PPRP-DC-4

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YOUGHIOGHENY RIVER TEMPERATURE ENHANCEMENT PROTOCOL FOR OPERATING DEEP CREEK HYDROELECTRIC STATION: MODEL DEVELOPMENT AND RESULTS FOR 1995-2000

February 2001

MARYLAND POWER PLANT RESEARCH PROGRAM

STATE OF MARYLAND
DEPARTMENT OF NATURAL RESOURCES

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Maryland Department of Natural Resources
Tawes State Office Building
Annapolis, Maryland 21401-2397
Phone: 1-800-620-8DNR
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Prepared for

Richard McLean
Power Plant Assessment Division
Maryland Department of Natural Resources
Tawes State Office Building, B-3
580 Taylor Avenue
Annapolis, Maryland 21401

Prepared by

Stephen P. Schreiner
Versar, Inc.
ESM Operations
9200 Rumsey Road
Columbia, Maryland 21045

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FOREWORD

This report, entitled *"Youghiogheny River Temperature Enhancement Protocol for Operating Deep Creek Hydroelectric Station: Model Development and Results for 1995-2000,"* was prepared by Steve Schreiner of Versar, Inc. at the request of Richard McLean, Power Plant Assessment Division, Maryland Department of Natural Resources, as part of Biology Integrator Contract No. PR 96-055-001 Task 14.

ABSTRACT

The Deep Creek Hydroelectric Station generates electricity by periodically releasing water impounded at Deep Creek Lake into the Youghiogheny River. Historically, the timing and duration of these releases were primarily driven by the economics of power generation and water availability in Deep Creek Lake. As part of the Federal Energy Regulatory Commission relicensing and State of Maryland permitting processes, the station owner, then the Pennsylvania Electric Company, and the Maryland Power Plant Research Program evaluated the uses of project releases to provide minimum flows for fish habitat, flows scheduled for whitewater boating recreation, and flows to moderate elevated river temperatures to enhance fish habitat. The evaluations designated temperature as the primary factor determining fish habitat quality; thus, improving the conditions for the fish by lowering the water temperature to a suitable range is incorporated in the term *temperature enhancement*. Previous studies indicated that appropriately timed power generation releases would be the most cost-effective and balanced use of project releases to lower the river temperature, thereby enhancing fish habitat from the power plant tailrace for a distance of at least 5.8 km (3.6 miles) downstream. This report describes 1) the development of a model to predict river temperature; 2) an operating protocol for temperature enhancement releases; and, 3) the results of the first six years during which the protocol was implemented.

A model and protocol for predicting maximum daily river temperature during summer was developed using daily measurements of river flow and temperature changes and available predictions of maximum daily air temperature and cloud cover in the region of the project. The prediction model consists of a series of equations (developed using multiple regression) to be used by power plant operators during the morning and early afternoon to predict river temperature. The operators use these predictions to determine whether a release is needed to enhance temperature. These releases are then announced to the public via a telephone recording. The target maximum river temperature is 25 °C, a maximum value for brown trout habitat. The model equations were based on historical data from 1987 through 1993 for daily average river flow, hourly river temperatures, maximum daily air temperature, and mid-day cloud-cover fraction. Using these equations for the time frame covered by the historical data, the rate of unnecessary releases (i.e., temperature enhancement releases not needed to improve water temperature conditions from unsuitable to suitable for fish habitat) was estimated to be about 14 percent, and the rate of failure to make needed releases for temperature improvements was estimated to be about 4 percent. In an average year needing 17 releases for temperature enhancement, only two to three unnecessary releases would be made.

During the first six years in which the protocol was implemented, the total number of days when temperature exceeded 25 °C at Sang Run ranged from two in 1996 to 18 in 1995. Temperatures in excess of 25 °C at Sang Run without operation of the Deep Creek Project would have ranged from 4 to 10 days in 1996 to between 44 and 69 days in 1999. Maximum river temperature rarely exceeded 27 °C at Sang Run and was less than 26 °C on most of the days when it exceeded 25 °C. In contrast, the actual maximum temperature at

Swallow Falls was above 27.5 °C 10 times in 1995 and 14 times in 1999. Maximum temperature exceeded 30 °C seven times and six times in those same years. The data from Swallow Falls suggest that there were very few days when releasing water for temperature enhancement was unnecessary.

Implementation of the temperature enhancement protocol between 1995 and 2000 was very successful at maintaining lower temperatures than would otherwise have occurred in the river without the releases. A small further improvement is possible with more effective operator training in implementing the protocol to make sure that water is released when necessary. The only feasible changes in the protocol that might improve the temperature enhancement plan would be to slightly reduce the low morning temperature threshold, which would have prevented a temperature exceedance on one date, and to raise the flow threshold to 120 cubic feet per second (cfs), which would have prevented exceedances on three dates during the 1995 to 2000 period.

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1.0 INTRODUCTION

The Pennsylvania Electric Company (Penelec)[1] received a Water Appropriations Permit to operate the Deep Creek Hydroelectric Station for power generation from the Maryland Department of Natural Resources (MDNR) Water Resources Administration (WRA).[2] Condition 16 of this permit requires Penelec to submit a plan for operating the project to maintain temperatures of less than 25 °C in the Youghiogheny River between the Deep Creek tailrace and Sang Run 5.8 km (3.6 miles) downstream (Figure 1-1). The purpose of this condition is to enhance cool-water habitat for trout in this reach of the river. In the plan, temperature was designated as the primary factor determining fish habitat quality; thus, improving the conditions for the fish by lowering the water temperature to a suitable range is incorporated in the term *temperature enhancement*.

Penelec outlined a general temperature enhancement protocol (Penelec 1994) for operating the power plant to (1) operate the Deep Creek Station, as necessary, to prevent water temperatures from exceeding 25 °C in the Youghiogheny River between the tailrace and Sang Run; (2) minimize unnecessary releases for this purpose; (3) provide maximum advance notice of releases to those interested in whitewater recreation; and, (4) provide simple, automated implementation. Using available historical river temperature and meteorological data, MDNR's Power Plant Research Program (PPRP) worked with Penelec to develop and test a model to meet these goals.

This report describes development of a model for predicting maximum daily river temperature during summer using daily measurements of river flow and temperature changes in the river and available predictions of maximum daily air temperature and cloud cover in the region of the project. The model consists of a series of equations (developed using multiple regression) to be used by power plant operators during the morning and early afternoon to predict river temperature. The operators use these predictions to determine whether a release is needed to maintain the desired temperature. These releases are then announced to the public via a telephone recording. This report also presents results of the first six years the protocol was implemented in the summers of 1995 through 2000.

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[1]GPU, the parent company of Penelec, has sold most of its generating assets including Deep Creek, to Sithe Energies, Inc., which subsequently transferred these assets to Reliant Energy, which currently operates the project.

[2]Following reorganization of state government in 1995, this permit is now administered by the Maryland Department of the Environment.

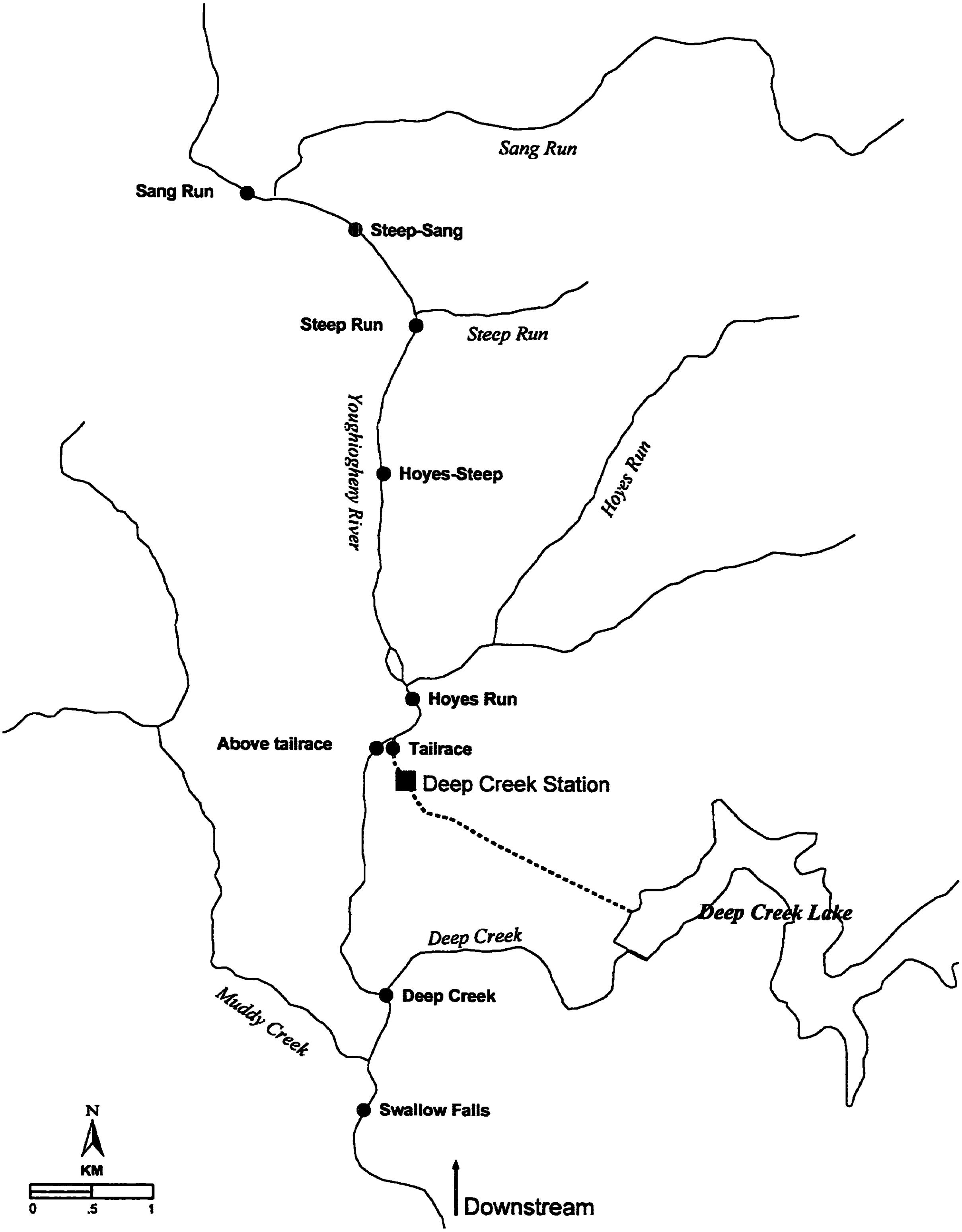

Figure 1-1. Map of the Youghiogheny River between Swallow Falls and Sang Run, MD, showing location of Deep Creek Station tailrace, temperature sampling stations and major tributaries.

2.0 MODEL DEVELOPMENT

2.1 INPUT DATA

Schreiner (1997a, b) used a combination of simulation modeling and test releases from the Deep Creek Station to show that a 2-hour, 2-unit release beginning at 1100 hours would be sufficient to maintain temperatures less than 25 °C in the river to Sang Run, even under very warm, low flow, conditions. Although other release scenarios are possible (e.g., several hours of a minimum flow of 2.83 m^3/s (100 cubic feet per second [cfs]) or a series of pulsed operational releases), a 2-hour, 2-unit release would generate power and could be used for whitewater recreation if potential users were notified in advance. The first step in developing a release protocol with advance notification was to identify means for predicting when river temperatures will exceed a certain target. In this case, 25 °C was used to trigger a temperature enhancement release based on the temperature requirements of brown trout (see Schreiner 1998). In developing this protocol, it was assumed that the power company would use a 2-hour, 2-unit release to maintain the desired temperature whenever at least three hours advance notice could be provided for potential use by whitewater boaters. Under less extreme conditions (maximum river temperatures of less than 26 °C to 27 °C), only a 1-hour, 2-unit release would be required, and would be used whenever less than three hours notice would be possible.

River temperature is affected by inflow volume and temperature, air temperature, solar radiation, humidity, wind speed, and other factors. Predicting river temperature requires forecasted meteorological parameters, measured river temperature, and flow measurements. The MDNR's Division of Freshwater Fisheries has monitored summer water temperature in the Youghiogheny River from locations above the tailrace to Sang Run since 1987. Data from 1987 to 1993 were used to develop a set of equations using multiple regression to predict maximum river temperature based on river flow, temperature, and meteorological variables. Since the historical data showed no occurrences of river temperature over 25 °C before June 1 or after August 31 during these years, only data from June through August were used.

The two most important meteorological factors affecting the diurnal increase in river temperature are air temperature over the river and solar radiation entering the river. These parameters are not measured at or near this section of the Youghiogheny River, although daily minimum and maximum air temperatures were recorded nearby in McHenry and Oakland, MD. Solar radiation is not measured routinely at any nearby locations; however, cloud cover can be used as a surrogate measure. The closest sites with recorded cloud cover are Elkins and Morgantown, WV. Hourly air temperature and cloud cover data for these locations are available from the National Climatic Data Center. Because river temperature will be predicted based on air temperature and cloud cover, a prediction model must be based on forecasts of this information. Forecasts are available for Elkins and Morgantown, WV, but not for Oakland or McHenry, MD.

Choosing which station to use for meteorological data depended on how well each candidate station represented the proposed site. Data are collected hourly on a 24-hour basis at Morgantown, which is about 47 km (29 miles) west-northwest of the Youghiogheny River site, at elevation 381 m (1250 feet) above mean sea level (MSL). Historically, data were collected hourly for approximately 18 hours per day at Elkins, which is about 84 km (52 miles) south-southeast of the Youghiogheny site, at elevation 607 m (1990 feet) MSL. The Youghiogheny site is at an elevation of about 610 m (2000 feet) MSL. To select the most appropriate source of data for predicting the temperature of the Youghiogheny River, available air temperature data from Elkins and Morgantown were compared with data from Oakland, MD.

Differences in maximum and minimum air temperature values between all stations were significant (based on a paired t-test, $p=0.0001$) for this data set. Differences in cloud cover between Morgantown and Elkins were not significant (based on a paired t-test, $p=0.22$). The Elkins station is more similar to Oakland than is the Morgantown station with regard to air temperature. No data on cloud cover in Oakland were available. These results, combined with the fact that the elevation at Elkins is closer to that at the Youghiogheny River site, showed that data from the Elkins station is the best to use for developing a model to predict the temperature of the Youghiogeny River.

Based on available observations of river temperature and flow, monitoring for a temperature release would be needed only when the river flow at Oakland was less than 2.8 m^3/s (100 cfs, equivalent to about 4.1 m^3/s [146 cfs] in the river just above the tailrace). This threshold allows the power company to limit monitoring to periods when river temperature is most likely to exceed the desired threshold for an enhancement release and minimize monitoring costs. The tailrace flow value was calculated from the equation $Q_{DC} = 1.68 \times Q_o^{0.97}$, where Q_{DC} is the flow (in cfs) above Deep Creek Station and Q_o is the flow at Oakland (Penelec 1994). Figure 2-1 illustrates the relationship between daily average river flow and daily maximum water temperature in the Youghiogheny River near Sang Run during the summer, when the project was not operating. The figure illustrates that river temperature exceeded 25°C only when flows at Oakland were less than about 2.8 m^3/s (100 cfs). There appears to be little relationship between flow and river temperature at low flows (i.e., less than 0.85 to 1.1 m^3/s [30 to 40 cfs]). Successive regressions between flow and temperature, with the flow range varying from 0.57 to 1.1 m^3/s (20 to 40 cfs) up to 4.8 m^3/s (170 cfs), shows a maximum correlation in the range of 0.85 to 4.8 m^3/s (30 to 170 cfs).

2.2 REGRESSION EQUATIONS

River flow, water temperature, air temperature, cloud cover, and project operation information were used to develop a series of regression equations to predict maximum river temperature at Sang Run at various times of the morning and early afternoon during summer days, when a temperature release could be required. Only data for days when the river flow at Oakland did not exceed 2.8 m^3/s (100 cfs) and generation did not occur from Deep Creek

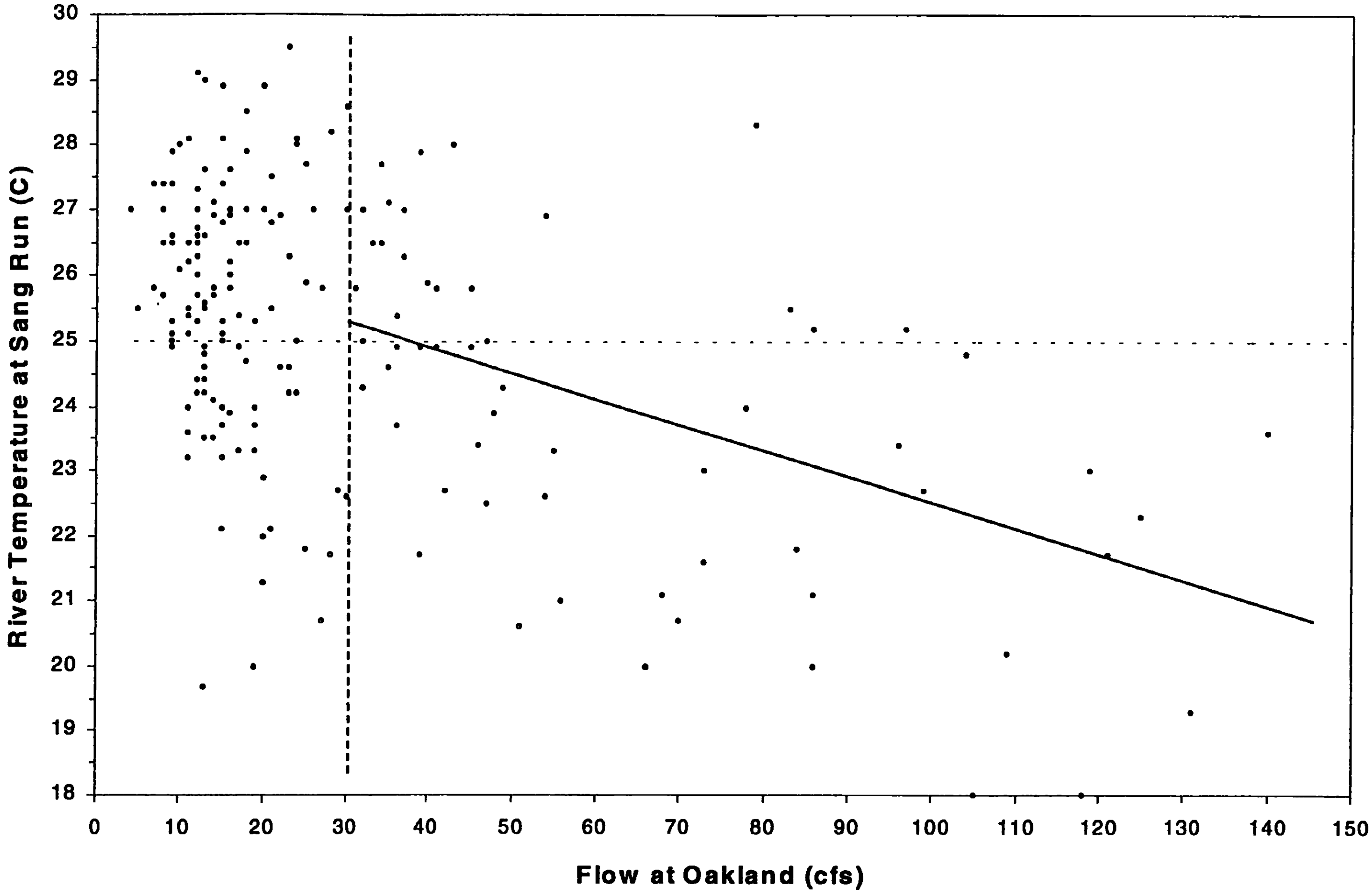

Figure 2-1. Daily average flow in the Youghiogheny River at Oakland, MD, and maximum daily water temperature at Sang Run for June through August 1987 to 1993, on days when the Deep Creek Station was not operated. Vertical line at 30 cfs (0.85m^3/s) shows the break-point below which there is no significant relationship between flow and river temperature. The diagonal line shows the relationship between flow and temperature between 30 and 170 cfs (0.85 to 4.8 m^3/s) at Oakland (river temperature = 26.5 - 0.04* flow; R^2 = 0.28).

Station (or when generation occurred after 1500 because generation after that time would not affect maximum river temperature) were used to develop the models.

Although the power company could use weather data forecasted the day before a potential release to predict maximum river temperature on the following day, rather than using data forecasted on the day of a release, the greater uncertainty in the information would probably result in more unnecessary releases. The resulting extra use of water could affect scheduled whitewater releases, lake levels, and other generation releases. Using data forecasted before the day of a release, therefore, was not considered a reasonable option for predicting maximum river temperature.

Combinations of variables were tested to obtain the best predictions of maximum daily river temperature for several times during the day. Table 2-1 lists these variables.

Table 2-1. Parameters tested for use as regression predictors of maximum daily river temperature in the Youghiogheny River at Sang Run.	
Flow (daily average)	
All flows < 2.8 m^3/s (100 cfs) at Oakland Flows < 0.85 m^3/s (30 cfs) Flows > 0.85 m^3/s (30 cfs) and < 2.8 m^3/s (100 cfs)	
Air Temperature (daily)	
Maximum at Elkins Minimum at Elkins	
Cloud Cover Fraction at Elkins (average of 1000-1400)	
Square of Cloud Cover Fraction at Elkins	
Cloud cover factor from physical water temperature model (Brown and Barnwell, 1987): $1 - (0.65 * (\text{cloud cover fraction}/10)^2)$	
Measured River Water Temperatures (at local times listed below)	
0700 0900 1100	1200 1400 1500

2.3 REGRESSION RESULTS

Table 2-2 lists the results of the multiple regression analyses, using the input data discussed above, to predict maximum water temperature in the river at Sang Run. Although many combinations of variables were analyzed, Table 2-2 includes only the model results with the highest R^2 and the variables with a statistically significant influence on maximum river

Table 2-2. Youghiogheny River temperature prediction regression results using 1987 through 1993 river temperatures at Sang Run and meteorological data from Elkins, WV, on days with either no generation or generation after 1500 and river flow at Oakland less than 2.8 m³/s (100 cfs).

Model Number and Hour of Prediction	Variables	Parameter Estimate	Partial R-Square	Model R-Square
PSANG1 (no water temperature available)	(intercept)	14.430	-	-
	TMAXAIR	0.356	0.53	0.53
	CLOUDCOV	-0.017	0.02	0.55
	TMINAIR	0.109	0.03	0.58
RMS=1.28				
PSANG2 (0700)	(intercept)	10.920	-	-
	TMAXAIR	0.322	0.53	0.53
	CLOUDCOV	-0.019	0.06	0.56
	S7	0.338	0.03	0.62
RMS = 1.21				
PSANG3 (0900)	(intercept)	10.203	-	-
	TMAXAIR	0.284	0.53	0.53
	CLOUDCOV	-0.021	0.07	0.60
	S9	1.208	0.04	0.64
	S7	-0.779	0.02	0.65
RMS = 1.16				
PSANG4 (1100)	(intercept)	6.202	-	-
	TMAXAIR	0.247	0.55	0.58
	S11	1.393	0.09	0.64
	S9	-0.828	0.08	0.72
	CLOUDCOV	-0.010	0.01	0.74
RMS = 1.08				
PSANG5 (1200)	(intercept)	5.555	-	-
	TMAXAIR	0.214	0.55	0.55
	S12	1.059	0.13	0.68
	S9	-0.448	0.06	0.74
RMS = 1.06	CLOUDCOV	-0.008	0.01	0.75
PSANG6 (1400)	(intercept)	3.563	-	-
	S14	1.356	0.80	0.80
	S12	-0.600	0.05	0.86
RMS = 0.76	TMAXAIR	0.103	0.01	0.87
PSANG7 (1500)	(intercept)	3.075	-	-
	S15	1.140	0.89	0.89
	S12	-0.312	0.02	0.91
RMS = 0.61	TMAXAIR	0.049	0.002	0.92

Variables:
TMAXAIR,TMINAIR = Maximum, minimum daily air temperature at Elkins, WV (°C)
CLOUDCOV = Square of total opaque cloud cover, as measured at Elkins, WV, from 1000 to 1500, fraction from 0 (no clouds) to 10 (totally cloud-covered)
S7 - S15 = Temperature at Sang Run 0700 to 1500 (°C)
OFLOW = Daily average flow at Oakland (cfs)
RMS = Root Mean Squared error

temperature. The most important variables for all equations were maximum daily air temperature at Elkins (TMAXAIR), average total opaque cloud cover at Elkins (CLOUDCOV), and various combinations of river temperature values measured throughout the day. Table 2-2 shows the diminishing importance of the predicted variables of TMAXAIR and CLOUDCOV as the day progresses as shown in the partial R-square column; the models rely more on measured river temperatures from 1200 through 1500. Equations based on earlier data will provide advance notice of the most likely releases (those needed for the highest temperatures) and minimize unnecessary releases. Releases needed for less severe temperatures are made later during the morning or early afternoon using the equations based on later information.

There are two distinct groups of data with respect to the relationship between flow and river temperature (see Figure 2-1). Initial results showed that two formulas, based on flows greater or less than 0.85 m^3/s (30 cfs), would provide the best model for predicting temperature. However, to avoid the greater operational complexity of using two formulas based on river flow, the regressions for models to be used before 1100 were run by adjusting the value of the measured temperature in the Youghiogheny River at Sang Run to account for the higher flows. This adjustment was made whenever the daily average flow at Oakland was greater than 0.85 m^3/s (30 cfs). The formula used was SMAXADJ = SMAX - 0.04 (OFLOW - 30), where SMAXADJ is Sang Run adjusted temperature, SMAX is Sang Run maximum daily temperature (°C), and OFLOW is daily average river flow at Oakland (cfs). The value of SMAXADJ was then used as the dependent variable in the regressions for these models (PSANG1 through PSANG3). This adjustment creates one set of parameter estimates for the independent variables (e.g., maximum air temperature, cloud cover) for the full range of flow being considered while still allowing for the effect of flow on river temperature.

Predictions must be conservative to minimize unnecessary releases. Since predicted air temperature and cloud cover data instead of measured data are used in implementing the protocol, predictions of maximum river temperature are less certain than suggested in Table 2-2, which is based on actual rather than forecasted data. The following adjustments were made to account for this uncertainty, at least partially, and to use historical data to estimate the number of releases that would be triggered. Measured maximum air temperature was adjusted downward by 1.5 °C (2.7 °F) because forecasts are often given as a range (e.g., upper 80s °F could be 87 to 89.9 °F). Cloud cover forecasts usually are provided as descriptions; Table 2-3 lists these descriptions and their quantitative definitions. The measured cloud cover values were adjusted to the upper limit of each of the first five categories.

Maximum river temperature was predicted using the equations listed in Table 2-4 with the historical data and adjusted maximum air temperature and cloud cover values as described above for PSANG2 through PSANG5. After 1200 (PSANG6 and PSANG7), maximum air temperature and cloud cover are less important predictors of maximum river temperature than measured temperatures; therefore, the uncertainty adjustments were not used.

PSANG1 is intended for use only when measured water temperature data are not available (e.g., due to sensor failure). A conservative estimate cannot be made in this case because only one prediction can be made on a given day. Higher numbers of false positives (unnecessary releases) and false negatives (failures to make needed releases) will occur with PSANG1 than with releases based on water temperature measurements (PSANG2 through PSANG7).

Table 2-3. Ranges of fractional cloud cover associated with descriptions of cloudiness. Source: National Weather Service, 1995

Description	Lower Limit	Upper Limit	Midpoint
Overcast or Cloudy	9	10	9.5
Mostly Cloudy or Considerable Cloudiness	7	8	7.5
Partly Cloudy or Partly Sunny	3	6	4.5
Mostly Clear or Mostly Sunny	1	3	2.0
Clear or Sunny	0	1	0.5
Fair	0	4	2.0
Variable Cloudiness	0	10	5.0

Sensor reading times were chosen to maximize the number of releases for which at least three hours of notice could be provided while minimizing the number of unneeded releases and limiting the total number of readings to six. The earliest temperature enhancement release would occur at 1100 hours, based on sensor readings at 0700 and 0900 hours, and the released water would reach Sang Run at 1300 hours. Releases based on these readings would provide maximum notice times of six and four hours, respectively. A sensor reading at 1100 hours originally was planned to trigger a release at 1200 hours, which would reach Sang Run at 1400 hours, for a maximum of three hours notice. At the request of American Whitewater Affiliation (AWA), a release time of 1230 (to reach Sang Run at 1430 and provide an additional half-hour of notice) was evaluated. The risk of river temperature exceeding 25 °C increased slightly with the later release time.

Table 2-5 summarizes the temperature enhancement release protocol and results using historical data. Trigger temperatures were selected so that releases would minimize false positives, particularly for PSANG2 through PSANG4, without severely restricting the number of releases for which notification could be provided. Based on historical data, using this model would result in about a 14-percent rate of unnecessary releases (false positives) and about a 4-percent rate of failure to make needed releases (false negatives). The actual temperature was 25 °C for four of the 16 "unnecessary" releases and 24.9 °C for three of those releases. This means that almost half of the unnecessary releases were triggered by temperatures very close to the threshold temperature. Based on total percentage of unnecessary releases estimated from historical data, two to three additional releases would be made during an average year that required 17 temperature enhancement releases.

Table 2-4. Youghiogheny River temperature prediction equations.

Hour	Equation
-	PSANG1a = 14.43 + .356*TMAXAIR - 0.017*CLOUDCOV + .109*TMINAIR : (oflow ≤ 30 cfs) PSANG1b = 14.43 + .356*TMAXAIR - 0.017*CLOUDCOV + .109*TMINAIR - 0.04* (OFLOW -30) : (oflow > 30 cfs)
0700	PSANG2a = 10.926 + .322*TMAXAIR - .019*CLOUDCOV + .338*S7 : (oflow ≤ 30 cfs) PSANG2b = 10.926 + .322*TMAXAIR - .019*CLOUDCOV + .338*S7 - 0.04* (OFLOW -30) : (oflow > 30 cfs)
0900	PSANG3a = 10.203 + .284*TMAXAIR - .021*CLOUDCOV + 1.208*S9 - 0.779*S7 : (oflow ≤ 30 cfs) PSANG3b = 10.203 + .284*TMAXAIR - .021*CLOUDCOV + 1.208*S9 - 0.779*S7 - 0.04* (OFLOW -30) : (oflow > 30 cfs)
1100	PSANG4 = 6.202 + .247*TMAXAIR - .010*CLOUDCOV - .828*S9 + 1.393*S11
1200	PSANG5 = 5.555 + .214*TMAXAIR - .008*CLOUDCOV - .448*S9 + 1.059*S12
1400	PSANG6 = 3.563 + .103*TMAXAIR - .600*S12 + 1.356*S14
1500	PSANG7 = 3.075 + .049*TMAXAIR - .312*S12 + 1.140*S15

Variables:

TMAXAIR = Predicted maximum air temperature for Elkins WV (°C)
CLOUDCOV = Square of predicted local cloud cover fraction (see Table 3)
TMINAIR = Measured minimum air temperature for Elkins WV (°C)
S7 - S15 = Measured temperature in the Youghiogheny River at Sang Run at hours indicated (°C)
OFLOW = Flow at Oakland gage (cfs)

Note: To test the models PSANG2 - PSANG5 under forecasting uncertainty using the measured data, TMAXAIR = TMAXAIR - 1.5 (measured maximum air temperature at Elkins, WV - 1.5) and CLOUDCOV = square of upper limit of the category listed in Table 2-3, based on the measured total opaque cloud cover at Elkins, WV between 1000 - 1400.

Table 2-5. Predicted results using Youghiogheny River temperature enhancement release protocol based on 177 days of historical data from 1987 through 1993.

	PSANG1	PSANG2	PSANG3	PSANG4	PSANG5	PSANG6	PSANG7	TOTAL
Read sensor	-	0700	0900	1100	1200	1400	1500	
Release time	1100	1100	1100	1230	1200	1400	1500	
Time at Sang Run	1300	1300	1300	1430	1400	1600	1700	
Release duration (hr)	2	2	2	2	1	1	1	
Maximum notice (hr)	6	6	4	3.5	2	2	2	
Trigger temperature °C	25.1	26.4	25.9	25.4	25.3	25.2	25.1	
Total releases	112	25	22	28	11	18	8	112
Percent total	-	22	20	25	10	16	7	
Cumulative percent	-	22	42	67	77	93	100	
False positive (unneeded release)	24	0	1	4	3	4	4	16 (14%)
False negative (needed release not made)	13						5	5 (4%)

Note: The distribution of actual maximum river temperature on dates with unneeded releases (false positives) is as follows: 4 @ 25.0; 3 @ 24.9; 2 @ 24.6; 1 @ 24.2; 3 @ 24.0, 2 @ 23.9; and 1 @ 23.4. The actual temperatures on dates when a needed release was not made (false negatives) are: 25.8, 25.4, 25.3, and 2 @ 25.2.

3.0 MODEL TESTING

3.1 DATA SOURCES

The power company recorded water temperatures at the Sang Run bridge at two-minute intervals from June through August in 1995 through 2000. These data were used by the station operators in real-time so they could decide whether to release water for temperature enhancement according to the protocol. For the analysis presented here, one two-minute data measurement was extracted from the data set at half-hour intervals for comparison with data collected by MDNR using TempMentors placed in the river at several locations (see Figure 1-1) from Swallow Falls to Sang Run. The TempMentors recorded temperatures at half-hour intervals for various dates in June through sometime in September of each year from 1995 through 2000. These data were available after the summer season to evaluate river temperature and its relationship to releases from Deep Creek Station.

The average of MDNR's TempMentor data from two recorders at the Sang Run station were used to determine if the target temperature of 25 °C was maintained because the power company data were at times missing or invalid. Data from the upstream Swallow Falls station were used to estimate what the river temperature at Sang Run would have been without releases from Deep Creek Station.

The power company used forecasted information from Elkins, WV, as part of the temperature release protocol. This information was used during June through August when no releases were made for any purpose other than temperature enhancement. Hourly records of actual meteorological data from the Elkins station were obtained from the National Climatic Data Center in Asheville, NC, after the summer season. These data were used to obtain daily values for actual cloud cover and daily minimum and maximum air temperatures for comparison with predicted values. Daily minimum and maximum air temperatures for Oakland, MD, were also obtained.

Prior to 1996, cloud cover information was available for the Elkins station as cloud cover fraction in tenths, a number ranging from 0 to 10. As shown in Table 2-3, these numerical values correspond to certain descriptive terms for cloud cover. In 1996, because the station was automated, cloud cover fraction was no longer reported using the same scale. Instead, sky cover descriptive terms were used. These descriptive terms were converted to an average numerical value on the same scale as the earlier data as follows: CLR or FEW = 0.5; SCT = 3; BKN = 7.5; OVC = 9.5. These values were used for analyses using the measured cloud cover fractions; the power company continued to use descriptions of cloud cover predictions as listed in Table 2-3.

The power company obtained instantaneous, early morning flow readings for the Youghiogheny River at Oakland from the U.S. Army Corps of Engineers' river bulletin board (Internet address: http://www.orp-wc.usace.army.mil/current/yc.html). Flow information recorded at 15-minute intervals was obtained after each summer season from the U.S. Geological Survey (station number 03075500) and summarized to provide daily averages. Average flow for June through August of each year is listed in Table 3-1.

Table 3-1. Average flow (cubic feet per second or cfs) in the Youghiogheny River for June through August, 1995 -2000, in comparison with the long-term average flow (1942-2000) at Oakland, Maryland (USGS station 03075500).

Year	Rank (58 = wettest)	June	July	August	June-August
1995	17	111	37	116	88
1996	57	273	567	362	401
1997	34	240	75	150	155
1998	44	417	205	78	231
1999	3	23	21	14	19
2000	39	254	257	75	195
Average (1942-2000)	29	204	163	131	166

3.2 RESULTS

Table 3-2 summarizes the releases from Deep Creek Station between June 1 and August 31. The table shows the percentage of the days during the period that had announced and scheduled releases (at least one day in advance). Announced and scheduled whitewater releases were 15% to 37% of the total (these are scheduled for Mondays, Fridays, and at least one Saturday per month, water levels permitting), and announced and scheduled releases for power generation were 0% to 27% of the total. Unscheduled releases were 21% to 45% of the total, consisting of 9% to 32% for temperature enhancement and 2% to 35% for unscheduled power generation. There were no releases of any kind on 21% to 51% of days during this period.

Comparing Tables 3-1 and 3-2 shows that a greater percentage of days with temperature releases occurred during dry years (1995 and 1999) and the smallest percentage occurred during the wettest year (1996). The percentage of whitewater releases decreased very slightly from 1995 through 1998 and 2000, but there was a large drop in 1999 due to lack of water. The percentage of announced releases for discretionary power generation decreased over this period due to lack of advance forecasting by the power company as

Table 3-2. Summary of releases from Deep Creek Station during implementation of the temperature enhancement protocol (June 1 through August 31).

Release Type	Number of days						Percentage of days					
Year:	1995	1996	1997	1998	1999	2000	1995	1996	1997	1998	1999	2000
Announced and scheduled for whitewater	34	33	33	31	14	29	37	36	36	34	15	32
Announced and scheduled for power	10	25	8	1	0	1	11	27	9	1	0	1
TOTAL announced and scheduled	**44**	**58**	**41**	**32**	**14**	**30**	**48**	**63**	**45**	**35**	**15**	**33**
Not announced or scheduled (for power)	8	11	7	32	2	21	9	12	8	35	2	23
Temperature enhancement	24	8	13	9	29	8	26	9	14	10	32	9
TOTAL unscheduled	**32**	**19**	**20**	**41**	**31**	**29**	**35**	**21**	**22**	**45**	**34**	**32**
Days with no release	16	15	31	19	47	33	17	16	34	21	51	36
TOTAL DAYS or percent	**92**	**92**	**92**	**92**	**92**	**92**	**100**	**100**	**101**	**101**	**100**	**101**

deregulation was introduced during this time. Unannounced generation correspondingly increased during this period, except in 1999 when lack of rainfall resulted in a loss of nearly all discretionary generation during the summer period.

Days on which the river temperature at Sang Run exceeded 25 °C (at either the DNR or power company sensors) were evaluated in detail. This evaluation includes a list of dates of exceedances (Appendix 1), the duration and time of the exceedance, the maximum temperature at each sensor, the time and duration of a release from the power plant (if any), and an evaluation of the protocol equation parameters. Exceedances could have several causes, including 1) failure of the protocol to be implemented correctly (operator error); 2) conditions under which the protocol was not required to be implemented (flow at Oakland greater than 100 cfs or 7 a.m. temperature prediction less than or equal to 23 °C); or, 3) uncertainty in the forecast data, river monitoring data, or uncertainty inherent in the regression model equations.

A summary of primary causes for the temperature exceedances is listed in Table 3-3. The causes listed in the first three rows of the table were not related to use of the protocol equations (the primary causes are indicated in the first column). Specifically, there were four times (7 percent of the total exceedances) in 1995 when the operators failed to follow the protocol correctly when it was first implemented. This failure was corrected and did not recur. There were eight times (14 percent) when the flow at Oakland was greater than 100 cfs and thus the protocol equations were not implement as specified in the protocol. As described in Section 2.2, there were no occasions in the test data collected in 1987 to 1993 when temperature exceeded 25 °C and river flow was greater than 100 cfs; however, this did occur five times in 1995 and one time each in 1996, 1997, and 2000. In four of the eight cases, raising the flow threshold from 100 to 120 cfs would likely have resulted in successfully maintaining temperature less than 25 °C. In the remaining four cases, river flow was well above 120 cfs at the time the protocol would have been implemented. Raising the flow threshold or eliminating it entirely would probably not have resulted in maintaining river temperature less that 25 °C. This is because the larger volume of stormwater runoff in the river would displace the power plant discharge relatively quickly unless the release was maintained for a much longer period than practicable. Once (in 1995), the 0700 prediction temperature was less than 23 °C but the maximum temperature eventually exceeded 25 °C; this suggests that lowering this criterion in the protocol might improve results. The remaining 41 (78 percent) exceedances were due to uncertainty in the forecast or monitoring data or due to uncertainty within the regression model itself. Evaluation of these exceedances is described in detail below.

Table 3-3. Summary of causes for temperature exceeding 25 °C at DNR sensors in the Youghiogheny River at Sang Run.

Primary Cause	Number of Times							
Year:	1995	1996	1997	1998	1999	2000	Total	Percent of Total
Operator error	4	0	0	0	0	0	4	7
Flow > 100 cfs at Oakland	5	1	1	0	0	1	8	14
Low a.m. temperature	1	0	0	0	0	0	1	2
Forecast uncertainty	4	0	3	2	4	0	13	23
Monitoring uncertainty	0	0	3	5	1	2	11	20
Forecast and monitoring uncertainty	0	1	2	2	2	0	7	13
Model uncertainty	4	0	2	1	5	0	12	21
TOTAL	**18**	**2**	**11**	**10**	**12**	**3**	**56**	**100**

The protocol equations were used to calculate the time when an exceedance would occur, using different variables to pinpoint the likely cause of the exceedance (i.e., what parameter or other factor led to a predicted river temperature less than 25 °C on days when the actual river temperature was greater than 25 °C). The variable combinations used in this evaluation are presented in Table 3-4. If all of the test combinations resulted in the same predicted exceedance time, inherent uncertainty in the protocol is assumed to be responsible for the temperature exceedance, rather than due to the uncertainty in the forecast or monitoring data. This usually occurred when the exceedance temperature was very close to the threshold value of 25 °C.

Table 3-4. Variable combinations used in the evaluation.

Variable combination	Parameter	Variation (substitution)	Resulting uncertainty
A	Approved protocol variables; all parameters as listed	None	N/A
B	TMAXAIR	Actual for predicted	Air temperature
C	Predicted cloud cover at Elkins (base for CLOUDCOV calculations)	Actual for predicted	Cloud cover
D	TMAXAIR, Predicted cloud cover at Elkins	Actual for predicted	Air temperature and cloud cover
E	S7 - S15 (water temperature)	DNR values for Penelec values	Monitoring data
F	TMAXAIR, Predicted cloud cover at Elkins, S7 - S15	Actual for predicted (air and cloud cover); DNR values for Penelec values (water temperature)	Forecast and monitoring data

As indicated above, results listed in Table 3-3 show that 77 percent of the exceedances between 1995 and 2000 were due to uncertainty in the weather forecast data (23 percent), in the monitoring data (20 percent), in a combination of forecast and monitoring data (13 percent), or in the model equations (21 percent). Forecast uncertainty can be divided into uncertainty in the cloud cover (46 percent), air temperature (8 percent), or a combination of the two (46 percent). This uncertainty could probably be improved to some extent by revising the protocol to use local weather data, but at considerable expense to collect the necessary data, revise the protocol, and provide a site-specific weather forecast. Monitoring uncertainty could be divided into uncertainty in the temperature measurement itself and that due to natural spatial and temporal variability in river temperature. Natural variability is probably greater than measurement uncertainty, suggesting there is no way to reduce the uncertainty in the way the protocol is implemented. Uncertainty within the model is due to a combination of the limited data that was used to develop it and by the fact that there is nearly a two-hour lag time between a power plant release and the temperature reduction at Sang Run. When the river temperature gets close to the target value, the model cannot predict an exceedance in time for a release to prevent it.

Table 3-5 illustrates the frequency distribution of river temperatures greater than 25 °C at Sang Run compared with actual temperatures at Swallow Falls, and adjusted to show a range of temperatures at Sang Run without releases from the Deep Creek Station. (As described earlier, the temperature at Swallow Falls was an average of 1.4 °C warmer than at Sang Run (in the absence of plant operation), based on data from 1987 and 1993.) Thus, the actual and adjusted Swallow Falls temperature values provide a range of estimates of what the river temperature would have been at Sang Run in the absence of releases from Deep Creek Station. Although there were between two and 18 days per year in which river temperatures exceeded 25 °C at Sang Run, the maximum temperature rarely exceeded 27 °C, and most of the time, the maximum temperature was less than 26 °C. In contrast, the actual maximum temperature at Swallow Falls was above 27.5 °C 10 times in 1995 and 14 times in 1999. Maximum temperature exceeded 30 °C seven times and six times in those same years.

Table 3-5. Distribution of temperatures greater than 25°C in the Youghiogheny River at Sang Run and Swallow Falls between June and August (Swallow Falls data were also adjusted to represent temperatures in Sang Run without releases from Deep Creek Station by subtracting 1.4 degrees (C) from the measured temperature at Swallow Falls).

Temperature Range (°C)	Sang Run, Days > 25 °C						Swallow Falls, Days > 25 °C						Adjusted Swallow Falls, Days > 25 °C					
	1995	1996	1997	1998	1999	2000	1995	1996	1997	1998	1999	2000	1995	1996	1997	1998	1999	2000
25.1 - 25.5	6	0	2	4	5	1	4	1	7	6	9	0	11	1	2	6	7	0
25.6 - 26.0	5	1	6	3	7	0	6	2	7	5	11	1	7	1	1	1	5	1
26.1- 26.5	2	1	1	1	0	2	4	3	1	1	6	2	4	2	2	3	9	0
26.6 - 27.0	3	0	2	2	0	0	13	1	2	5	7	1	6	0	1	2	5	0
27.1 - 27.5	2	0	0	0	0	0	3	1	1	1	4	0	0	0	4	0	6	0
27.6 - 28.5	0	0	0	0	0	0	10	2	4	3	14	0	4	0	0	0	6	0
28.6 - 30.0	0	0	0	0	0	0	5	0	3	0	12	0	6	0	0	0	3	0
> 30.0	0	0	0	0	0	0	7	0	0	0	6	0	2	0	0	0	3	0
Total	18	2	11	10	12	3	52	10	25	21	69	4	40	4	10	12	44	1

4.0 SUMMARY AND CONCLUSIONS

In summary, the total number of days when temperature exceeded 25 °C at Sang Run ranged from two in 1996 to 18 in 1995 (Table 4-1). Temperatures in excess of 25 °C at Sang Run without operation of the Deep Creek Project would have ranged from a minimum of four to 10 days in 1996 to a maximum of 44 to 69 days in 1999. Maximum river temperature rarely exceeded 27 °C at Sang Run and was less than 26 °C on most of the days when it exceeded 25 °C. The data from Swallow Falls suggest that there were very few days when releasing water for temperature enhancement was unnecessary.

Implementation of the temperature enhancement protocol between 1995 and 2000 was very successful at maintaining lower temperatures than would otherwise have occurred in the river without the releases. A small further improvement is possible with more effective operator training in implementing the protocol to make sure that water is released when necessary. The only feasible changes in the protocol that might improve the temperature enhancement plan would be to reduce the low morning temperature threshold, which would have prevented a temperature exceedance on one date, and raise the flow threshold to 120 cfs, which would have prevented exceedances on three dates during the 1995 to 2000 period.

Table 4-1. Summary of temperature enhancement releases from Deep Creek Station over the 6-year period from 1995 through 2000.

	Year					
River conditions	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Total releases for temperature	24	8	13	10	29	8
Days > 25 °C at Swallow Falls	52	10	25	21	69	4
Days > 25 °C at Sang Run[a]	18	2	11	10	12	3
Days < 25 °C at Swallow Falls on temperature enhancement release day[b]	1	1	1[c]	1[c]	0	4

[a] False negatives, meaning needed release not made or not made in time.
[b] Potential false positives, meaning release made but may not have been not needed.
[c] Sang Run exceeded 25 °C on these days even though Swallow Falls did not.

5.0 REFERENCES

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APPENDIX

Appendix 1. Summary of temperatures exceeding 25 °C in the Youghiogheny River at Sang Run, 1995 - 2000. Start Time Variables: A = approved protocol; B = substitute actual max air temp with predicted cloud cover; C = substitute actual cloud cover with predicted air temp; D = substitute actual cloud cover and actual air temp; E = substitute DNR sensor data with forecasted variables; F = substitute DNR sensor data and actual cloud cover and actual air temp. Start Time Codes: w = whitewater release; p = power generation

Date	Duration of exceed-ance (hours)	Time of exceed-ance	Max Temp (°C) power co.	Max Temp (°C) MDNR	Actual start time of release	TIME EXCEEDANCE PREDICTED Start Time Variables						Duration of release	Reasons for exceedance
						A	B	C	D	E	F		
6/21/95	0.4	14.2	25.9	25.7	12.5	11	11	11	9	11	9	2	forecast (cloud/air)
7/9/95	2.8	16.7	25.8	25.6	none	-	-	-	-	-	15	-	operator error
7/11/95	0.1	14.2	24.9	25.3	12.5	11	11	11	11	11	11	2	model
7/16/95	6.4	15.4	27.6	26.9	none	-	-	-	-	-	7	-	flow > 100 cfs
7/18/95	6.0	13.4	27.1	26.7	none	-	-	-	-	-	7	-	operator error
7/19/95	3.4	16.7	25.6	25.3	none	-	-	-	-	-	11	-	low 7 a.m. temp
7/22/95	3.0	15.7	27.1	26.4	15.5	11	7	11	7	11	11	1	operator error
7/23/95	2.9	15.4	27.3	27.2	15.3	12	11	15	12	12	12	1	operator error
7/25/95	1.4	15.4	26.4	26.0	14	14	11	14	7	14	7	1	forecast (cloud/air)
7/27/95	0.4	13.6	25.5	25.8	12	12	11	11	7	12	7	2	forecast (cloud/air)
8/13/95	0.1	14.2	24.9	25.1	12	11	11	11	11	11	11	2	model
8/14/95	3.4	16.7	26.2	25.9	10 (w)	-	-	-	-	-	7	3	flow > 100 cfs
8/15/95	1.6	12.4	25.9	26.4	12.5	11	11	11	11	11	11	6	flow > 100 cfs
8/16/95	2.0	12.4	26.2	26.7	12.8 (p)	-	-	-	-	-	7	6	flow > 100 cfs

Appendix 1. (Continued)

Date	Duration of exceed-ance (hours)	Time of exceed-ance	Max Temp (°C) power co.	Max Temp (°C) MDNR	Actual start time of release	TIME EXCEEDANCE PREDICTED: Start Time Variables A	B	C	D	E	F	Duration of release	Reasons for exceedance
8/17/95	1.7	12.3	26.1	27.1	12 (p)	-	-	-	-	-	7	4	flow>100 cfs
8/20/95	0.1	14.2	24.4	25.1	12.5	11	11	11	11	11	11	2	model
8/23/95	1.3	16.7	26.5	25.4	15.3	15	15	15	15	none	none	1	model
8/24/95	0.6	16.3	26.1	25.4	14.5	14	9	9	7	none	9	1	forecast (cloud/air)
6/23/96	4.1	14.4	26.4	26.1	none	-	-	-	-	-	7		flow>100 cfs
6/29/96	0.5	13.9	25.4	24.1	12.5	11	11	9	11	11	11	2	forecast (cloud)
7/2/96	1.5	14.9	25.8	26.0	14.5	14	14	11	11	11	11	1	forecast (cloud) and monitoring
7/3/97	2.3	13.9	26.3	26.8	13.8 (p)	-	-	-	11	-	11	6.2	flow > 100 cfs
7/8/97	2.0	14.9	25.9	26.1	14.3	14	14	14	14	11	11	1	monitoring
7/16/97	0.5	14.4	24.9	26.0	12.5	11	11	9	7	11	7	6	forecast (cloud/ air)
7/20/97	1.8	15.2	26.0	26.8	14.0	14	11	14	11	11	9	2	forecast (air) and monitoring
7/27/97	1.8	15.0	26.0	25.9	14.1	14	14	11	14	11	14	2	forecast (cloud) and monitoring
7/29/97	0.8	14.2	24.8	25.7	12.5	11	11	11	11	11	11	2	model
7/30/97	1.3	16.3	26.3	25.7	15.1	15	15	15	15	15	15	1	model
7/31/97	1.8	16.1	26.2	25.9	15.3	15	15	15	15	14	14	1	monitoring

Appendix 1. (Continued)

Date	Duration of exceed-ance (hours)	Time of exceed-ance	Max Temp (°C) power co.	Max Temp (°C) MDNR	Actual start time of release	TIME EXCEEDANCE PREDICTED — Start Time Variables						Duration of release	Reasons for exceedance
						A	B	C	D	E	F		
8/9/97	2.0	16.6	25.7	25.2	none	-	14	12	14	15	15	none	forecast (cloud)
8/10/97	1.3	15.5	25.9	25.8	14.3	14	14	14	14	11	11	1	monitoring
8/12/97	0.5	15.6	25.6	25.4	14.3	14	14	7	7	11	7	1	forecast (cloud)
7/23/98	3.0	14.4	25.4	25.4	14.3	14	14	7	12	12	9	1	monitoring
7/26/98	2.0	14.9	25.2	25.8	14.1	14	14	14	14	12	11	1	monitoring
7/30/98	2.0	15.1	25.5	25.6	14.5	14	14	7	7	11	7	1	forecast (cloud) and monitoring
8/2/98	2.5	15.4	26.6	26.6	15.3	15	15	15	15	11	11	1	monitoring
8/4/98	1.0	15.4	26.0	26.4	14.3	14	14	7	14	11	11	1	monitoring
8/5/98	3.0	15.1	27.1	26.6	15.4	15	15	7	7	11	7	1	forecast (cloud) and monitoring
8/6/98	0.5	14.5	24.5	25.2	12.5	11	11	7	7	9	7	2	forecast (cloud)
8/13/98	2.5	15.4	25.5	25.5	none	-	-	-	-	11	11	none	monitoring
8/23/98	0.5	14.0	24.8	25.2	13.0	11	11	9	11	11	11	2	forecast (cloud)
8/26/98	0.5	13.8	25.2	25.6	12.5	11	-	11	-	11	11	5	model
6/9/99	0.5	14.4	25.3	26.0	12.5	11	11	7	9	9	9	2	forecast (cloud) and monitoring
6/10/99	0.5	14.4	24.9	25.7	12.5	11	7	7	7	11	7	2	forecast (cloud/air)

Appendix 1. (Continued)

Date	Duration of exceed-ance (hours)	Time of exceed-ance	Max Temp (°C) power co.	Max Temp (°C) MDNR	Actual start time of release	TIME EXCEEDANCE PREDICTED — Start Time Variables A	B	C	D	E	F	Duration of release	Reasons for exceedance
6/23/99	2.5	17.4	25.8	25.2	-	-	-	-	-	15	15	-	model
7/1/99	2.5	17.2	25.3	25.0	-	-	-	-	7	-	9	-	forecast (cloud/air) (Power Co. only)
7/5/99	0.5	12.9	25.4	25.8	11.0	7	7	7	7	7	7	2	model
7/8/99	0.5	18.0	25.3	24.7	-	-	-	-	-	9	11	-	monitoring (Power Co. only)
7/11/99	2.5	17.7	25.7	25.2	-	-	-	-	-	-	-	-	model
7/15/99	3.0	17.7	25.6	25.2	-	-	-	-	-	-	11	-	model
7/18/99	0.5	15.9	25.5	25.3	14.0	14	14	14	11	14	7	1	forecast (cloud/air) and monitoring
7/27/99	1.5	15.2	26.9	25.6	14.0	14	14	7	7	14	7	1	forecast (cloud)
8/3/99	0.5	15.9	25.8	25.7	14.0	14	14	14	14	14	14	1	model
8/4/99	2.0	16.2	26.2	25.9	15.0	15	11	15	11	12	11	1	forecast (air)
8/12/99	1.5	16.7	26.1	25.9	15.0	15	15	15	15	11	11	1	model
8/16/99	3.5	17.7	26.0	25.3	-	-	7	-	7	11	9	-	forecast (air)
7/2/00	2.0	15.1	26.4	26.3	15.5	15	15	15	15	11	11	1	monitoring
7/8/00	1.0	15.8	26.2	25.5	15.5	15	15	15	15	14	14	1	monitoring
8/2/00	4.5	13.8	26.7	26.3	-	-	-	-	-	11	11	-	flow > 100cfs