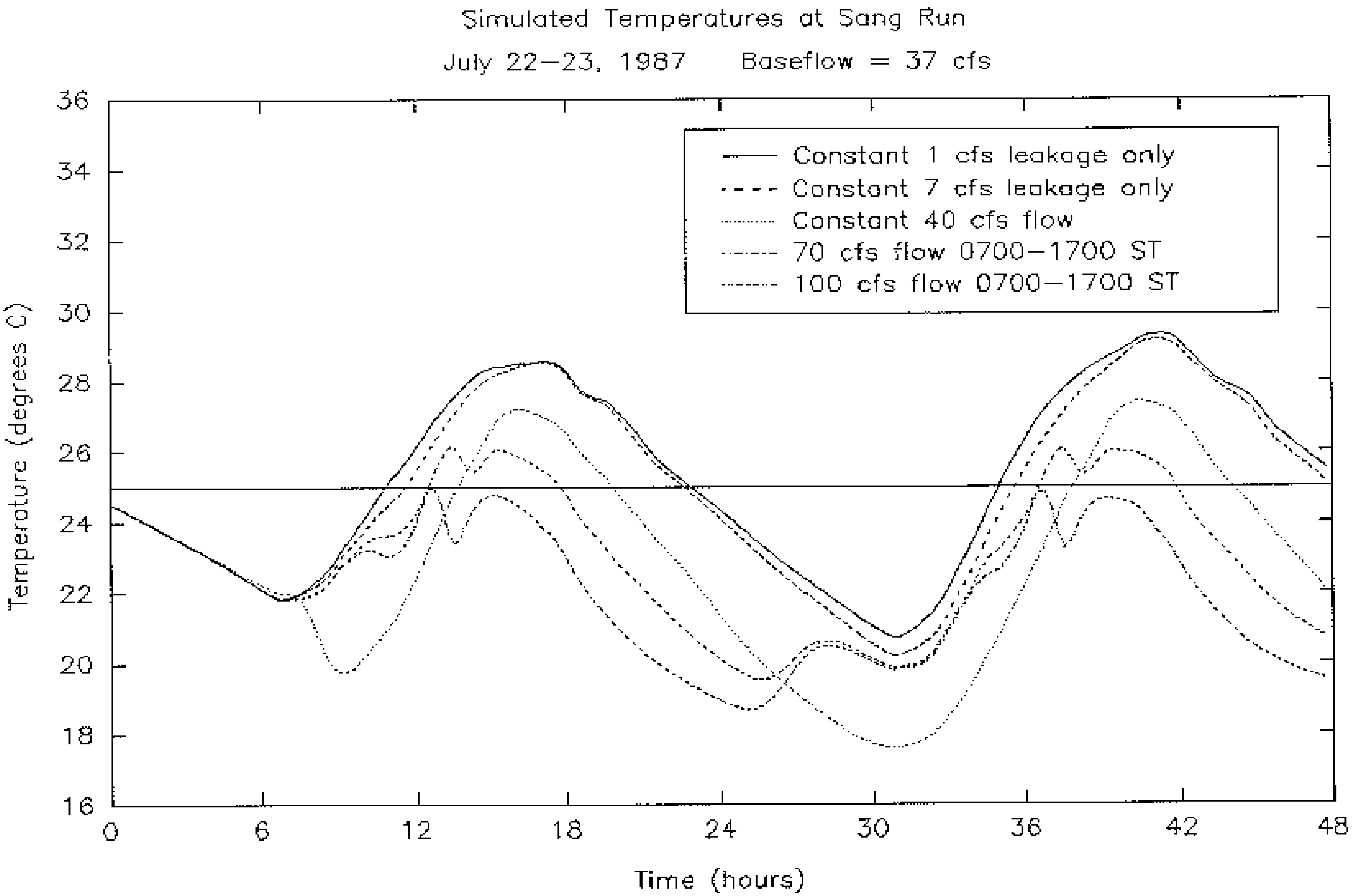

Figure 3-1. YOUGH-RIV1 model simulations for July 22-23, 1987, at Sang Run, with an upstream baseflow of 37 cfs and various supplemental low flows from the tailrace.

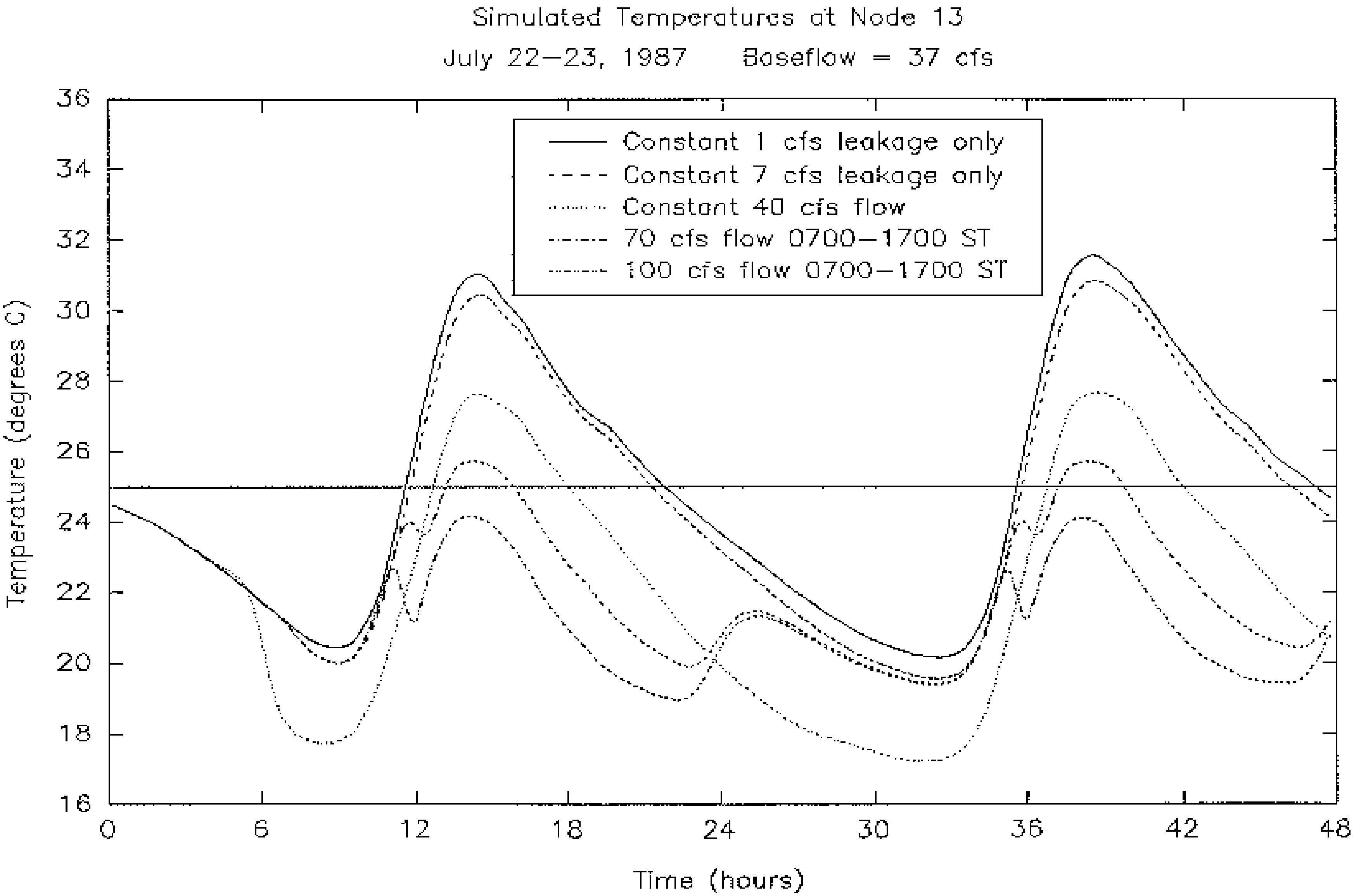

Figure 3-2. YOUGH-RIV1 model simulations for July 22-23, 1987, at node 13, with an upstream baseflow of 37 cfs and various supplemental low flows from the tailrace.

temperatures less than 25°C at all times. A summary of the maximum and average temperatures for these scenarios is presented in Table 3-1.

Table 3-1. Maximum and average temperatures predicted with YOUGH-RIV1 for simulations of the Youghiogheny River with various supplementary discharge flows. Simulation period: July 23, 1987, 37 cfs upstream baseflow.

	Node 17 (Sang Run) Temperature C		**Node 13 Temperature C**	
Simulation Tailrace Flow	**Maximum**	**Average**	**Maximum**	**Average**
LOW FLOW SUPPLEMENTS				
1 cfs only	29.3	25.2	31.6	25.0
7 cfs only	29.2	24.8	30.8	24.4
add 40 cfs	27.4	22.1	27.7	21.5
add 70 cfs 0700-1700 ST	26.1	22.4	25.7	21.8
add 100 cfs 0700-1700 ST	24.9	21.4	24.1	20.9
GENERATION FLOW				
7 cfs during non-generation				
630 cfs 1000-1100 ST	25.8	23.4	26.3	22.4
630 cfs 1000-1200 ST	25.3	22.3	25.3	21.5
40 cfs during non-generation				
630 cfs 1000-1100 ST	25.2	21.1	25.5	20.4
630 cfs 1000-1200 ST	24.1	20.5	24.2	19.9

The effect of generation releases for 1 to 2 hours commencing at 1000 hours ST, with the 7 cfs leakage flow from the tailrace at other times, are illustrated for Sang Run and node 13 in Figures 3-3 and 3-4. It appears that a one-hour release is almost as effective at keeping the maximum temperature less than 25°C as a two-hour release. (The temperature peak which occurs just prior to the release flow reaching Sang Run is probably exaggerated, based on the verification results shown in Figures 2-11 to 2-13). There is a considerable lowering of average temperature when a 40 cfs additional flow is maintained continuously, with generation flows for short periods of time each day (Figures 3-5 and 3-6). However, peak temperatures are only slightly decreased (Table 3-1).

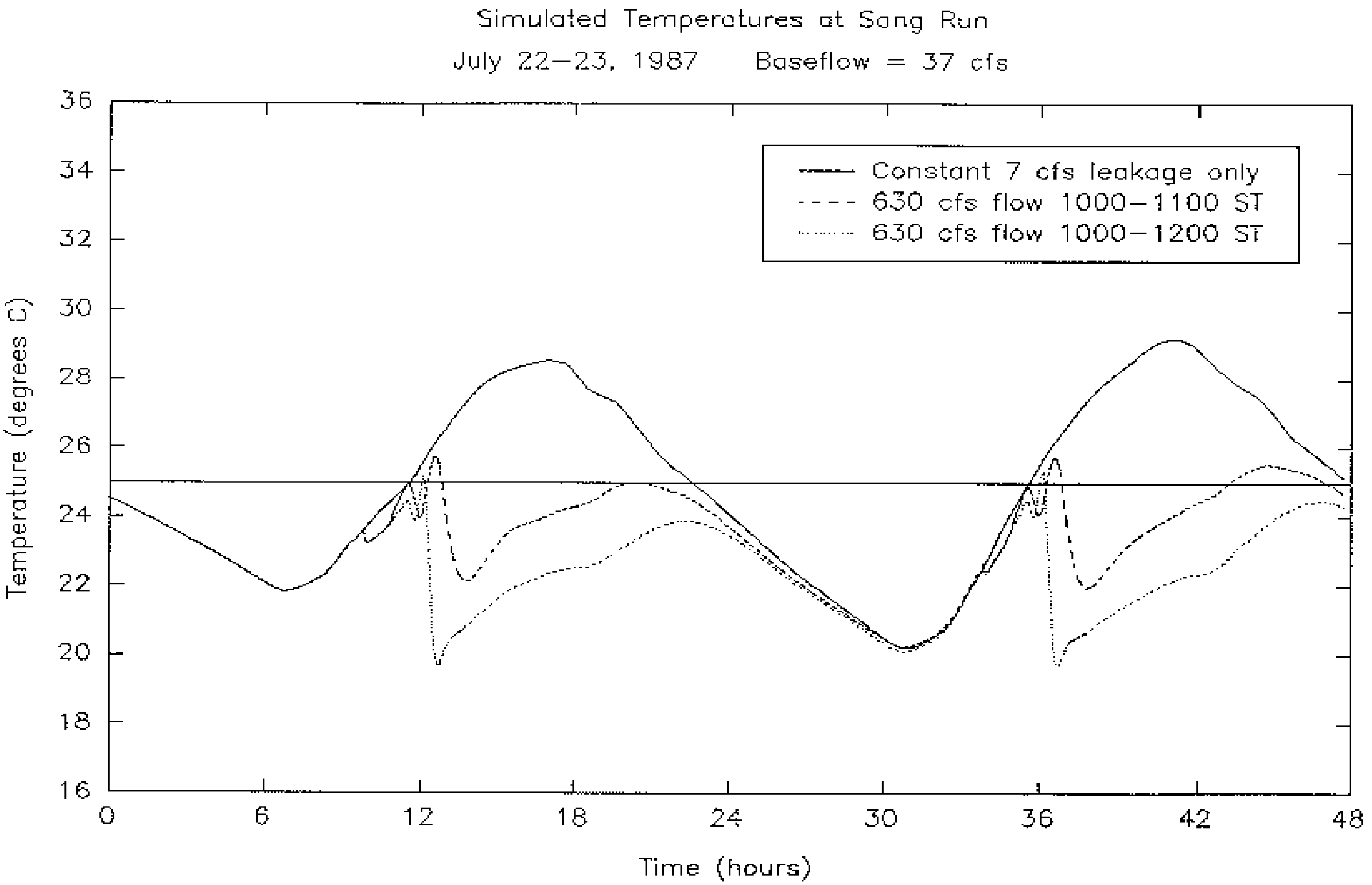

Figure 3-3. YOUGH-RIV1 model simulations for July 22-23, 1987, at Sang Run, with an upstream baseflow of 37 cfs and a tailrace flow of 7 cfs, alone and in combination with generation flows of 1 hour each day from 10-11 ST or 2 hours each day from 10-12 ST.

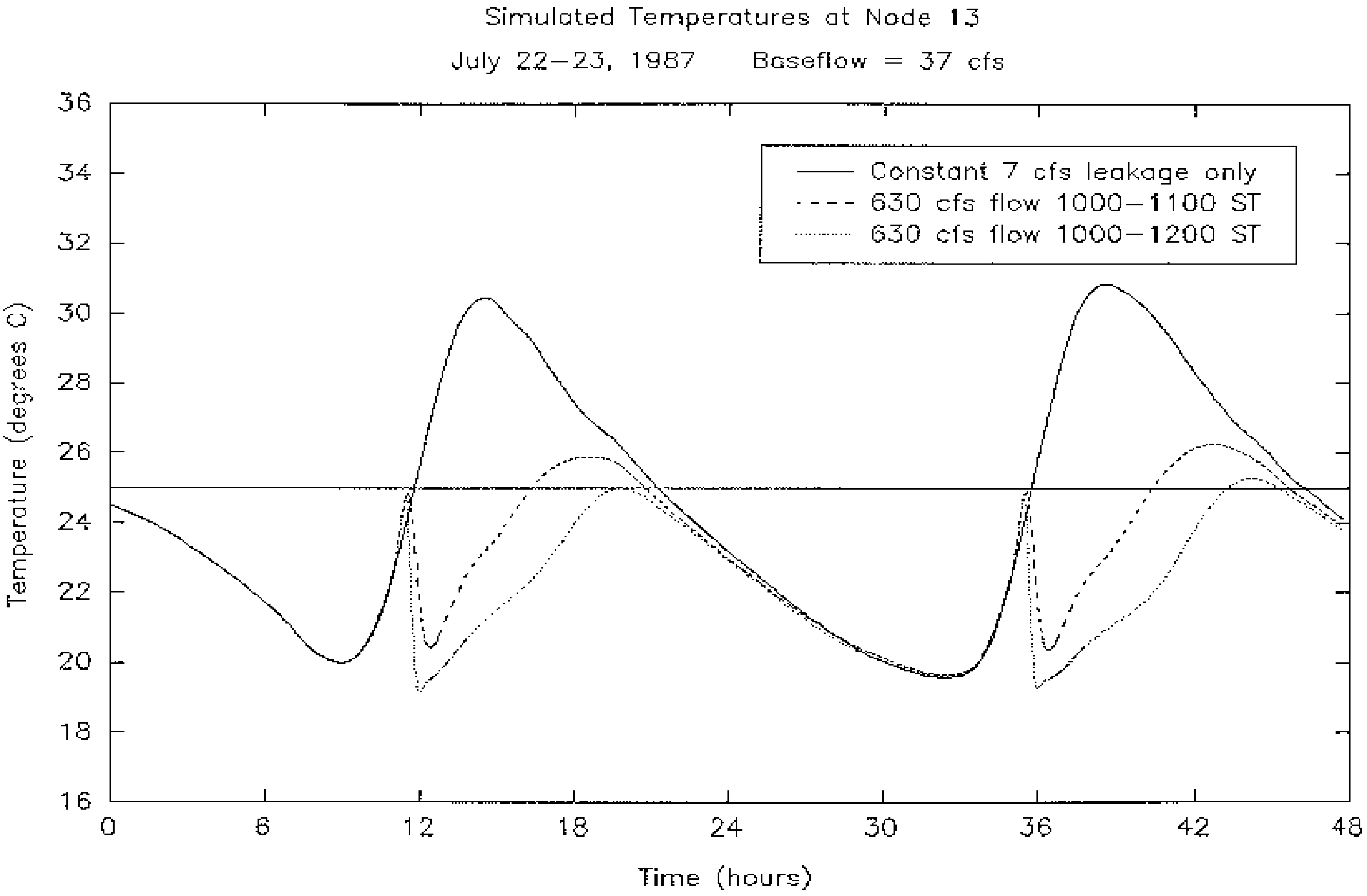

Figure 3-4. YOUGH-RIV1 model simulations for July 22-23, 1987 at node 13, with an upstream baseflow of 37 cfs and a tailrace flow of 7 cfs, alone and in combination with generation flows of 1 hour each day from 10-11 ST or 2 hours each day from 10-12 ST.

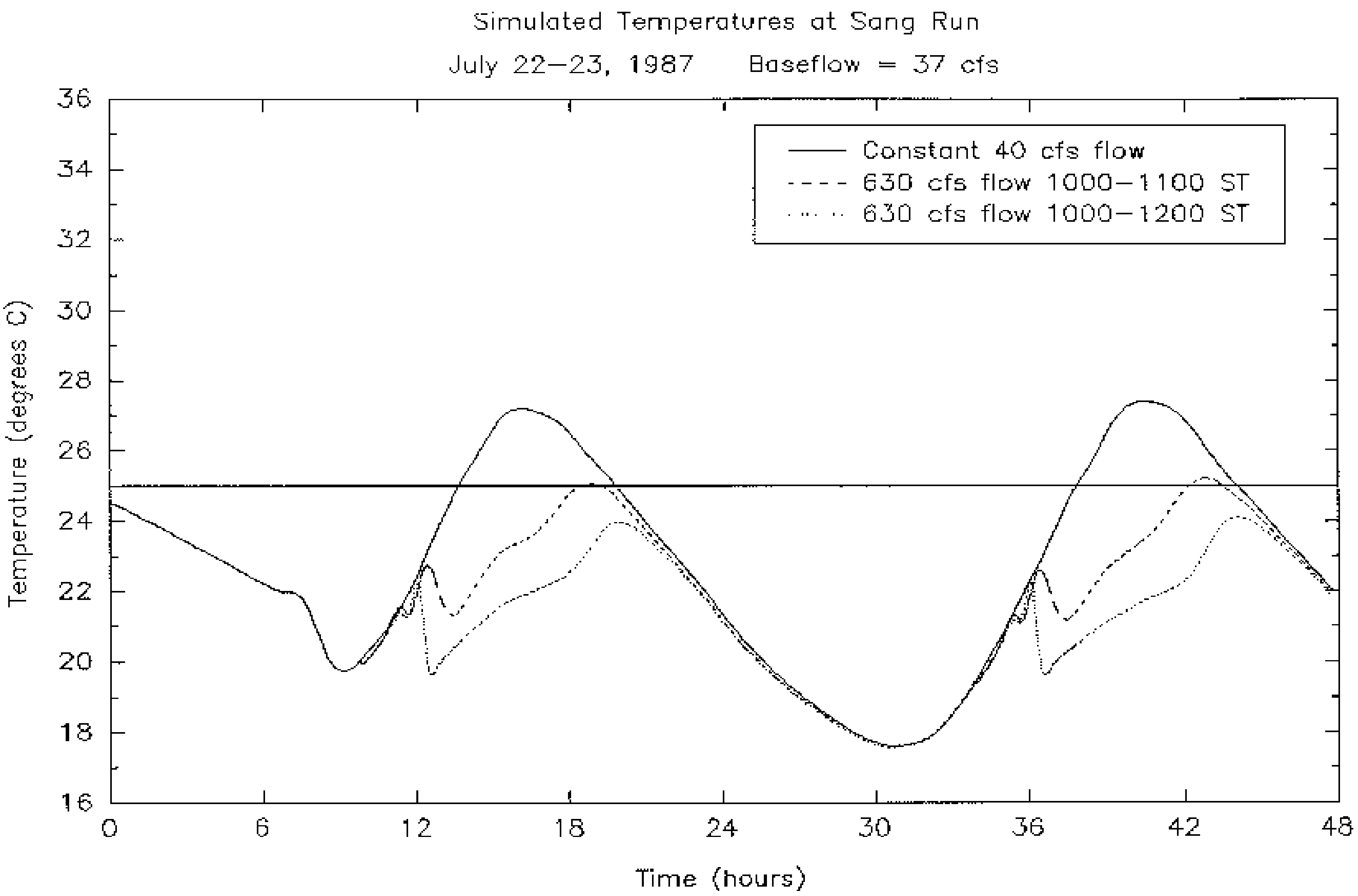

Figure 3-5. YOUGH-RIV1 model simulations for July 22-23, 1987, at Sang Run, with an upstream baseflow of 37 cfs and a tailrace flow of 40 cfs, alone and in combination with generation flows of 1 hour each day from 10-11 ST or 2 hours each day from 10-12 ST.

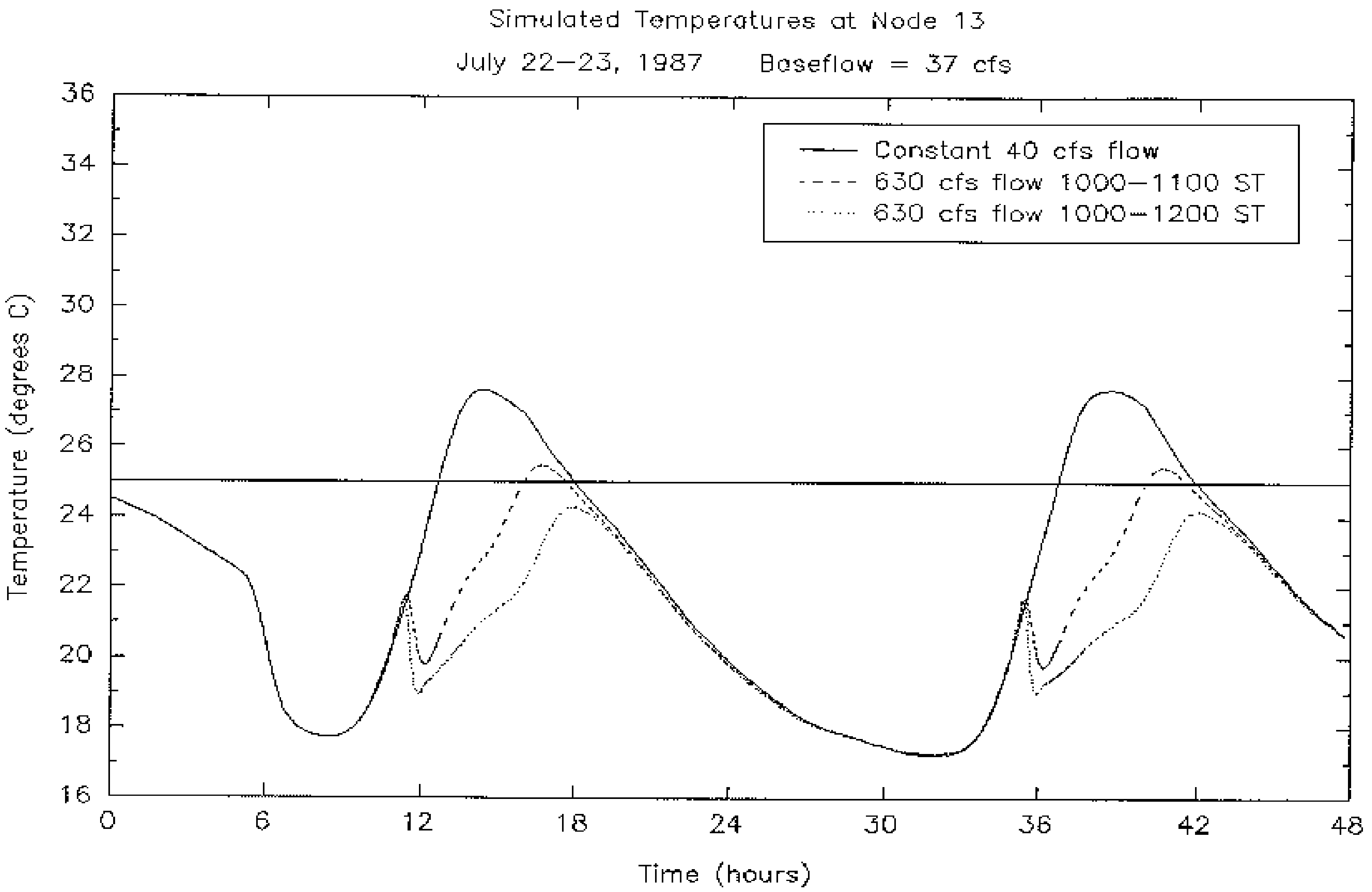

Figure 3-6. YOUGH-RIV1 model simulations for July 22-23, 1987, at node 13, with an upstream baseflow of 37 cfs and a tailrace flow of 40 cfs, alone and in combination with generation flows or 1 hour each day from 10-11 ST or 2 hours each day from 10-12 ST.

The effect of various minimum flow release scenarios under different baseflow conditions is illustrated next. The calibration datasets were used as above, but the baseflow values were set to 20 and 25 cfs. Temperature responses in the river for baseline conditions (7 cfs leakage flow only), and while maintaining a 40 cfs and 60 cfs minimum flow are illustrated in Figures 3-7 and 3-8. Average and maximum temperatures (Table 3-2) are lowest with a baseflow of 20 cfs due to the fact that less of the warmer baseflow water needs to be diluted with the cooler released water. Intermediate temperatures are found at 25 cfs baseflow, as compared with the original 37 cfs baseflow scenario.

Table 3-2. Maximum and average temperatures predicted with YOUGH-RIV1 for simulations of the Youghiogheny River with various minimum and generation discharge flows. Simulation period: July 23, 1987, various upstream baseflows.

	Node 17 (Sang Run) Temperature C		**Node 13 Temperature C**	
Simulation Tailrace Flow	**Maximum**	**Average**	**Maximum**	**Average**
Baseflow = 20 cfs				
40 cfs minimum	28.1	23.5	29.5	22.7
60 cfs minimum	27.2	21.7	27.6	20.9
Baseflow = 25 cfs **40 cfs minimum**				
minimum only	28.5	24.0	30.0	23.4
+ 630 cfs 10-11 ST	25.2	22.6	25.9	21.5
+ 630 cfs 10-12 ST	24.1	21.7	24.9	20.7
Baseflow = 25 cfs **60 cfs minimum**				
minimum only	27.5	22.2	28.0	21.4
+ 630 cfs 10-11 ST	25.2	21.0	25.5	20.2
+ 630 cfs 10-12 ST	24.1	20.4	24.3	19.7
Baseflow = 37 cfs **60 cfs minimum**				
minimum only	28.4	23.4	29.2	22.9
+ 630 cfs 10-11 ST	25.5	22.2	25.9	21.3
+ 630 cfs 10-12 ST	24.4	21.4	24.8	20.7

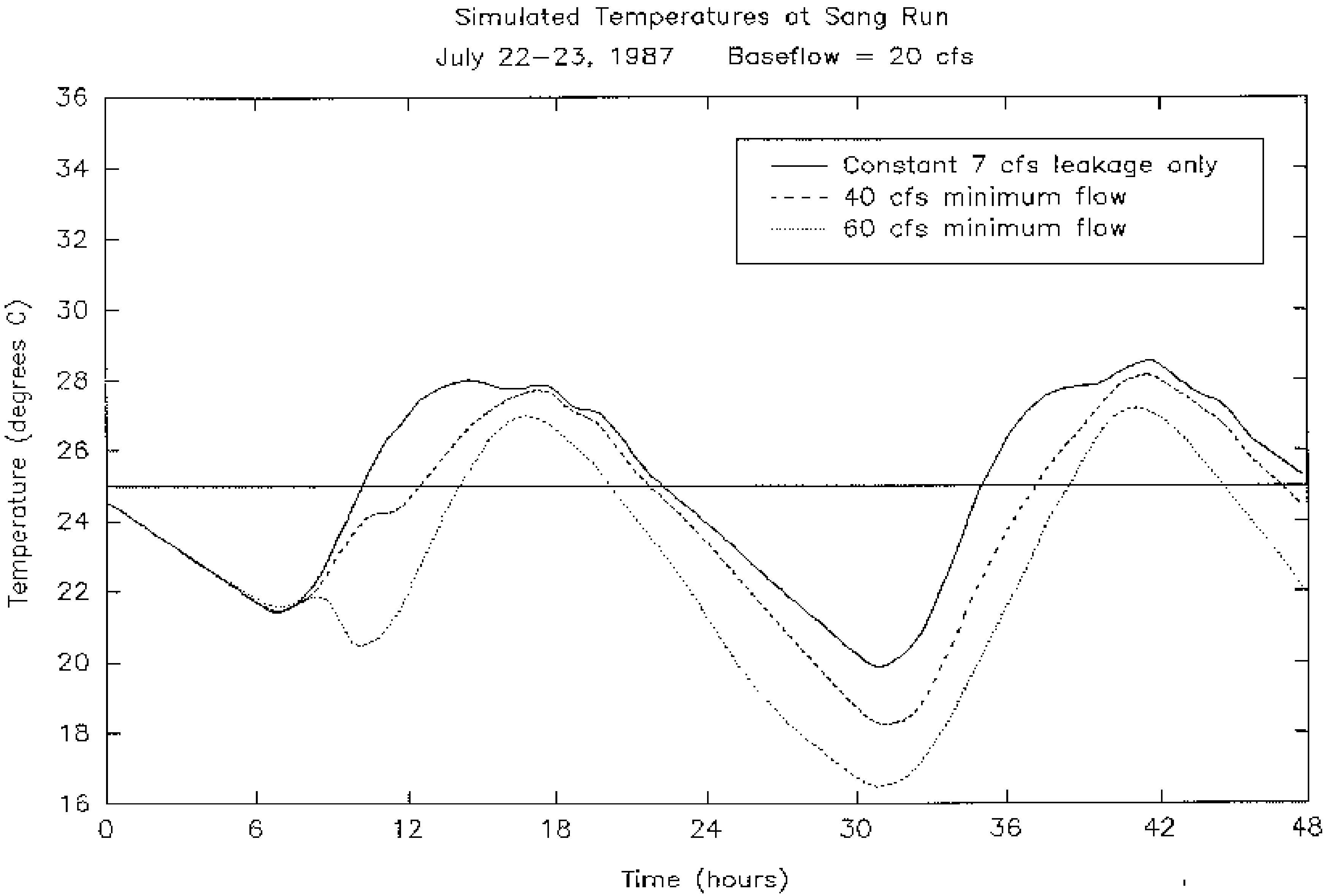

Figure 3-7. YOUGH-RIV1 model simulations for July 22-23, 1987 at Sang Run, with an upstream baseflow of 20 cfs and a tailrace flow of 7 cfs or minimum flows to maintain 40 or 60 cfs continuously.

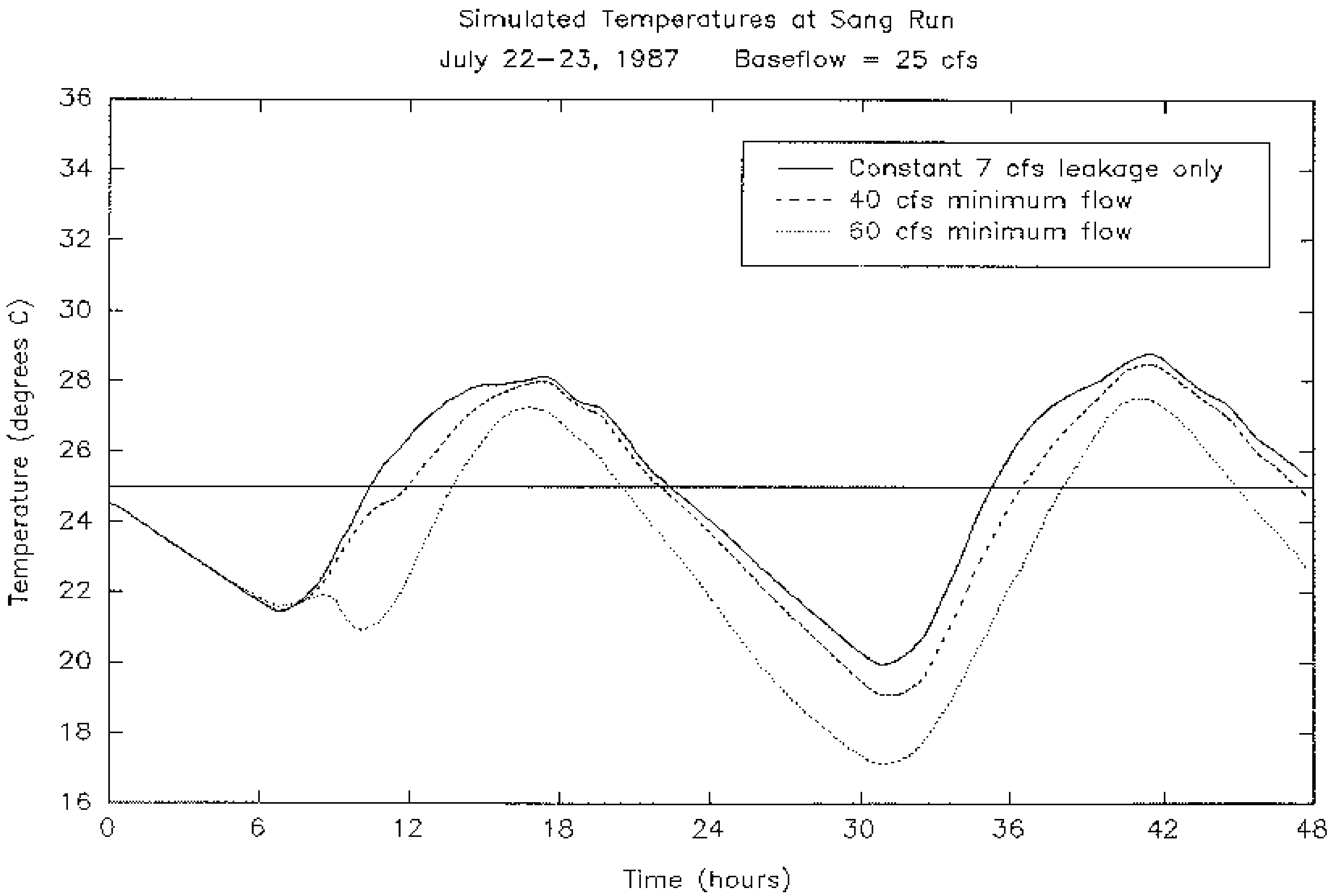

Figure 3-8. YOUGH-RIV1 model simulations for July 22-23 1987 at Sang Run, with an upstream baseflow of 25 cfs and a tailrace flow of 7 cfs or minimum flows to maintain 40 and 60 cfs continuously.

Temperature patterns on days with generation releases, a baseflow of 25 cfs, and minimum flows of 32 cfs (7 cfs leakage flow only), 40 cfs and 60 cfs are shown in Figures 3-9, 3-10, and 3-11. The temperature patterns on days with generation releases, a baseflow of 37 cfs, and a minimum flow of 60 cfs is shown in Figure 3-12. (With a leakage flow of 7 cfs, the minimum flow was already above 40 cfs, and this result was previously illustrated in Figure 3-1). As expected, maximum and average temperatures are lower with the greater minimum flows and are lower than at a baseflow of 37 cfs, again due to mass balance considerations (Table 3-2). (These scenarios were unable to be simulated at a baseflow of 20 cfs due to model instability.)

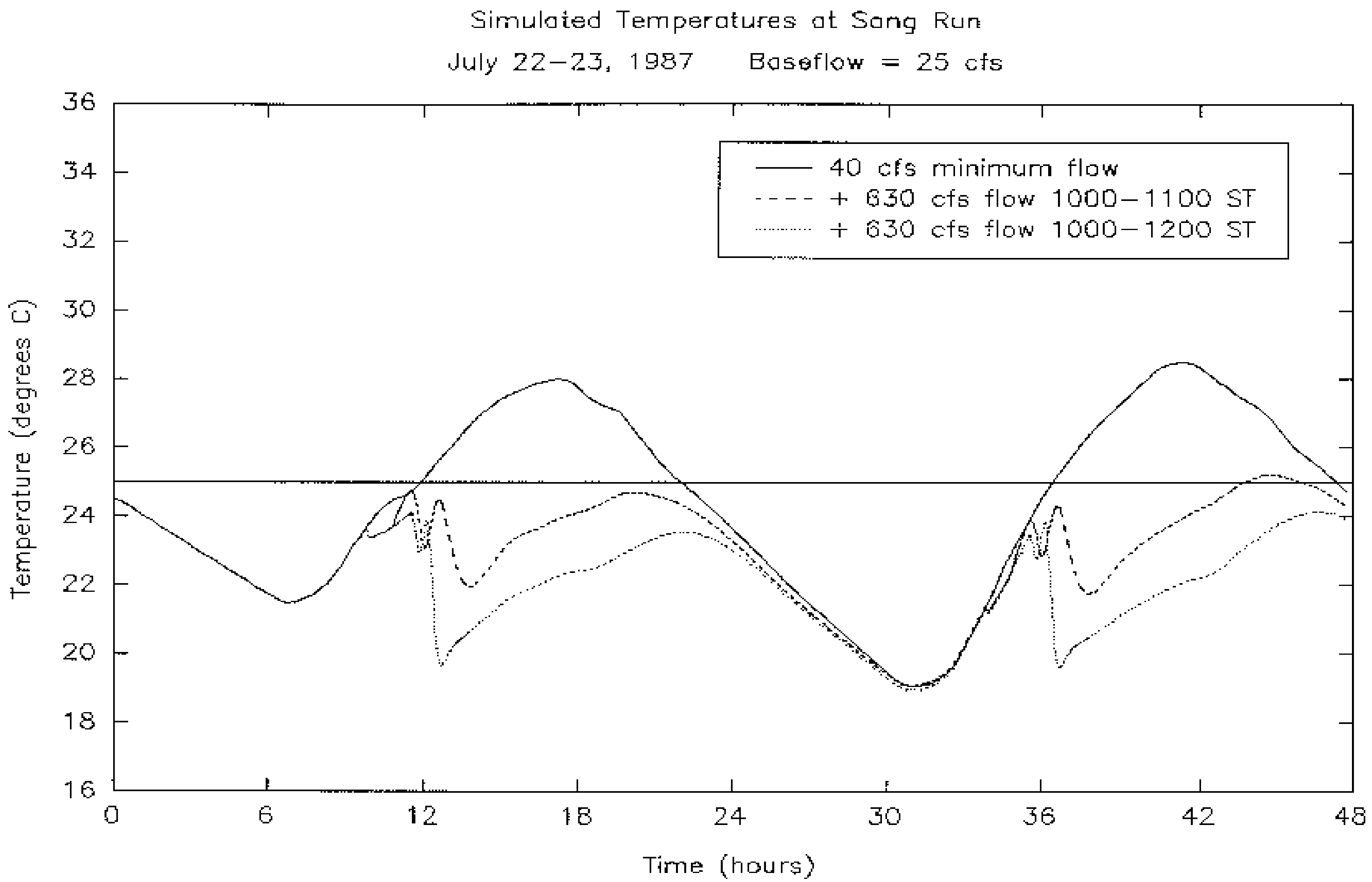

Figure 3-10. YOUGH-RIV1 model simulations for July 22-23, 1987, at Sang Run, with an upstream baseflow of 25 cfs and a tailrace flow to maintain a minimum flow of 40 cfs, alone and in combination with generation flows of 1 hour each day from 10-11 ST or 2 hours each day from 10-12 ST.

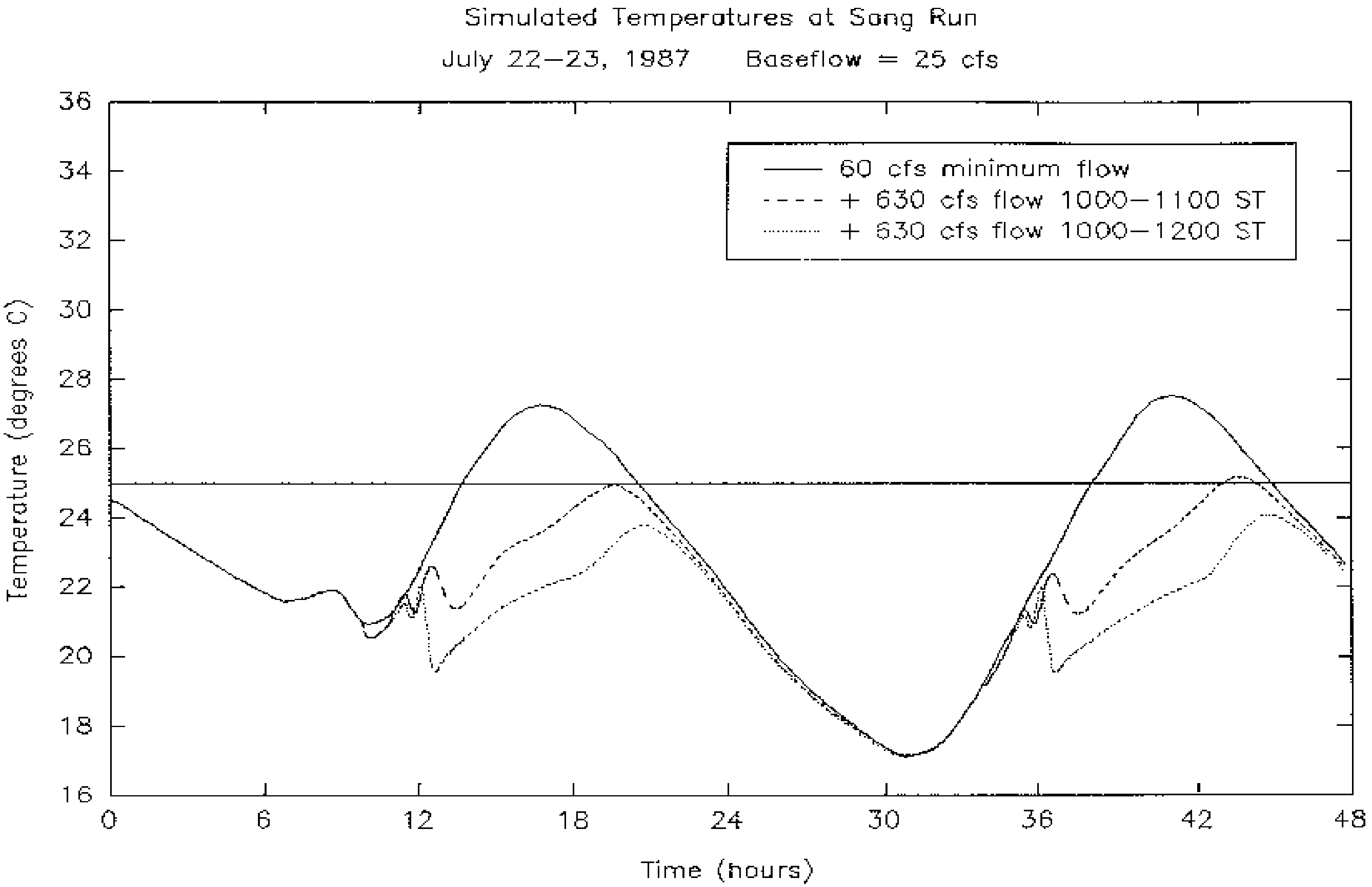

Figure 3-11. YOUGH-RIV1 model simulations for July 22-23, 1987, at Sang Run, with an upstream baseflow of 25 cfs and a tailrace flow to maintain a minimum flow of 60 cfs, alone and in combination with generation flows of 1 hour each day from 10-11 ST or 2 hours each day from 10-12 ST.

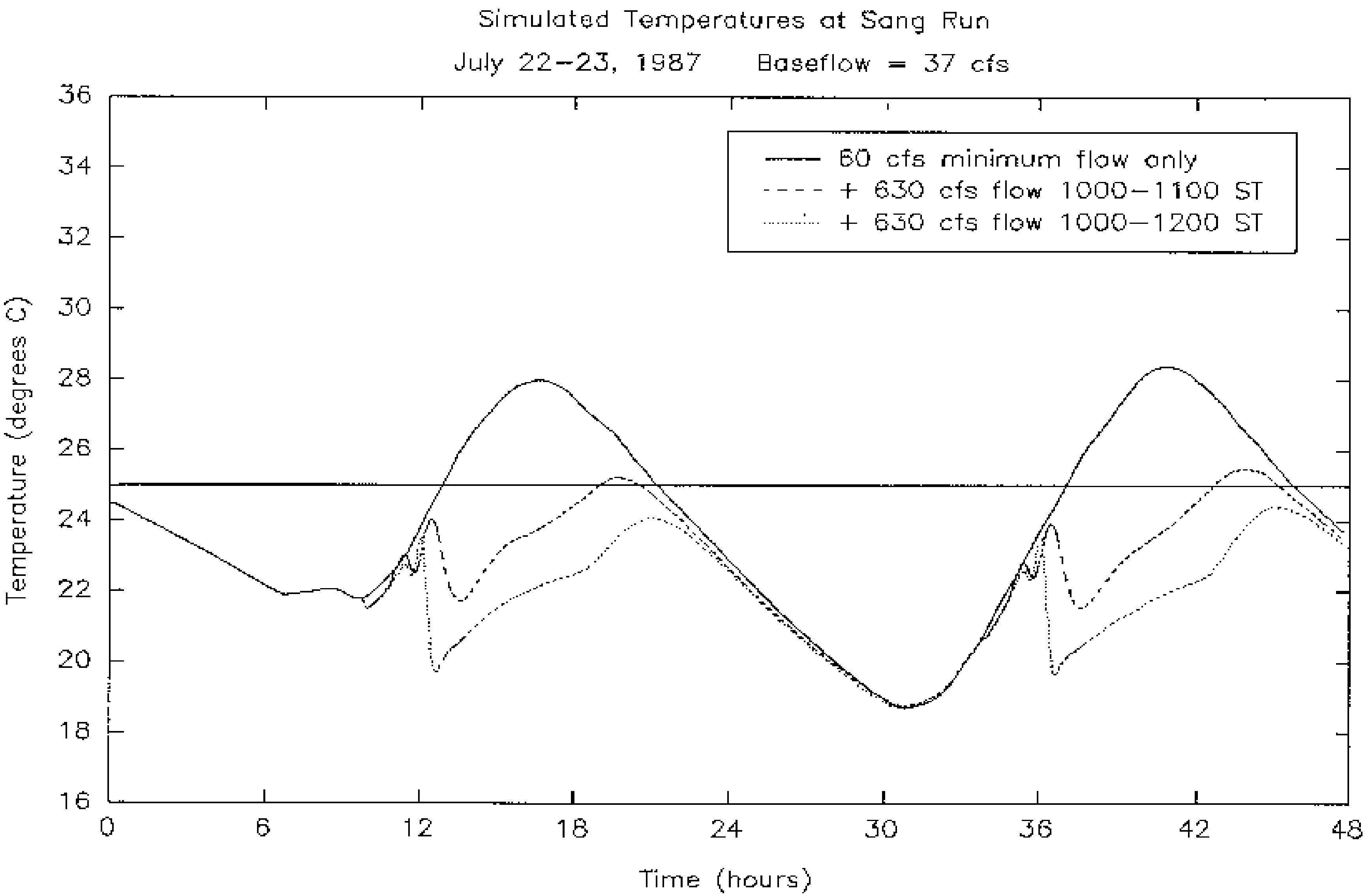

Figure 3-12. YOUGH-RIV1 model simulations for July 22-23, 1987, at Sang Run, with an upstream baseflow of 37 cfs and a tailrace flow to maintain a minimum flow of 60 cfs, alone and in combination with generation flows of 1 hour each day from 10-11 ST and 2 hours each day from 10-12 ST.

4.0 TEST RELEASE RESULTS FOR 1991

A preliminary version of the YOUGH-RIV1 model suggested several possible generation release scenarios which could be tested with the existing project. Results of these tests are described below. MDNR placed several Ryan Tempmentors (continuous recording temperature monitors) in the Youghiogheny River in late May to early June, 1991. The instruments were placed at the following locations:

1) Just above the confluence of the original Deep Creek tributary to the Youghiogheny River,

2) Above the tailrace, outside the influence of leakage or generation flows ('above tailrace'),

3) In the tailrace, about 50 feet downstream of powerhouse discharge ('tailrace'),

4) Above the confluence of Hoyes Run with the Youghiogheny River, 0.3 miles downstream of the tailrace ('Hoyes').

5) At a point approximately half-way between Hoyes Run and Steep Run tributaries, 1.4 miles downstream of the tailrace ('Hoyes-Steep'),

6) At a point above the confluence of Steep Run with the Youghiogheny River, 2.4 miles downstream of the tailrace ('Steep'), and

7) At a point about 100 yards upstream of the Sang Run bridge, downstream of the confluence of Sang Run with the Youghiogheny River, 3.6 miles downstream of the tailrace ('Sang').

Monitors were submerged in the river at these locations in areas where they would not be exposed to the air during low flows. Instruments in the tailrace and downstream were set to record every 10 minutes to capture the short-term responses which could occur during generation releases. The 'Deep Creek' and 'above tailrace' monitors were set to record at 30-minute intervals. In mid-July and mid-August, the instruments set to 10-minute intervals were retrieved from the river, the data downloaded to a laptop computer, and the instruments returned to the same location to continue recording. Each 10-minute station also had a second instrument set to record at 30-minute intervals at a nearby location for use as a backup and to assess whether the locations were representative of that portion of the river. All monitors were retrieved by mid-October.

Test releases were requested of Penelec by Versar in conjunction with Ebasco Services, Inc., Penelec's relicensing consultant. The tests were requested to occur during low flow and hot weather conditions to the extent possible. Some of the tests may have occurred during less than desirable periods due to the fact that they had to be scheduled a few days in advance. Lake levels were also lower than desired, precluding releases more often than about once per week. Test releases usually occurred in lieu of a normal generation release; often there was no release the day before or after the test, and the data collected on these days can be used as a control. The 'above tailrace' data can be used to assess the influence of changing weather conditions on control days, since that station was not influenced by project releases.

The first test release consisted of four 1-hour releases of one turbine at reduced gate on June 27 (perhaps about 200 cfs - Figure 4-1). The amount of water released is slightly more than 1-hour of a 2-turbine release. The gage at Friendsville on that day (prior to generation) was reading approximately 1.9 feet, which corresponds to a flow above the tailrace of 28 cfs. The day of the test release probably had somewhat greater warming than the day before, as shown by the higher peak temperature above tailrace (23.2°C vs. 22.4°C). The highest temperature in the river was 22.2°C between Hoyes and Steep, while on the previous day with no release, temperature reached 25.5°C at Steep. The peak temperature at Sang was 25.8°C on the test release day, as compared with 26.5°C at the same location on the previous day. However, temperature was 25°C or higher for only 1 hour with the test release, as compared with 4.8 hours the previous day.

The second test release consisted of four one-half hour releases of one turbine at full gate on July 17 (about 320 cfs - Figure 4-2). The amount of water released is equivalent to a 1-hour, 2-turbine release. Flow above the tailrace was about 21 cfs. The day of the test release probably had considerably greater warming than the day before, as shown by the higher peak temperature above tailrace (25.0°C vs. 23.5°C). The highest temperature in the

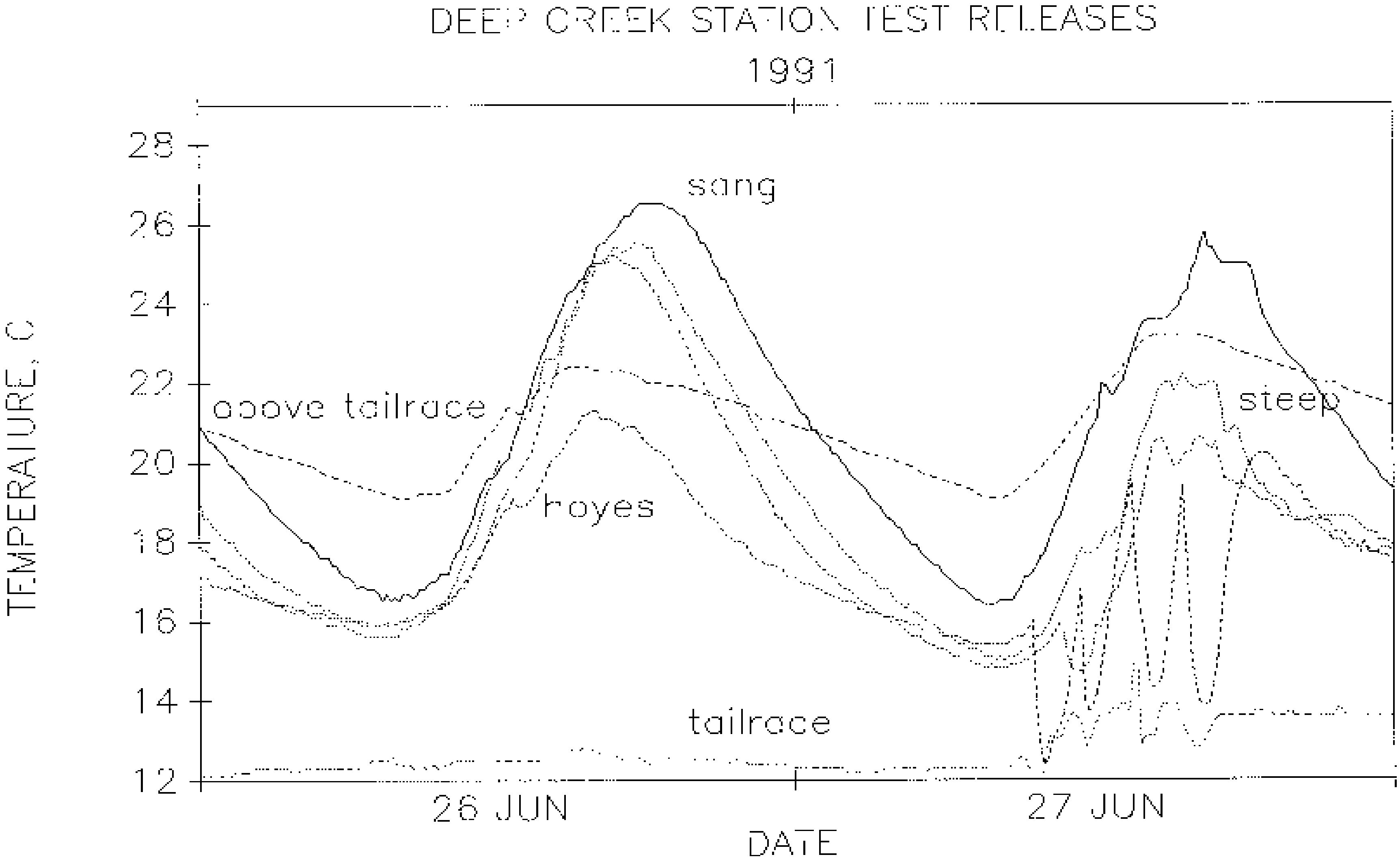

Figure 4-1. Youghiogheny River temperatures recorded for June 26-27, 1991. No project releases occurred on June 26. Test releases occurred on June 27 and consisted of 1-turbine at reduced gate (approximately 200 cfs) at 0800, 1000, 1200, and 1400 hours ST, for one hour. Station locations are described in detail in the text. Not labeled on the figure is the station half-way between Hoyes and Steep. Daily average upstream baseflows were 31 and 28 cfs for each day, respectively.

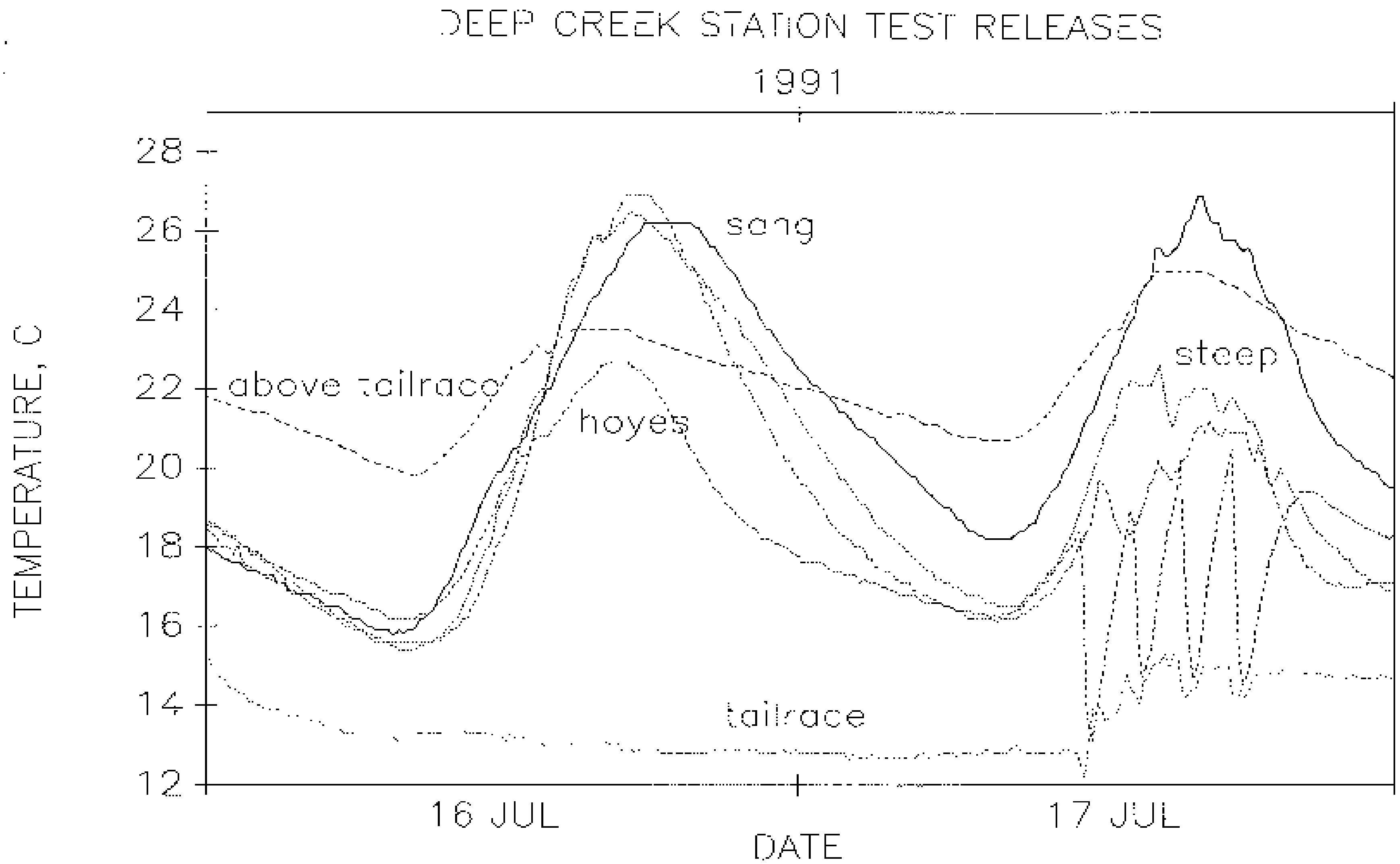

Figure 4-2. Youghiogheny River temperatures recorded for July 16-17, 1991. No project releases occurred on July 16. Test releases occurred on July 17 and consisted of 1-turbine at full gate (approximately 315 cfs) at 1000, 1200, 1400, and 1600 hours ST, for one-half hour. Station locations are described in detail in the text. Not labeled on the figure is the station half-way between Hoyes and Steep. Daily average upstream baseflows were 26 and 21 cfs for each day, respectively.

river below the tailrace was 22.6°C, between Hoyes and Steep, while on the previous day with no release, temperature reached 26.9°C between Hoyes and Steep. The peak temperature at Sang was 26.9°C on the test release day, as compared with 26.2°C at the same location on the previous day. Temperature was 25°C or higher for 3.8 hours with the test release, as compared with 4.7 hours the previous day.

The third test release consisted of one three-hour release of two turbines at full gate on July 19 (about 640 cfs - Figure 4-3). Flow above the tailrace was about 16 cfs. The day of the test release probably had somewhat less warming than the day before or after, as shown by the lower peak temperature above tailrace (25.2°C vs. 25.8°C the day before and 25.4°C the day after). The highest temperature in the river below the tailrace on the day of the release was 21.7°C at Sang Run, while on the previous day with a small release (12 minutes starting at 1750 ST), temperature reached 28.1°C at Sang. The peak temperature at Sang was 26.6°C on the day after the test release; however another release of 27 minutes commencing at 1525 ST occurred on that day.

A fourth test release occurred on July 26 and consisted of one two-hour release which commenced at 1000 ST (Figure 4-4). Flow above the tailrace was about 26 cfs. The day of the release was probably somewhat cooler than either the day before or after the release, since the temperature above the tailrace reached only 23.1°C, vs. 24.7°C the day before and 23.5°C the day after the release occurred. The highest temperature in the river below the tailrace on the day of the release was 21.1°C at Sang Run, while on the previous day with no release, temperature reached 26.2°C at Sang. The peak temperature at Sang was 24.9°C on the day after the test release.

Another release of interest (not a requested test release) occurred on August 2 and consisted of one two-hour release which commenced at 1100 ST (Figure 4-5). Flow above the tailrace was about 21 cfs. The day of the release was probably somewhat warmer than either the day before or after the release, since the temperature above the tailrace reached 25.7°C, vs. 24.2°C the day before and 25.2°C the day after the release. The highest temperature in the river below the tailrace on the day of the release was 26.2°C at Sang Run, while on the previous and following days it was 27.6°C and 25.4°C, respectively.

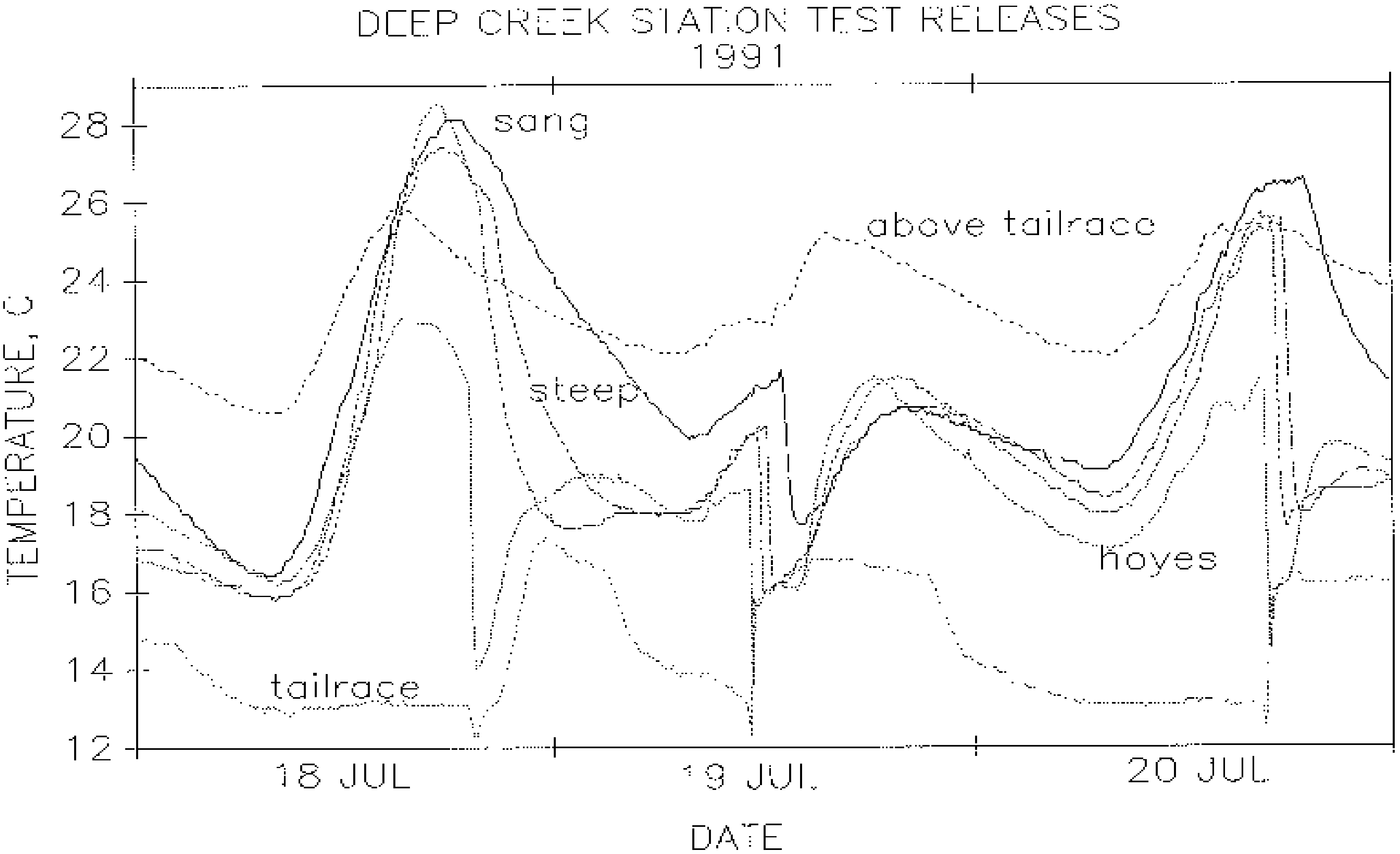

Figure 4-3. Youghiogheny River temperatures recorded for July 18-20, 1991. Two-turbine unscheduled releases occurred on July 18 (1750-1802 ST) and on July 20 (1525-1552 ST). A two-turbine test release occurred on July 19 for 3 hours commencing at 1000 ST. Station locations are described in detail in the text. Not labeled on the figure is the station half-way between Hoyes and Steep. Daily average upstream baseflows were 19, 16, and 16 cfs for each day, respectively.

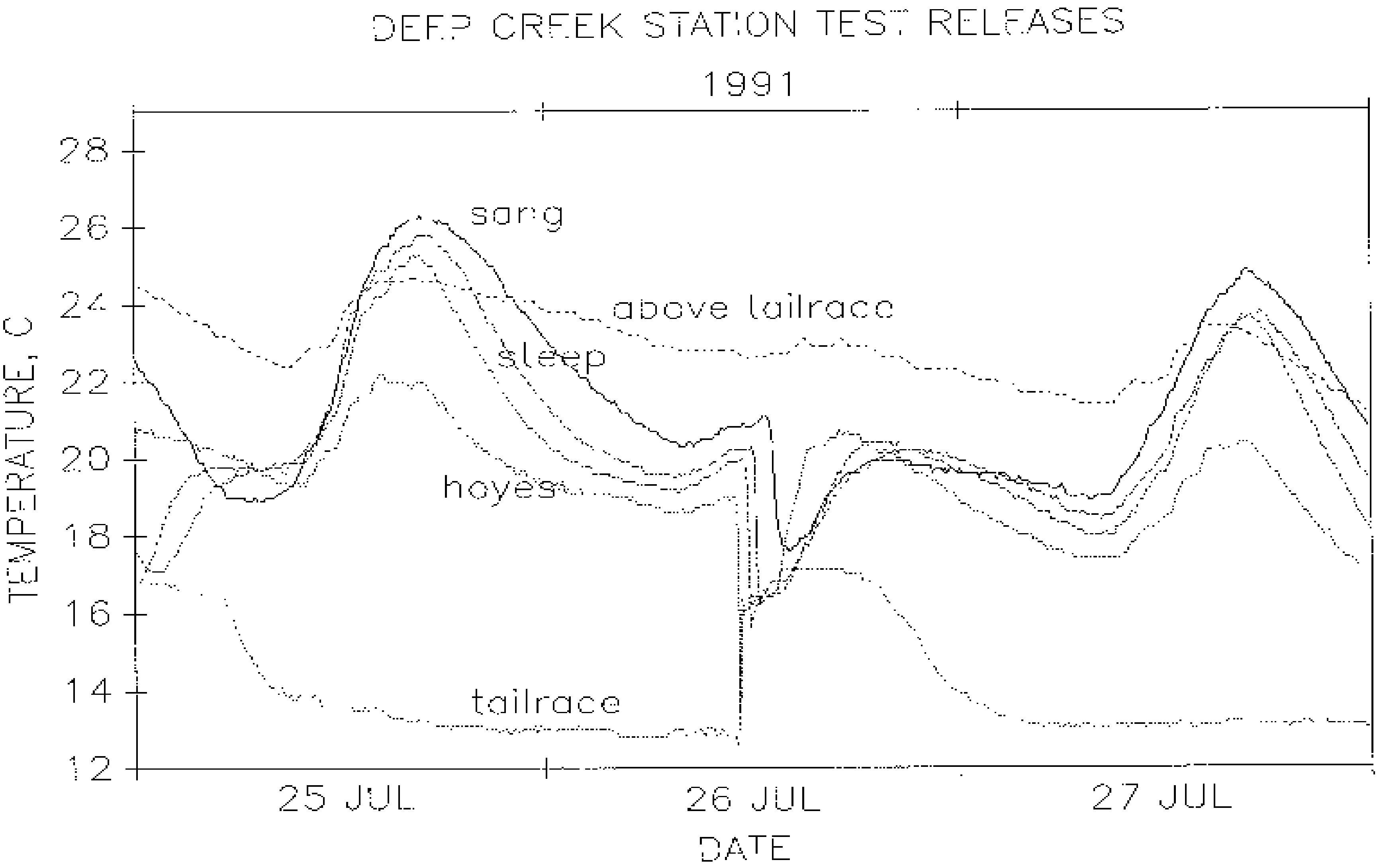

Figure 4-4. Youghiogheny River temperatures recorded for July 25-27, 1991. No project releases occurred on July 25 or 27. A two-turbine test release occurred on July 26 for 2 hours commencing at 1000 ST. Station locations are described in detail in the text. Not labeled on the figure is the station half-way between Hoyes and Steep. Daily average upstream baseflows were 19, 16, and 16 cfs for each day, respectively.

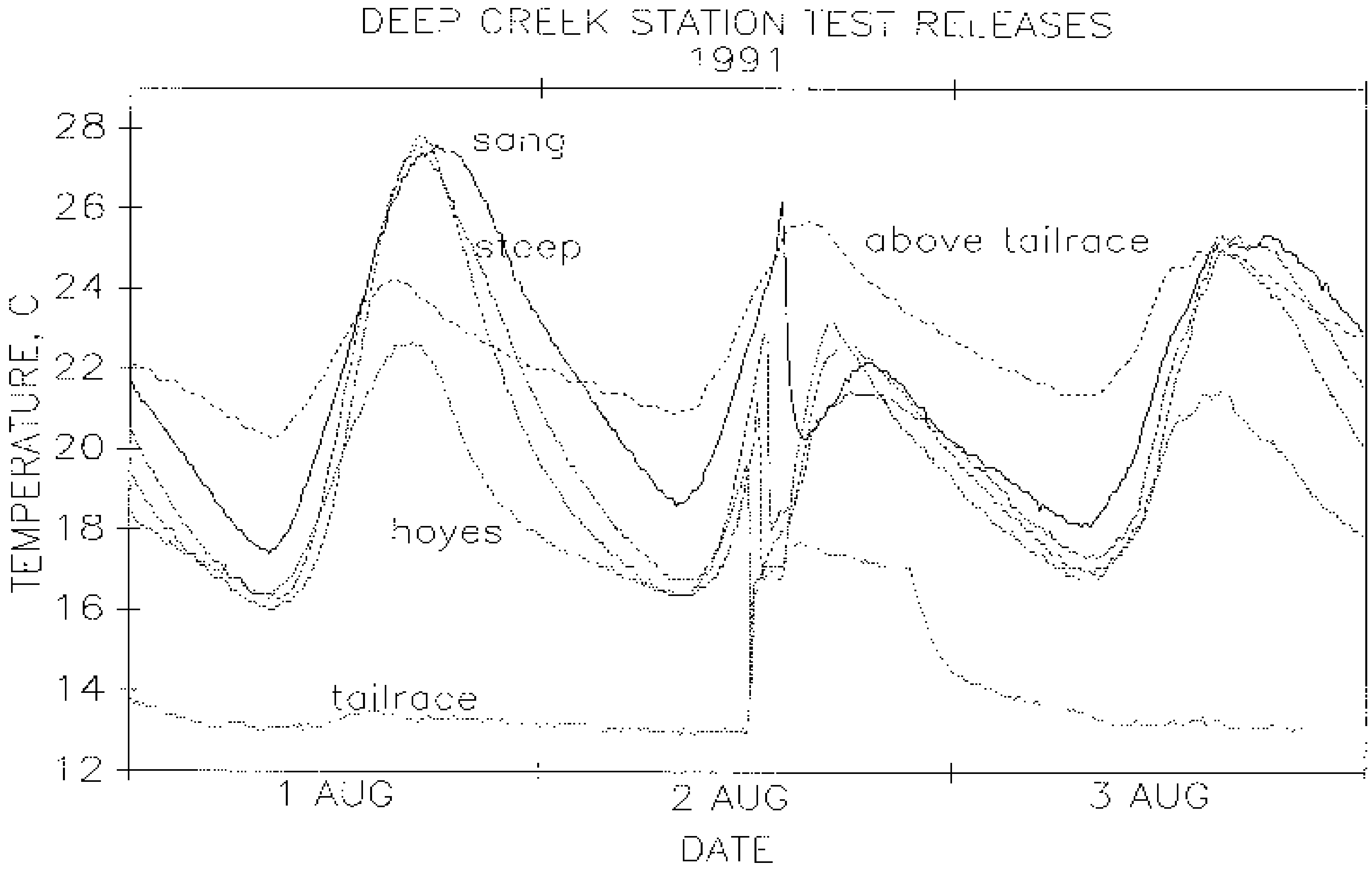

Figure 4-5. Youghiogheny River temperatures recorded for August 1-3, 1991. No project releases occurred on August 1 or 3. A two-turbine test release occurred on August 2 for 2 hours commencing at 1100 ST. Station locations are described in detail in the text. Not labeled on the figure is the station half-way between Hoyes and Steep. Daily average upstream baseflows were 28, 21, and 19 cfs for each day, respectively.

Temperature at Sang Run exceeded 25°C for only about 30 minutes, suggesting that an earlier release probably would have prevented the river temperature from exceeding that value.

The final test release occurred on August 29 and consisted of a one-hour release commencing at 1000 (Figure 4-6 - julian day 241). Flow above the tailrace was about 25 cfs. The day of the test release was probably similar in terms of temperature as compared with two days before and two days after this test release (the day before and the day after also had releases, as shown in Figure 4-6). Maximum daily temperatures above the tailrace were 24.2°C, 24.9°C, and 24.8°C, two days before the test release, on the day of release, and two days after, respectively. Warmest downstream temperatures on a non-release day occurred two days before the test release, with a maximum value of 27.1°C occurring between Hoyes and Steep. The highest temperature in the river below the tailrace on the day of the release was 25.7°C, which occurred between Hoyes and Steep, at about 1600 ST. From the figure, it is evident that the release lowered the downstream river temperature at all stations for a short period (perhaps 1-2 hours). Temperatures then increased, although not to as great a level as they probably would have without the release. Since this test release was not able to maintain river temperature below 25°C at all times, a one-hour release probably is not sufficient for temperature control under many low flow conditions likely to occur in the river. This is especially so, since this test occurred late in the season, and heating was probably not as great as it would have been in mid-July, for instance.

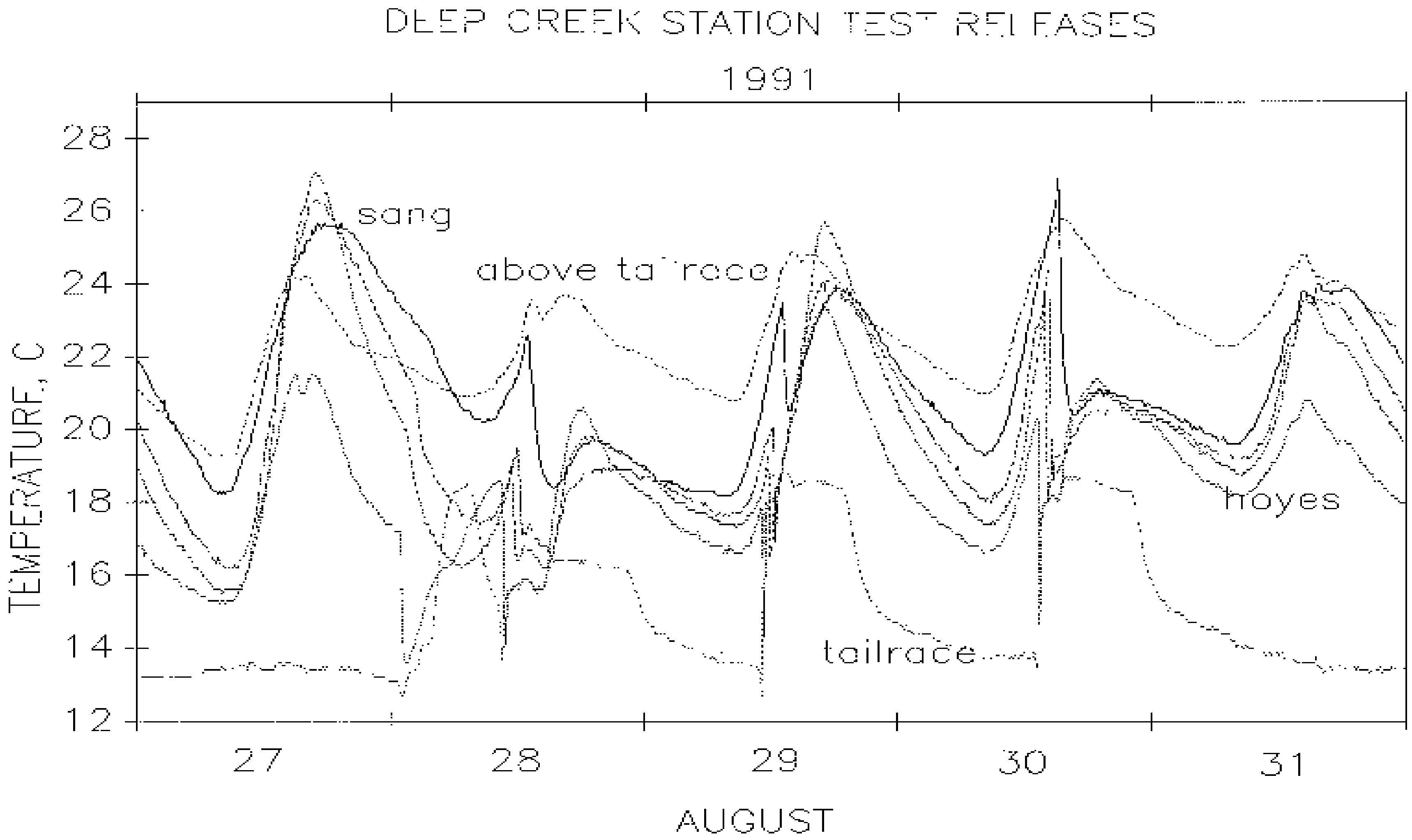

Figure 4-6. Youghiogheny River temperatures recorded for August 27-31, 1991. No project releases occurred August 31. A two-turbine unscheduled releases occurred on August 27 (2343-2353 ST) and on August 28 (0924-1321 ST). A two-turbine test release occurred on August 29 for 1 hour commencing at 1000 ST. A scheduled two-turbine generation release occurred on August 30 (1200-1400 ST). Station locations are described in detail in the text. Not labeled on the figure is the station half-way between Hoyes and Steep. Daily average upstream baseflows were 23, 23, 25, 26, and 17 cfs for each day, respectively.

5.0 CONCLUSIONS

Modeling results and test releases seem to indicate that a 2-turbine, 2-hour release commencing at 1000 hours (ST) would be more effective at maintaining temperature below some specified limit than would a 2-turbine, 1-hour release or a pulsed release. The test releases are not directly comparable with each other, since flow and weather conditions varied from day to day and week to week. Results do suggest however, that the two-hour releases (at the appropriate time of day) may provide enough cooling of the river bed to buffer temperature increases for the remainder of the day. The 1-hour and pulsed releases provided too little water for too short a period. For the pulsed releases, by the time the released water reached half-way to Sang Run, it did not provide enough cooling capacity to the river bed to buffer heating once the release water had passed through. However, under less than worst case conditions, a 1-hour release may be sufficient to maintain temperature less than 25°C. The pulsed releases did have some positive benefit and greater volumes of water would have been more effective. However, since no whitewater benefit would occur and power generation revenues would be less with the pulsed releases than with the single-event releases, this option is probably less desirable.

Bypass flow release scenarios show that as much as 10 hours of 100 cfs of supplementary flow might be required to maintain temperatures of less than 25°C under worst case baseflow and temperature conditions. This is slightly less total water volume than a 2-turbine, 2-hour generation release and would be more beneficial to fish populations in the river since flow fluctuations would not be as great. However, water releases would not be available for peaking power generation or for whitewater recreation. These scenarios would also require an unknown additional capital expense to construct a larger flow bypass than would be required solely to maintain a continuous but smaller minimum flow in the range of 40-60 cfs. Bypass flows would have to be released earlier in the day than a 2-turbine generation release in order to provide the desired level of temperature enhancement between the power plant and Sang Run. Because of this, there would be a greater number of days in summer when water releases would have to occur for temperature enhancement, even though such releases might not actually be required due to weather or river flow and temperature conditions which could not be anticipated as far in advance. Bypass releases would probably not be as feasible for enhancement purposes for these reasons, although some additional fishery benefits would likely occur since water temperatures and flows would fluctuate to a much lesser degree than with generation releases.

These results may be used for a more detailed economic evaluation of the cost of various release alternatives which might be considered for temperature control. Such releases would not be needed when river flows are greater than some critical level or when natural meteorological conditions would preclude heating above some critical value. Existing data on river temperatures and flows (1987-1991) could be evaluated to determine how often temperature enhancement would be required to meet the desired maximum temperature goal. River baseflow and temperature criteria could be established as trigger points for when temperature control would be needed on a given day. The cost and feasibility of providing the necessary telemetry for a temperature release trigger (e.g., sensors to measure river baseflows and temperature) could then be estimated, along with the cost of providing the necessary flows in terms of lost or reduced power revenue and possible loss of use by other users of river flows.

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APPENDIX A-1

SHADING SUBROUTINE FOR RIV1Q

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c ----------------------------------------------------------------------
c  Subroutine srss determines the times (in hour angles) of local
c  sunrise (hsr) and sunset (hss) on a particular day, accounting for
c  the terrain.  This subroutine is called for every node, each time
c  a new day is begun.  The results are stored in arrays for later use
c  on the same day.
c  The algorithm is based on Theurer, Voos, & Miller,
c  "Instream Water Temperature Model" (1984), pp. II-18...24.
c  G D Birky  12/16/91
c ----------------------------------------------------------------------

      subroutine srss
      COMMON/ABLOCK/ IND1,             IND2,            IND3,
     *               IND4,             IND5,            NS, MTIME

      COMMON/TIME/   STB,              STE,             DELTAT,
     *               TOFDAY,           JDYO,            LII,

     *               LMN,              CONS7,           I,

     *               J,                ELAPSE
      parameter (maxseg=2,maxnode=20)
      common /shparms/ shflag,orderc,node1c,azr,altte,alttw,
     *   vde,vdw,vce,vcw,vhe,vhw,voe,vow,
     *   desun,sindec,cosdec,cons2,sinlat,coslat,
     *   hsr,hss
      integer shflag,orderc(maxseg),node1c(maxseg)
      real azr(maxnode),altte(maxnode),alttw(maxnode),
     * vde(maxnode),vdw(maxnode),vce(maxnode),vcw(maxnode),
     * vhe(maxnode),vhw(maxnode),voe(maxnode),vow(maxnode),
     * desun,sindec,cosdec,cons2,sinlat,coslat,
     * hsr(maxnode),hss(maxnode)

c  Local variables:
      real    altsr,altss,      ! local sunrise/sunset solar altitude
     &        altsrs,           ! local sunrise or sunset solar altitude
     &        alttr,altts,      ! sunrise/sunset side topographic altitude
     &        aso,              ! level-plain sunset azimuth
     &        asr,ass,          ! local sunrise/sunset solar azimuth
     &        asrs,             ! local sunrise or sunset solar azimuth
     &        cosaltsrs,        ! cosine of altsrs
     &        det,              ! determinant of Jacobian matrix
     &        epsilon,          ! convergence criterion for Newton's method
     &        f1,f2,            ! value of f1/f2 at current approximations
     &        f1arg,f2arg,      ! expression used in f1/f2 and Jacobian matrix
     &        hs,               ! level-plain sunset hour angle
     &        ijac11,ijac12,ijac21,ijac22   ! entries in inverse of Jacobian
      integer it,               ! iteration number
     &        pos               ! position of current node in arrays
      real    jac12,jac21       ! entries in Jacobian matrix
      integer maxit,            ! max number of iterations for Newton's method
     &        sgn               ! approx asr,altsr,...: -1 for rise, 1 for set
      real    praltsrs,prasrs,  ! in Newton's method, prev val of altsrs/asrs
     &        sinaltsrs,        ! sine of altsrs
     &        sindif,           ! sine of (asrs-azrn)
     &        tanalttr,tanaltts,! tangent of alttr/altts
     &        tanalttrs         ! tangent of alttr or altts
      parameter (epsilon=1.e-6,maxit=20)

C  Calculate level-plain sunset hour angle and azimuth (p. II-23).

      hs=acos(-sinlat*sindec/(coslat*cosdec))
      aso=asin(cosdec*sin(hs))
```

```
C  Calculate local sunrise and sunset altitudes,
c  hour angles, and solar azimuths (p. II-24).
c  First determine alttr and altts.

      pos=node1c(orderc(ns-lmn+1))+i-1
      if (-aso .le. azr(pos)) then
       alttr=altte(pos)
      else
       alttr=alttw(pos)
      endif
      if (aso .le. azr(pos)) then
       altts=altte(pos)
      else
       altts=alttw(pos)
      endif

C  Constants for use in approximation of asr,altsr,ass,altss.

      tanalttr=tan(alttr)
      tanaltts=tan(altts)

c  Approximate asr,altsr,ass,altss.
c  sgn=-1 for asr,altsr (use alttr); sgn=1 for ass,altss (use altts)

      do sgn=-1,1,2
       if (sgn .eq. -1) then
          tanalttrs=tanalttr
       else
          tanalttrs=tanaltts
       endif

c  Initial values for iteration.

       asrs=sgn*aso
       prasrs=4.
       altsrs=0.
       praltsrs=-1.
       it=0

c  Use Newton's method to approximate asr,altsr or ass,altss.

       do while (abs(asrs-prasrs) .gt. epsilon .and.
     &             abs(altsrs-praltsrs) .gt. epsilon .and.
     &             it .lt. maxit)
          it=it+1
          prasrs=asrs
          praltsrs=altsrs
```

```
c  Calculate value of functions at current approximations asrs,altsrs.

          sinaltsrs=sin(altsrs)
          cosaltsrs=cos(altsrs)
          f1arg=(sinlat*sinaltsrs-sindec)/(coslat*cosaltsrs)
          f1=asrs-sgn*acos(f1arg)
          sindif=sin(asrs-azr(pos))
          f2arg=tanalttrs*abs(sindif)
          f2=atan(f2arg)-altsrs

c  Calculate Jacobian matrix and invert it.

          jac12=sgn*(sinlat-sindec*sinaltsrs)/
     &         (sqrt(1.-f1arg*f1arg)*coslat*cosaltsrs*cosaltsrs)
          jac21=tanalttrs*cos(asrs-azr(pos))*sign(1.,sindif)/
     &         (1.+f2arg*f2arg)
          det=-1.-jac12*jac21
          ijac11=-1./det
          ijac12=-jac12/det
          ijac21=-jac21/det
          ijac22=1./det

c  New approximations.

          asrs=asrs-ijac11*f1-ijac12*f2
          altsrs=altsrs-ijac21*f1-ijac22*f2
c            write (*,*) it,asrs,altsrs
       enddo
       if (it .ge. maxit)
     *      print *,' Shading uncertain; lack of convergence.'

c  Store results in asr,altsr or ass,altss.

       if (sgn .eq. -1) then
          asr=asrs
          altsr=altsrs
       else
          ass=asrs
          altss=altsrs
       endif
      enddo

c  Calculate hsr and hss.

      if (sin(altsr) .le. sinlat*sindec+coslat*cosdec .and.
     *    sin(altss) .le. sinlat*sindec+coslat*cosdec) then
       hsr(pos)=-acos( (sin(altsr)-sinlat*sindec)/(coslat*cosdec) )
       hss(pos)= acos( (sin(altss)-sinlat*sindec)/(coslat*cosdec) )
      else
       hsr(pos)=0.
       hss(pos)=0.
      endif
      return
      end



c -------------------------------------------------------------------
c  Function shfct returns a shading factor between 0 and 1.
c  0 means completely shaded, 1 is no shade.  It is determined
c  based on whether the time is between local sunrise and sunset
c  (accounting for terrain) and shading due to vegetation.  See
c  Theure et al., p. II-25...26.
```

```
c  G D Birky  12/16/91
c ------------------------------------------------------------------

      function shfct (h,alt,b,mnode)
      real shfct
      COMMON/ABLOCK/ IND1,             IND2,            IND3,
     *               IND4,             IND5,            NS, MTIME

      COMMON/TIME/   STB,              STE,             DELTAT,
     *               TOFDAY,           JDYO,            LII,

     *               LMN,              CONS7,           I,

     *               J,                ELAPSE

      parameter (maxseg=2,maxnode=20)
      common /shparms/ shflag,orderc,node1c,azr,altte,alttw,
     *   vde,vdw,vce,vcw,vhe,vhw,voe,vow,
     *   desun,sindec,cosdec,cons2,sinlat,coslat,
     *   hsr,hss
      integer shflag,orderc(maxseg),node1c(maxseg)
      real azr(maxnode),altte(maxnode),alttw(maxnode),
     * vde(maxnode),vdw(maxnode),vce(maxnode),vcw(maxnode),
     * vhe(maxnode),vhw(maxnode),voe(maxnode),vow(maxnode),
     * desun,sindec,cosdec,cons2,sinlat,coslat,
     * hsr(maxnode),hss(maxnode)

              ! Input variables:
      integer mnode ! no. of nodes in current segment; elt of "nnode" in MAIN2
      real h,       ! current time in hour angles
     &     alt,     ! current solar altitude
     &     b(mnode) ! widths of stream (in meters), from MAIN2

              ! Local variables:
      real arg,     ! expression used in finding "as"
     &     as,      ! current solar azimuth
     &     bs       ! stream solar shade width
      integer pos   ! position of current node in shading arrays

      pos=node1c(orderc(ns-lmn+1))+i-1
      if (h .lt. hsr(pos) .or. h .gt. hss(pos)) then
       shfct=0.
      else
       arg=(sinlat*sin(alt)-sindec)/(coslat*cos(alt))
       if (arg .gt. 1.) arg=1.
       as=sign(1.,h)*acos(arg)
       if (as .le. azr(pos)) then
          bs=vhe(pos)*cotan(alt)*abs(sin(as-azr(pos)))+
     *         (vce(pos)/2.-voe(pos))
          bs=max(0.,min(bs*.3048,b(i)))
          shfct=1.-vde(pos)*bs/b(i)

       else
          bs=vhw(pos)*cotan(alt)*abs(sin(as-azr(pos)))+
     *         (vcw(pos)/2.-vow(pos))
          bs=max(0.,min(bs*.3048,b(i)))
          shfct=1.-vdw(pos)*bs/b(i)
       endif
      endif
      return
      end
```

APPENDIX A-2

BENTHIC CONDUCTION SUBROUTINE FOR RIV1Q

```
C
      SUBROUTINE HEATSLAB (ELAPSE,DELTAT,CV,Z,TDK,NNODE,IT,NSEG,
     &                       DTEMP,HT,DH,HP)
C
C  PROGRAM TO COMPUTE BED CONDUCTION, BASED ON JOBSON (1977), ASCE J. HYD. DIV
C  103(HY10)
C
C   BTUCAL = CONVERSION FACTOR, BTU PER CAL
C       CV = HEAT STORAGE CAPACITY OF SLAB (E.G., 0.75 CAL/CM**3 - DEG)
C   DELTAT = TIME STEP, SECONDS
C       DH = DELTA HEATING RATE
C    DTEMP = DELTA TEMPERATURE
C   ELAPSE = ELAPSED TIME, HOURS
C   FT2CM2 = CONVERSION FACTOR, SQ. FT. PER SQ. CM.
C     HMEM = TEMPERATURE MEMORY, HOURS
C       HP = HEATFLUX, BTU/FT2
C       HT = INCREASE IN HEAT CONTENT BETWEEN 0 AND TIME IT
C       IT = TIMESTEP NUMBER
C     MAXN = TOTAL ITERATIONS
C    NNODE = NODE NUMBER
C     NSEG = SEGMENT NUMBER
C      TDK = THERMAL DIFFUSIVITY (E.G., 0.05 CM*2/SEC)
C       TI = CURRENT TIME, SECONDS
C       Z  = THICKNESS OF SLAB (E.G., 50 CM)
C
      COMMON/ABLOCK/ IND1,              IND2,             IND3,
     *               IND4,              IND5,             NS, MTIME
C
      DIMENSION HT(IND1,MTIME,NS),DH(IND1,MTIME,NS),
     *            DTEMP(IND1,MTIME,NS)
C
      DATA HMEM / 24. /
      DATA PI / 3.141592654 /
      DATA MAXN / 20 /
      DATA BTUCAL / 3.9683207E-03 /
      DATA FT2CM2 / 1.076391E-03 /
C
         TI = ELAPSE*3600.
         SUMN = 0.
         NSTEPS = HMEM/DELTAT

         DO N = MAXN,0,-1
          HSUB = ( 1. / (2*N+1)**2)
     &            * EXP ((-TDK * (2*N+1)**2 * PI**2 * TI) / (4. * Z**2))
          SUMN = SUMN + HSUB
         END DO

         HT(NNODE,IT,NSEG) = CV * Z * (1. - 8./PI**2 * SUMN)
         IS = IT-NSTEPS
         IF (IS .LE. 0) IS=1
         HP = 0.
         IF (IT .GT. 1) THEN
           DH(NNODE,IT,NSEG) = HT(NNODE,IT-1,NSEG) - HT(NNODE,IT,NSEG)
           DO J=IS,IT-1
             HP = HP + DTEMP(NNODE,J,NSEG)*DH(NNODE,IT-J,NSEG)
          END DO
         END IF
         HP = HP * BTUCAL / FT2CM2
      RETURN
      END
```