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YOUGHIOGHENY RIVER TEMPERATURE ENHANCEMENT PROTOCOL FOR OPERATING DEEP CREEK HYDROELECTRIC STATION: MODEL DEVELOPMENT AND RESULTS FOR 1995-2005

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Maryland Department of Natural Resources
Tawes State Office Building
580 Taylor Avenue
Annapolis, Maryland 21401-2397
Toll Free in Maryland: 1-877-620-8DNR x8660
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YOUGHIOGHENY RIVER TEMPERATURE ENHANCEMENT PROTOCOL FOR OPERATING DEEP CREEK HYDROELECTRIC STATION: MODEL DEVELOPMENT AND RESULTS FOR 1995-2005

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
Jodi R. Dew
Craig M. Bruce
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 1995-2005," was prepared by Steve Schreiner, Jodi Dew, and Craig Bruce 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. K00B0200109.

ABSTRACT

The Maryland Department of Natural Resources (DNR) Power Plant Research Program evaluated the use of hydroelectric releases to provide flows to moderate elevated Youghiogheny River temperatures to enhance trout habitat. A model and protocol for predicting maximum daily river temperature during summer was developed for the Deep Creek Hydroelectric Station (DCHS) using river flow, water temperature, maximum daily air temperature, and cloud cover in the region of the DCHS. The prediction model consists of a series of equations used by DCHS operators during the morning and early afternoon to predict temperature in the river. Operators use these predictions to determine whether a release is needed to lower the water temperature for trout habitat.

During the first 11 years in which the protocol was implemented, the total number of days per year when temperature exceeded 25 °C at Sang Run ranged from 3 in 1996 to 25 in 2005. Temperatures in excess of 25 °C at Sang Run without operation of the DCHS would have ranged from none in 2003 to between 42 to 67 days in 1999. During the 11-year period, river temperature exceeded 25 °C on 126 days but 59% of the exceedances were less than 26.1 °C. In contrast, there were a total of 286 days exceeding 25 °C in the river upstream of DCHS at Swallow Falls, with a maximum temperature above 27.5 °C 22 days in 1995 and 32 days in 1999.

Implementation of the temperature enhancement protocol between 1995 and 2005 was successful at maintaining lower temperatures than would otherwise have occurred in the river without the releases. Further improvements in maintaining lower river temperatures are possible by increasing effective operator training in implementing the protocol for necessary water releases. Minor changes in the protocol would also improve the temperature enhancement plan.

EXECUTIVE SUMMARY

The Deep Creek Hydroelectric Station (DCHS) in Garrett County, Maryland, 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 – at the time, the Pennsylvania Electric Company - and the Maryland Department of Natural Resources (DNR) Power Plant Research Program evaluated the uses of hydroelectric 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 conditions for fish by lowering 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 hydroelectric releases to lower river temperature, thereby enhancing fish habitat from the DCHS 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 11 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, water temperature, available predictions of maximum daily air temperature, and cloud cover in the region of the hydroelectric station. The prediction model consists of a series of equations (developed using multiple regression) to be used by DCHS operators during the morning and early afternoon to predict river temperature. 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. Target maximum river temperature is 25 °C, a maximum value for brown trout habitat. Model equations were based on historical data from 1987 through 1993 for average daily river flow, hourly river temperatures, maximum daily air temperature, and mid-day cloud-cover fraction. Using these equations on 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%, and the rate of failure to make needed releases for temperature improvements was estimated to be about 4%. In an average year needing 17 releases for temperature enhancement, only two to three unnecessary releases would be made.

The study area involved in this analysis is the Youghiogheny River in the vicinity of the Deep Creek Hydroelectric Station and its associated tailrace. Maryland DNR established water temperature recorders at nine stations — one in the tailrace before the confluence with the river, and eight in the river — to record river temperatures at half-hour intervals during the study periods. The uppermost station, Swallow Falls, is located approximately 3.5 km (2.2 miles) upstream of the tailrace; the most downstream station, Sang Run, is located approximately 5.8 km (3.6 miles) from the tailrace. During the first 11 years in which the protocol was implemented, the total number of days when temperature exceeded 25 °C at Sang Run ranged from 3 in 1996 to 25 in 2005. It is estimated that temperatures in excess of 25 °C at Sang Run without operation of the DCHS would have ranged from no days in 2003 to between 42 to 67 days in 1999. During the 11-year period, maximum river temperature exceeded 27 °C at Sang Run 14 times; 126 days exceeded 25 °C and 52 of those days exceeded 26 °C (59% of the exceedances were less than 26.1 °C). In contrast, there were a total of 286 days exceeding 25 °C at Swallow Falls, with a maximum temperature above 27.5 °C 22 days in 1995 and 32 days in 1999. Maximum temperature of 30 °C was exceeded 7 days and 6 of these days were in 1995 and 1999. Data from Swallow Falls suggest there were few days when releasing water for temperature enhancement was unnecessary.

Implementation of the temperature enhancement protocol between 1995 and 2005 was successful at maintaining lower temperatures than would otherwise have occurred in the river without the releases. Further improvements are possible by increasing effective operator training in implementing the protocol for necessary water releases. Changes in protocol that could improve the temperature enhancement plan are 1) slightly reduce the low morning temperature threshold, which could have prevented a temperature exceedance on 8 dates; 2) raise the flow threshold to 150 cubic feet per second (cfs), which could have prevented exceedances on at least 12 dates during the 1995 to 2005 period; and 3) revise the cloud cover factor (CCF) table in the protocol to include additional forecast variables.

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1.0 INTRODUCTION

Pennsylvania Electric Company (Penelec)[1] received a Water Appropriations Permit to operate the Deep Creek Hydroelectric Station (DCHS) for power generation from the Maryland Department of Natural Resources (MDNR) Water Resources Administration (WRA).[2] Condition 16 of this permit required Penelec to submit a plan for operating the Station to maintain temperatures of less than 25 °C in the Youghiogheny River between the DCHS tailrace and Sang Run 5.8 km (3.6 miles) downstream (Figure 1-1). The purpose of this permit 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 conditions for fish by lowering water temperature to a suitable range is incorporated in the term *temperature enhancement*.

Penelec outlined a general temperature enhancement protocol (Penelec 1994) to 1) operate the Deep Creek Hydroelectric 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, water temperature in the river, available predictions of maximum daily air temperature, and cloud cover in the region of the hydroelectric station. The model consists of a series of equations (developed using multiple regression) to be used by DCHS operators during morning and early afternoon to predict river temperature. Operators use these predictions to determine whether a release is needed to maintain the desired temperature range. The public is then notified of these releases via a telephone recording. This report also presents results of the first eleven years the protocol was implemented in the summers of 1995 through 2005.

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[1]GPU, the parent company of Penelec, sold the Deep Creek Hydroelectric Station in 1998. Brookfield Power currently owns and operates the station.

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

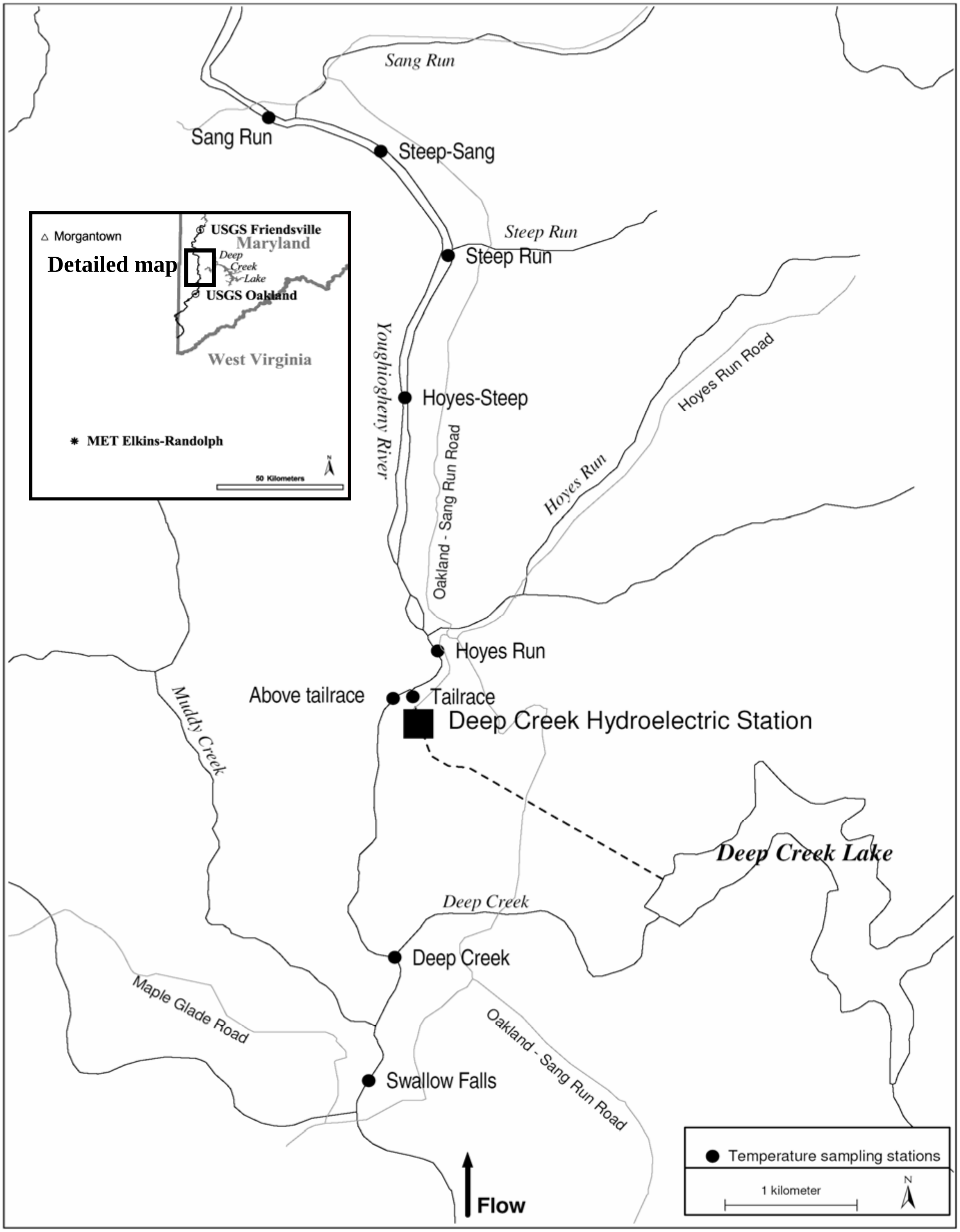

Figure 1-1. Map of the Youghiogheny River between Swallow Falls and Sang Run, MD, showing the location of the Deep Hydroelectric Creek Station tailrace, temperature sampling stations, and major tributaries

2.0 MODEL DEVELOPMENT

2.1 INPUT DATA

Schreiner (1997a, b) used a combination of simulation modeling and test releases from Deep Creek Station to show a 2-hour, 2-unit release beginning at 1100 hrs would be sufficient to maintain temperatures less than 25 °C in the Youghiogheny 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 (Schreiner 1998). In developing this protocol, we 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. 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 historical data showed no occurrences of river temperature over 25 °C before June 1 or after August 31 during these years, only data from these months were used.

The two most important meteorological factors affecting 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 minimum and maximum daily 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 were 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 (1,250 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 (1,990 feet) MSL. The Youghiogheny site is at an elevation of about 610 m (2,000 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, $p=0.0001$). 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 more similar elevation at Elkins to that at the Youghiogheny River site, showed that data from the Elkins station is the most suitable to use for developing a model to predict the temperature of the Youghiogheny River.

Based on available observations of river temperature and flow, monitoring for a temperature release would be needed only when 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 using the following equation:

$$Q_{DC} = 1.68 \times Q_o^{0.97}$$

where,

Q_{DC} = flow (cfs) above Deep Creek Hydroelectric Station, and
Q_o = flow at Oakland

Figure 2-1 illustrates the relationship between average daily river flow and maximum daily water temperature in the Youghiogheny River near Sang Run during the summer, when the station was not operating. The figure illustrates river temperature exceeding 25°C only when flows at Oakland were less than about 2.8 m^3/s (100 cfs). There is 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 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).

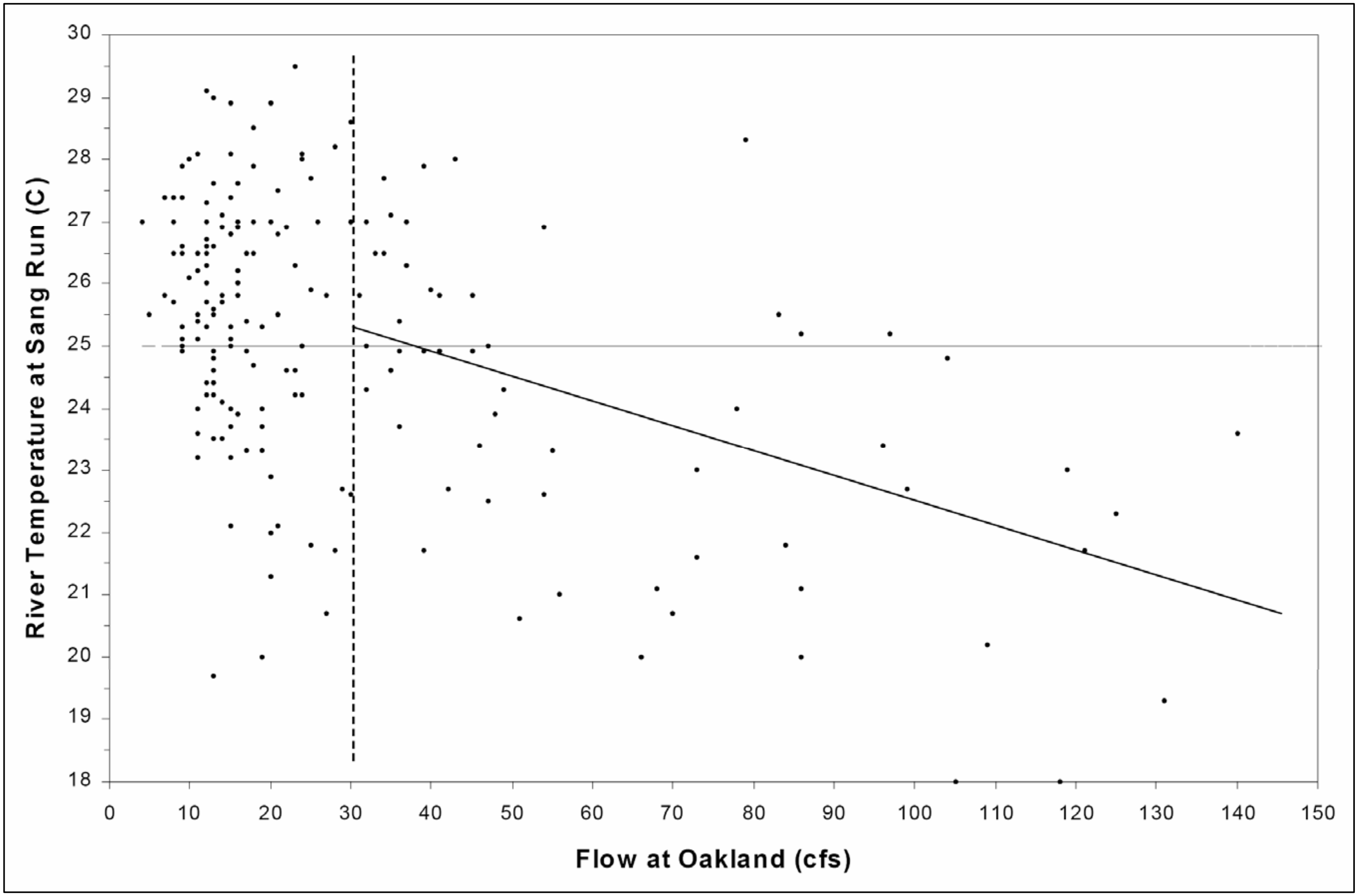

Figure 2-1. Daily average flow in the Youghiogheny River at Oakland, MD, and maximum daily water temperature at Sang Run for June through August 1987 to 1993, on days when the Deep Creek Station was not operated. Vertical line at 30 cfs (0.85m^3/s) shows the break-point below which there is no significant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

2.2 REGRESSION EQUATIONS

River flow, water temperature, air temperature, cloud cover, and station 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. The model only used data for days when river flow at Oakland did not exceed 2.8 m^3/s (100 cfs) and generation did not occur from the Deep Creek Hydroelectric Station (or when generation occurred after 1500 hrs since generation after that time would not affect maximum river temperature).

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, greater uncertainty in 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).

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 hrs to 1500 hrs)	
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 hrs	1200 hrs
0900 hrs	1400 hrs
1100 hrs	1500 hrs

2.3 REGRESSION RESULTS

Table 2-2 lists the results of the multiple regression analyses, using the input data discussed in Table 2-1, 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 variables with a statistically significant influence on maximum river temperature. 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 predicted variables of TMAXAIR and CLOUDCOV as the day progresses as shown by the partial R-square, and increased importance of measured river temperatures from 1200 hrs through 1500 hrs. 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 equations based on later information.

There are two distinct groups of data with respect to the relationship between flow and river temperature (Figure 2-1). Initial results showed 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 greater operational complexity of using two formulas based on river flow, regressions for models to be used before 1100 hrs were run by adjusting the value of measured temperature in the Youghiogheny River at Sang Run to account for higher flows. This adjustment was made whenever average daily flow at Oakland was greater than 0.85 m^3/s (30 cfs) using the equation:

$$SMAXADJ = SMAX - 0.04\ (OFLOW - 30)$$

where,

SMAXADJ = Sang Run adjusted temperature,
SMAX i=Sang Run maximum daily temperature (°C), and
OFLOW = average daily 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 are used instead of measured data 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

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 hrs and river flow at Oakland less than 2.8 m^3/s (100 cfs)

Model Number and Hour of Prediction	Variables	Parameter Estimate	Partial R-Square	Model R-Square
PSANG1	(intercept)	14.430	-	-
(no water temperature	TMAXAIR	0.356	0.53	0.53
available)	CLOUDCOV	-0.017	0.02	0.55
	TMINAIR	0.109	0.03	0.58
RMS=1.28				
PSANG2	(intercept)	10.920	-	-
(0700)	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	(intercept)	10.203	-	-
(0900)	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	(intercept)	6.202	-	-
(1100)	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	(intercept)	5.555	-	-
(1200)	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	(intercept)	3.563	-	-
(1400)	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	(intercept)	3.075	-	-
(1500)	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 hrs to 1500 hrs, fraction from 0 (no clouds) to 10 (totally cloud-covered)

S7 - S15 = Temperature (°C) at Sang Run 0700 hrs to 1500 hrs

OFLOW = Daily average flow at Oakland (cfs)

RMS = Root Mean Squared error

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) and measured cloud cover values were adjusted to the upper limit of each category.

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

Maximum river temperature was predicted using equations listed in Table 2-4 with historical data and adjusted maximum air temperature and cloud cover values for PSANG2 through PSANG5. After 1200 hrs (PSANG6 and PSANG7), maximum air temperature and cloud cover are less important predictors of maximum river temperature than measured temperatures; therefore, 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).

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 hrs, based on sensor readings at 0700 and 0900 hrs, and released water would reach Sang Run at 1300 hrs. Releases based on these readings would provide maximum notice times of six and four hours, respectively. A sensor reading at 1100 hrs originally was planned to trigger a release at 1200 hrs, which would reach Sang Run at 1400 hrs, for a maximum of three hours notice. At the request of American Whitewater Affiliation (AWA), a release time of 1230 hrs (to reach Sang Run at 1430 hrs 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 2-4. 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 2-3)
TMINAIR = Measured minimum air temperature for Elkins, WV (°C)
7 - 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 = <u>square</u> of upper limit of the category listed in Table 2-3, based on the measured total opaque cloud cover at Elkins, WV, between 1000 hrs to 1500 hrs.

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 a 14% rate of unnecessary releases (false positives) and 4% rate of failure to make needed releases (false negatives). Actual temperature was 25 °C for four of the 16 "unnecessary" releases and 24.9 °C for three of those releases; therefore, almost half of 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 2-5. 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 (hour of the day)	-	0700	0900	1100	1200	1400	1500	
Release time (hour of the day)	1100	1100	1100	1230	1200	1400	1500	
Time at Sang Run (hour of the day)	1300	1300	1300	1430	1400	1600	1700	
Release duration (hours)	2	2	2	2	1	1	1	
Maximum notice (hours)	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 2005. These data were used by station operators in real time so they could decide whether to release water for temperature enhancement according to the protocol described in Section 2 of this report. In our analysis, one two-minute data measurement was extracted from the data set at half-hour intervals for comparison with data collected by MDNR using temperature probes[3] placed in the river at several locations (Table 3-1 and Figure 1-1) from Swallow Falls to Sang Run. Temperature probes recorded temperatures at half-hour intervals for various dates in June through sometime in September of each year from 1995 through 2005. These data were available after the summer season to evaluate river temperature and its relationship to releases from Deep Creek Hydroelectric Station (DCHS).

Table 3-1. Youghiogheny River temperature monitoring stations (distances approximate)

Station	Distance from DCHS Tailrace	Tributary Proximity
Swallow Falls	2.7 miles upstream	2500 feet upstream of Muddy Creek
Deep Creek	1.8 miles upstream	50 feet upstream of Deep Creek
Above Tailrace	0.1 miles upstream	N/A
Tailrace	0	N/A
Hoyes Run	0.5 miles downstream	300 feet upstream of Hoyes Run
Hoyes-Steep	1.6 miles downstream	N/A
Steep Run	2.7 miles downstream	300 feet upstream of Steep Run
Steep-Sang	3.5 miles downstream	N/A
Sang Run	4.2 miles downstream	1000 feet downstream of Sang Run

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

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 planned on a given day for any purpose other than temperature

[3]Ryan TempMentors from 1995-2001 and StowAway TidBit temperature data loggers (onsetcomp.com) since 2001.

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 minimum and maximum daily air temperatures for comparison with predicted values. Minimum and maximum daily air temperatures for Oakland, MD, were also obtained for all years except 2005. See Table 3-2 for stream flow and meteorological station information.

Table 3-2. Stream flow and meteorological stations used for analysis of DCHS temperature enhancement program

Station Name	Station Number	Period of Record	Location
Oakland USGS	3075500	1941- present	39° 25′ 17.9″ N 79° 25′ 29.6″ W
Oakland Coop	186620	1948 - present	39° 25′ N 79° 24′ W
Elkins NWS	13729	1979 - present	38° 53′ 07″ N 79° 51′ 10″ W

Prior to 1996 and after 2003, 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. From 1996 to 2003, cloud cover fraction was reported using sky cover descriptive terms. 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 measured cloud cover fractions.

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.lrp.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 shown in Table 3-3.

3.2 RESULTS

Table 3-4 summarizes releases from the Deep Creek Hydroelectric Station between June 1 and August 31 of each study year as the percentage of days during the period that had announced and scheduled releases (at least one day in advance). Announced and scheduled whitewater releases ranged from 15% to 37% of the total (these are scheduled for Mondays, Fridays, and usually one Saturday per month, water levels permitting), and announced and scheduled releases for power generation ranged from 0% to 27% of the total. Unscheduled releases ranged from 17% to 49% of the total, consisting of 1% to

32% for temperature enhancement and 2% to 48% for unscheduled power generation. There were no releases of any kind on 16% to 51% of days during this period.

Table 3-3. Average flow (cubic feet per second or cfs) in the Youghiogheny River for June through August, 1995-2005, in comparison with the long-term average flow (1942 through 2005) at Oakland, Maryland (USGS station 03075500)

Year	Rank (64 = wettest)	June	July	August	June-August
1995	18	111	37	116	88
1996	62	273	567	362	401
1997	36	240	75	150	155
1998	48	417	205	78	231
1999	3	23	21	14	19
2000	42	254	257	75	195
2001	52	273	438	115	296
2002	15	38	145	41	84
2003	64	766	539	358	554
2004	38	368	58	110	176
2005	33	101	290	54	149
Average (1942-2005)		203	167	128	166

Comparing Tables 3-3 and 3-4 shows a greater percentage of days with temperature releases occurring during dry years (1995, 1999, and 2002) and the smallest percentage occurring during the wettest year (2003). Percentage of whitewater releases has remained fairly consistent from 1995 through 2005 except in 1999 due to drought conditions that year. Percentage of announced releases for discretionary power generation was highest in 1996 at 27% and lowest during 1999, 2002, and 2003 at 0%. Unannounced releases for generation have ranged from 2% in 1999 and 2002 when lack of rainfall resulted in a loss of nearly all discretionary generation during the summer period to 48% in 2003 which had the wettest summer period in the 64-year flow record.

Days on which river temperature at Sang Run exceeded 25 °C (at either DNR or power company sensors) were evaluated including dates of exceedances, duration and time of exceedance, maximum temperature at each sensor, time and duration of a release from the hydroelectric station (if any), and an evaluation of the protocol equation parameters (Appendix 1). Causes of exceedances can be grouped into 3 main categories, 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

Table 3-4. Summary of releases[4] from Deep Creek Hydroelectric Station during implementation of the temperature enhancement protocol (June 1 through August 31, 1995-2005)

Release Type	**Number of days**											**Percentage of days**										
Year:	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Announced and scheduled whitewater	34	33	33	31	14	29	28	31	27	28	31	37	36	36	34	15	32	30	34	29	30	34
Announced and scheduled power	10	25	8	1	0	1	11	0	0	6	6	11	27	9	1	0	1	12	0	0	7	7
TOTAL announced and scheduled	**44**	**58**	**41**	**32**	**14**	**30**	**39**	**31**	**27**	**34**	**37**	**48**	**63**	**45**	**35**	**15**	**33**	**42**	**34**	**29**	**37**	**41**
Not announced or scheduled (for power)	8	11	7	32	2	21	20	13	44	15	2	9	12	8	35	2	23	22	14	48	16	2
Temperature enhancement	24	8	13	9	29	8	11	21	1	2	14	26	9	14	10	32	9	12	23	1	2	15
TOTAL unscheduled	**32**	**19**	**20**	**41**	**31**	**29**	**31**	**34**	**45**	**17**	**16**	**35**	**21**	**22**	**45**	**34**	**32**	**34**	**37**	**49**	**18**	**17**
Days with no release	16	15	31	19	47	33	22	27	20	41	39	17	16	34	21	51	36	24	29	22	45	42
TOTAL DAYS or percent	**92**	**92**	**92**	**92**	**92**	**92**	**92**	**92**	**92**	**92**	**92**	**100**	**100**	**101**	**101**	**100**	**101**	**100**	**100**	**100**	**100**	**100**

[4] Scheduled release – a release scheduled by the power company, one week or more in advance. Currently these consist primarily of whitewater releases scheduled according to the permit, on Mondays, Fridays and one Saturday per month, from mid-April through mid-October.

Announced release – a release that is announced on the publicly available telephone recording. These include scheduled whitewater and power releases and may include temperature enhancement releases that are determined prior to 1200 hrs.

greater than 100 cfs, or 0700 hrs temperature prediction less than or equal to 23 °C); or, 3) uncertainty in forecast data, river monitoring data, or uncertainty inherent in the regression model equations.

The first three primary causes for temperature exceedances were not related to uncertainty in use of the protocol equations (Table 3-5). Specifically, 19% of the total exceedances were caused by operators failing to follow the protocol correctly or due to equipment problems. Protocol equations were not implemented for 14% of the total exceedances when flow at Oakland was greater than 100 cfs. There were no occasions in historical data (collected in 1987 to 1993) when temperature exceeded 25 °C and river flow was greater than 100 cfs; however, this did occur on five days in both 1995 and 2005, three days in 2001, twice in 2002, and one day each in 1996, 1997, 2000, and 2003. In 12 of the 19 cases, raising the flow threshold from 100 to 150 cfs would have resulted in successfully maintaining temperature less than 25 °C. Raising the flow threshold does not necessarily trigger a release but does result in the need for the operator to monitor the actual need for a release. Only 12 potential days in the 11 years that the existing protocol has been implemented would have required additional monitoring, slightly more than one day per year. In five of the remaining seven cases, river flow was well above 150 cfs at the time the protocol would have been implemented. Raising the flow threshold further or eliminating it entirely would probably not have resulted in maintaining river temperature less than 25 °C due to increased volume of stormwater runoff in the river displacing hydroelectric station discharge relatively quickly unless the release was maintained for a much longer period than practicable.

Once in 1995, 2001, 2003, and 2005, and four times in 2002, the prediction temperature at 0700 hrs was less than 23 °C but maximum temperature eventually exceeded 25 °C, which suggests lowering this criterion in the protocol to improve results. Based on calculations of the temperature predicted at 0700 hrs in those eight cases, lowering the prediction threshold to 20 °C would eliminate most of these exceedances. There may also be a small amount of overlap in the enhancement benefits of lowering the low morning temperature threshold and raising the high flow threshold for implementing the temperature enhancement plan. Two of the 8 dates on which the low morning temperature threshold resulted in the enhancement protocol not being implemented, occurred on dates with an average river flow greater than 100 cfs at the Oakland gage. No temperature predictions were made on the 12 dates that the high river flow threshold resulted in cancellation of the protocol implementation; thus, there is no easy way to estimate whether the morning temperature prediction may also have been low.

The remaining 60% of exceedances were due to uncertainty in forecast or monitoring data, or due to uncertainty within the regression model itself. 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 ultimately exceeded 25 °C; Table 3-6). If all test combinations

Table 3-5. Summary of causes for temperature exceeding 25 °C at DNR sensors in the Youghiogheny River at Sang Run

Primary Cause	Number of Times of Temperature Exceedance Per Year												
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	% of Total
Operator error	4						4	3		7	6	24	19.0
Flow > 100 cfs at Oakland	5	1	1			1	3	2	1		4	18	14.3
Low morning temperature	1						1	4	1		1	8	6.3
Forecast Uncertainty	4	1	3	1	2		1	4			5	21	16.7
Monitoring Uncertainty			2	3	1	2						8	6.3
Forecast and Monitoring Uncertainty			3	5	4			4	1			17	13.5
Protocol Uncertainty	4	1	2	1	5		1	6		1	9	30	23.8
Total	18	3	11	10	12	3	10	23	3	8	25	126	100.0

Note: Seven temperature exceedances are not included in this table but are listed in the appendix since the temperature at Sang Run did not exceed 25.1 at the MDNR sensors, but did exceed 25.1 based on the power company sensor.

resulted in the same predicted exceedance time, inherent uncertainty in the protocol is assumed to be responsible for the temperature exceedance, rather than uncertainty in forecast or monitoring data. This usually occurs when exceedance temperature is very close to the threshold value of 25 °C.

Table 3-6. Variable combinations used in the evaluation of protocol uncertainty

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 power company values	Monitoring data
F	TMAXAIR, Predicted cloud cover at Elkins, S7 - S15	Actual for predicted (air and cloud cover); DNR values for power company values (water temperature)	Forecast and monitoring data
G	Same as A except using correct readings for water temperature, PCLD, and TAIR; used only in 2004*		N/A

* In 2004, there were seven false negatives due to operator error because the model predicted a low morning temperature due to operator error in failing to read the 0700 hrs river temperature, PCLD (predicted cloud cover), and/or TAIR (predicted maximum air temperature at Elkins). To test the protocol equations for 2004, a new variable combination was created using the correct river temperature, PCLD, and TAIR input to demonstrate that if correct data had been applied to the model, releases would have been made on all seven of these days.

Results listed in Table 3-5 show 60% of exceedances between 1995 and 2005 were due to uncertainty in weather forecast data (17%), monitoring data (6%), in a combination of forecast and monitoring data (14%), or protocol uncertainty (24%). When forecast uncertainty was the only reason for exceedance, a combination of uncertainty in cloud cover and air temperature or cloud cover uncertainty separately accounted for the exceedance at equal probability. Uncertainty could be improved to some extent by revising the protocol to use local weather data, but at considerable expense to collect necessary data, revise the protocol, and provide a site-specific weather forecast. Some improvement could be made in the cloud forecast uncertainty by adjusting the cloud cover factor used for certain cloud cover descriptions; for example, the descriptions for 'thunder storms' and 'showers' are not listed in the approved protocol document but these terms have been assigned high cloud cover factor values, which may result in under-predicting maximum daily temperature until later in the day. (The benefit of this correction is not easily quantified but the cost should be minimal since the cloud cover factor is not used after 1100 hours; use of more correct values would only result in an earlier release on a day when a release would likely have been made later.) Monitoring uncertainty could be separated into uncertainty in temperature measurement and natural spatial and temporal variability in river temperature. Natural variability is greater than measurement uncertainty, suggesting there is no simple way to reduce uncertainty in protocol implementation. Uncertainty within the model is due to a combination of limited data used in development and the two-hour lag time between the DCHS release and temperature reduction at Sang Run. When river temperature gets close to the target value, the model cannot predict an exceedance in time for a release to prevent it.

The majority of the causes of temperature exceedances occurred when river temperatures were between 25.1 and 26.0 °C, with the exception of operator error and flow greater than 100 cfs at Oakland (Table 3-7; Figure 3-1). The number of temperature exceedances caused by operator error fluctuated little with increasing temperature. Flow greater than 100 cfs at Oakland had the greatest number of exceedances when the temperature ranged from 26.1 to 26.5 °C (7 exceedances) and the second highest number of exceedances (4 each) in 25.6-26.0 °C and 26.6-27.0 °C temperature ranges. Increasing the flow threshold to 150 cfs could decrease the number of exceedances in the higher temperature ranges.

Table 3-8 and Figure 3-2 illustrate the frequency distribution of river temperatures greater than 25 °C at Sang Run compared with temperatures in the river at Swallow Falls or the Deep Creek tributary confluence, and adjusted to show a range of what temperatures at Sang Run could have been without releases from the DCHS. Actual and adjusted Swallow Falls temperature values provide a range of estimates of predicted river temperature at Sang Run in the absence of releases from DCHS. Maximum daily temperatures at the Swallow Falls or Deep Creek tributary confluence and Sang Run stations were evaluated to determine the average difference between them. Data used for this evaluation were from June through August of 1987 through 2004 on days when the DCHS was not operated and when river flow as measured in Oakland was less than 100 cfs. Based on these data, the average upstream river temperature was 0.8 °C ± 1.5 (standard error) greater than at Sang Run. This factor was used to estimate a range of maximum temperatures at Sang Run in the absence of DCHS operation. (In 2001 and 2003, data from the Deep Creek confluence station were used in place of Swallow Falls temperature data due to equipment failure at the Swallow Falls station.) Although there were between 3 and 25 days per year in which river temperatures exceeded 25 °C at Sang Run, maximum temperature rarely exceeded 27.5 °C. In contrast, actual

Table 3-7. Summary of causes for temperature exceeding 25 °C at DNR sensors in the Youghiogheny River at Sang Run based on distribution of temperatures greater than 25 °C between June and August (1995-2005)

Primary Cause of Exceedance	**Temperature Range (C)**								
	25.1 - 25.5	**25.6 - 26.0**	**26.1 - 26.5**	**26.6 - 27.0**	**27.1 - 27.5**	**27.6 - 28.0**	**28.1 - 28.5**	**28.6 - 30.0**	**Total**
Operator error	5	4	4	4	2	0	1	4	24
Flow > 100 cfs at Oakland	1	4	7	4	1	1	0	0	18
Low morning temperature	4	2	0	1	0	0	1	0	8
Forecast Uncertainty	9	6	5	0	0	1	0	0	21
Monitoring Uncertainty	2	3	2	1	0	0	0	0	8
Forecast and Monitoring Uncertainty	6	6	2	2	0	1	0	0	17
Protocol Uncertainty	13	9	4	2	1	1	0	0	30
Total	40	34	24	14	4	4	2	4	126

Note: Seven temperature exceedances are not included in this table but are listed in the appendix since the temperature at Sang Run did not exceed 25.1 at the MDNR sensors, but did exceed 25.1 based on the power company sensor.

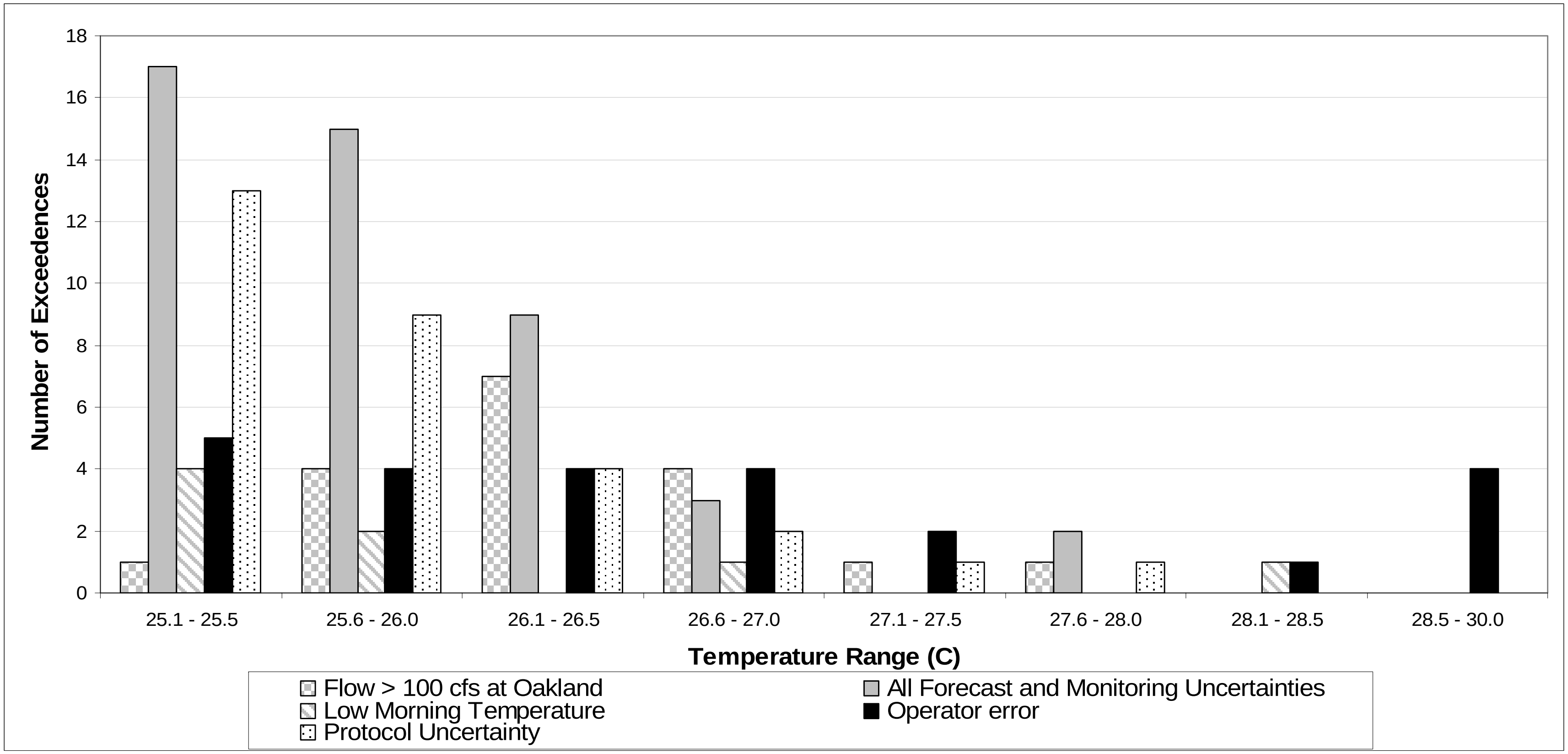

Figure 3-1. Summary of causes for temperature exceeding 25 °C at MDNR sensors in the Youghiogheny River at Sang Run based on distribution of temperatures greater than 25 °C between June and August (1995-2005)

Table 3-8. Distribution of temperatures greater than 25 °C in the Youghiogheny River at Sang Run and Swallow Falls between June and August, 1995-2005, (Swallow Falls data were also adjusted to represent temperatures in Sang Run without releases from Deep Creek Hydroelectric Station by subtracting 0.8 °C from the measured temperature at Swallow Falls).

Temperature Range (°C)	Sang Run, Days > 25 °C										
	95	96	97	98	99	00	01	02	03	04	05
25.1 - 25.5	6	1	2	4	5	1	3	6	2	3	6
25.6 - 26.0	5	1	6	3	6		5	3	1	1	4
26.1 - 26.5	2	1	1	1	1	2	2	7		2	5
26.6 - 27.0	3		2	2				2		2	4
27.1 - 27.5	2							1			
27.6 - 28.5								4			2
28.6 - 30.0											4
> 30.0											
Total	18	3	11	10	12	3	10	23	3	8	25

Temperature Range (°C)	Swallow Falls, Days > 25 °C										
	95	96	97	98	99	00	01*	02	03*	04	05
25.1 - 25.5	4	1	7	5	9		3	4		7	6
25.6 - 26.0	6	2	7	5	9	1	4	8		6	2
26.1 - 26.5	4	3	1	2	6	2	2	7		5	2
26.6 - 27.0	12	1	2	5	7	1		4			9
27.1 - 27.5	4	1	1	2	4			10			2
27.6 - 28.5	10	2	4	4	16			7			9
28.6 - 30.0	5		3		10			4			4
> 30.0	7				6						
Total	52	10	25	23	67	4	9	44	0	18	34

Temperature Range (°C)	Predicted Sang Run with Adjusted Swallow Falls, Days >25 °C										
	95	96	97	98	99	00	01*	02	03*	04	05
25.1 - 25.5	4	3	2	1	5	2	1	7		7	2
25.6 - 26.0	7	1	2	4	4		1	4			6
26.1 - 26.5	7	1	1	1	3	1		6			7
26.6 - 27.0	4	2	2	2	7			4			3
27.1 - 27.5	6			2	5			3			6
27.6 - 28.5	3		4		10			2			3
28.6 - 30.0	5				4			2			1
> 30.0	4				4						
Total	40	7	11	10	42	3	2	28	0	7	28

* Data from the river near the Deep Creek tributary confluence was used in 2001 and 2003 due to sensor failure at Swallow Falls.

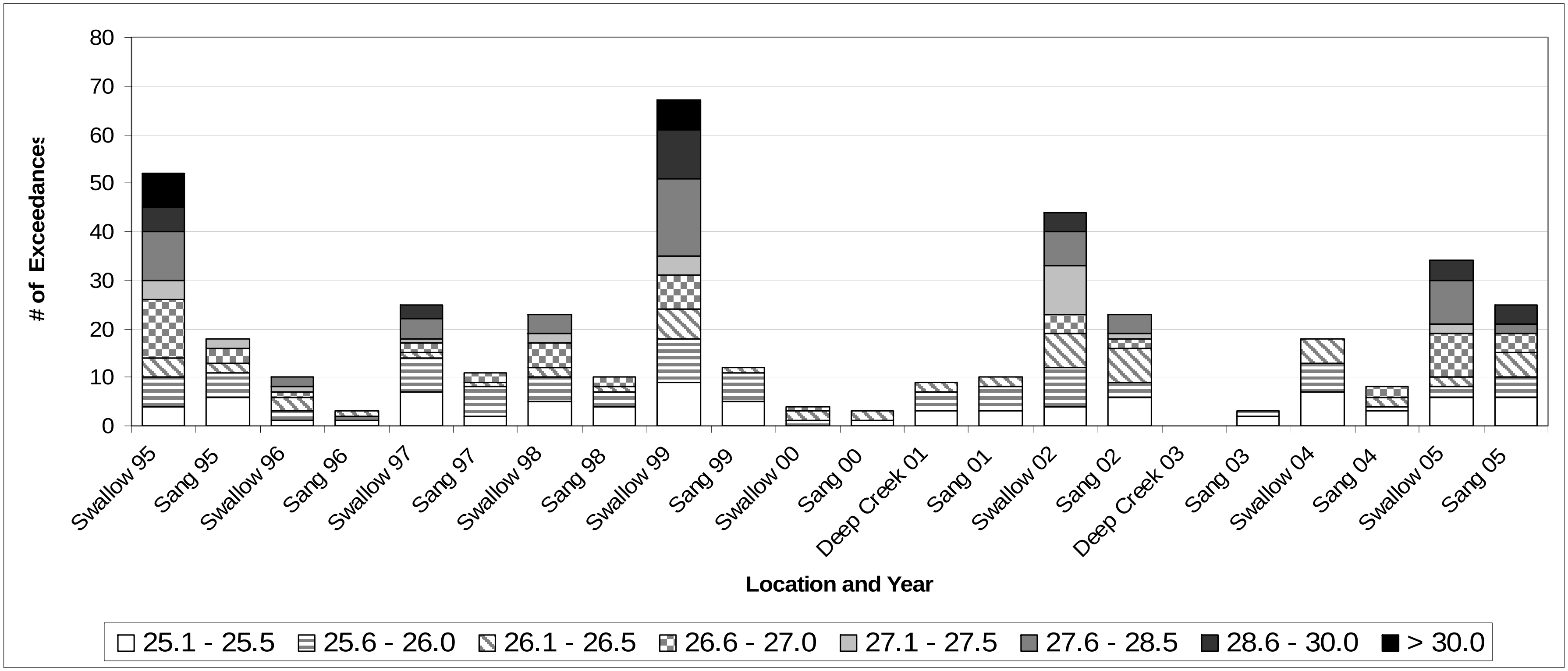

Figure 3-2. Distribution of temperatures greater than 25 °C in the Youghiogheny River at Sang Run (Sang) and Swallow Falls (Swallow) between June and August. Data from the station at the Deep Creek tributary confluence (Deep Creek) replaced Swallow Falls data (due to equipment failure) in 2001 and 2003.

maximum temperature at Swallow Falls was above 27.5 °C on 22 days in 1995 and 32 days in 1999. Maximum temperature of 30 °C was exceeded 7 days and 6 days in those same years.

In summary, total number of days when temperature exceeded 25 °C at Sang Run ranged from 3 in 1996 and 2000 to 25 in 2005 (Table 3-9). Temperatures in excess of 25 °C at Sang Run without operation of the DCHS (as represented by data from the Swallow Falls or Deep Creek stations) would have ranged from a minimum of 0 days in 2003 to a maximum of 67 days in 1999. Maximum river temperature exceeded 27 °C at Sang Run 13 times from 1995 through 2005; 25 °C was exceeded 126 times and 52 of those days exceeded 26 °C; 59% of the exceedances were less than 26 °C. Data from Swallow Falls suggest that there were very few days when releasing water for temperature enhancement was unnecessary.

Table 3-9 Summary of temperature enhancement releases from Deep Creek Station over the 11-year period from 1995 through 2005

River Conditions	**Year**										
	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Total releases for temperature	24	8	13	9	29	8	11	21	1	2	14
Days > 25 °C at Swallow Falls	52	10	25	23	67	4	9*	44	0*	18	34
Days > 25 °C at Sang Run[(a)]	18	3	11	10	12	3	10	23	3	8	25
Days < 25 °C at Swallow Falls on temperature enhancement release day[(b)]	1	1	1[©]	1[©]	0	4	5*	0	1*	1	

[(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.

[©] Sang Run exceeded 25 °C on these days even though Swallow Falls did not.

* Data from Deep Creek tributary confluence was used due to sensor failure at Swallow Falls.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Implementation of the temperature enhancement protocol between 1995 and 2005 was successful at maintaining lower temperatures in the Youghiogheny River between Swallow Falls and Sang Run than would otherwise have occurred in the river without the releases. An improvement in maintaining river temperature below 25 °C is possible by increasing effective operator training in implementing the protocol for necessary water releases. Based on the 11-year course of the protocol, changes in specifications of the protocol that could improve the temperature enhancement plan are 1) slightly reduce the low morning temperature threshold, which would have prevented a temperature exceedance on 8 dates; 2) raise the flow threshold to 150 cubic feet per second (cfs), which could have prevented exceedances on at least 12 dates during the 1995 to 2005 period; and 3) revise the cloud cover factor (CCF) guidelines in the protocol to include additional forecast variables. Additional costs to operation of the project to make these small changes should be minimal.

5.0 REFERENCES

Brown, L.C. and T.O. Barnwell, Jr. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: documentation and user manual. EPA/600/3-87/007.

Pennsylvania Electric Company (Penelec). 1994. Deep Creek Station support document for permit application to appropriate and use water of the state. Revised section 4.0. June 1994.

Schreiner, S.P. 1997a. A temperature simulation model of the Youghiogheny River for predicting cold water releases to improve trout habitat. The Environmental Professional 19(1):209-220.

Schreiner, S.P. 1997b. A temperature simulation model of the Youghiogheny River from Deep Creek Station to Sang Run. Prepared for Maryland Department of Natural Resources (DNR), Power Plant Research Program. PPRP-DC-1. Final report, 1997.

Schreiner, S.P. 1998. Youghiogheny River temperature enhancement protocol: model development and results for 1995 and 1996. Prepared for Maryland DNR Power Plant Research Program. PPRP-DC-2. Final report, February 1998.

APPENDIX

Table A-1. Summary of temperatures exceeding 25 °C in the Youghiogheny River at Sang Run, 1995-2005. Start Time Variables: A = approved protocol; B = substitute actual maximum air temperature with predicted cloud cover; C = substitute actual cloud cover with predicted air temperature; D = substitute actual cloud cover and actual air temperature; E = substitute DNR sensor data with forecasted variables; F = substitute DNR sensor data and actual cloud cover and actual air temperature. Start Time Codes: w = whitewater release; p = power generation; ND = no data; NE = no exceedance predicted.

Date	Duration of Exceed-ance (decimal hours)	Time of Exceed-ance (decimal hours)	Max Temp (EC) MDNR	Max Temp (EC) Power Co.	Actual Start Time of Release (decimal hours)	Start Time Variables and Time of Predicted Exceedance (decimal hour)							G	Duration of Release (decimal hours)	Reasons for exceedance
						A (Log file)	A (cal-culated)	B	C	D	E	F			
6/21/1995	0.4	14.2	25.7	25.9	12.5	11	11	11	9	9	11	9		2	Forecast (cloud/ air)
7/9/1995	2.8	16.7	25.6	25.8	none		ND	ND	ND	ND	ND	15		none	Operator error
7/11/1995	0.1	14.2	25.3	24.9	12.5	11	11	11	11	11	11	11		2	Model - Protocol Uncertainty
7/16/1995	6.4	15.4	26.9	27.6	none		ND	ND	ND	ND	ND	14		none	Flow > 100 cfs
7/18/1995	6.0	13.4	26.7	27.1	none		ND	ND	ND	ND	ND	11		none	Operator error
7/19/1995	3.4	16.7	25.3	25.6	none		ND	ND	ND	ND	ND	11		none	Low morning temperature
7/22/1995	3.0	15.7	26.4	27.1	15.5	11	11	11	11	11	11	11		1	Operator error
7/23/1995	2.9	15.4	27.2	27.3	15.3	12	12	11	12	12	12	12		1	Operator error
7/25/1995	1.4	15.4	26.0	26.4	14.0	14	14	11	14	9	14	9		1	Forecast (cloud/ air)
7/27/1995	0.4	13.6	25.8	25.5	12.0	12	12	11	11	9	12	9		2	Forecast (cloud/ air)
8/13/1995	0.1	14.2	25.1	24.9	12.0	11	11	11	11	11	11	11		2	Model - Protocol Uncertainty
8/14/1995	3.4	16.7	25.9	26.2	10 (w)		ND	ND	ND	ND	ND	7		3	Flow > 100 cfs
8/15/1995	1.6	12.4	26.4	25.9	12.5	11	11	11	11	11	11	11		6	Flow > 100 cfs
8/16/1995	2.0	12.4	26.7	26.2	12.8 (p)		ND	ND	ND	ND	ND	7		6	Flow > 100 cfs
8/17/1995	1.7	12.3	27.1	26.1	12 (p)		ND	ND	ND	ND	ND	7		4	Flow > 100 cfs
8/20/1995	0.1	14.2	25.1	24.4	12.5	11	11	11	11	11	11	11		2	Model - Protocol Uncertainty
8/23/1995	1.3	16.7	25.4	26.5	15.3	15	15	NE	15	15	NE	NE		1	Model - Protocol Uncertainty
8/24/1995	0.6	16.3	25.4	26.1	14.5	14	14	9	9	7	15	9		1	Forecast (cloud/ air)
6/23/1996	4.1	14.4	26.1	26.4	none		ND	ND	ND	ND	ND	9		none	Flow > 100 cfs
6/29/1996	0.5	13.9	25.4	25.4	12.5	11	11	11	9	11	11	11		2	Forecast (cloud)
7/2/1996	1.5	14.9	25.8	25.8	14.5	14	11	NE	11	11	11	11		1	Model - Protocol Uncertainty
7/3/1997	2.3	13.9	26.8	26.3	13.8 (p)	11	ND	NE	ND	11	ND	11		6.2	Flow > 100 cfs
7/8/1997	2.0	14.9	26.1	25.9	14.3	14	14	NE	14	11	11	11		1	Forecast(cloud/air) and Monitoring Uncertainty
7/16/1997	0.5	14.4	26.0	24.9	12.5	11	11	11	9	7	11	7		6	Forecast (cloud/ air)

Table A-1. (Continued)

Date	Duration of Exceed-ance (decimal hours)	Time of Exceed-ance (decimal hours)	Max Temp (EC) MDNR	Max Temp (EC) Power Co.	Actual Start Time of Release (decimal hours)	Start Time Variables and Time of Predicted Exceedance (decimal hours)							G	Duration of Release (decimal hours)	Reasons for exceedance
						A (Log file)	A (cal-culated)	B	C	D	E	F			
7/20/1997	1.8	15.2	26.8	26.0	14.0	14	11	11	11	11	11	9		2	Model - Protocol Uncertainty
7/27/1997	1.8	15.0	25.9	26.0	14.1	14	14	NE	11	14	11	11		2	Forecast (cloud) and monitoring
7/29/1997	0.8	14.2	25.7	24.8	12.5		11	11	11	11	11	11		2	Model - Protocol Uncertainty
7/30/1997	1.3	16.3	25.7	26.3	15.1	15	15	NE	15	15	14	14		1	Monitoring Uncertainty
7/31/1997	1.8	16.1	25.9	26.2	15.3	15	15	NE	15	14	14	14		1	Monitoring Uncertainty
8/9/1997	2.0	16.6	25.2	25.7	none		14	NE	12	14	14	15		none	Forecast (cloud)
8/10/1997	1.3	15.5	25.8	25.9	14.3	14	14	NE	14	14	14	11		1	Forecast (cloud) and monitoring
8/12/1997	0.5	15.6	25.4	25.6	14.3	14	14	NE	7	7	14	7		1	Forecast (cloud)
7/23/1998	3.0	14.4	25.4	25.4	14.3	14	12	NE	9	9	12	9		1	Forecast (cloud) and monitoring
7/26/1998	2.0	14.9	25.8	25.2	14.1	14	14	NE	14	14	12	11		1	Monitoring Uncertainty
7/30/1998	2.0	15.1	25.6	25.5	14.5	14	14	NE	7	7	11	7		1	Forecast (cloud) and monitoring
8/2/1998	2.5	15.4	26.6	26.6	15.3	15	15	NE	15	15	11	11		1	Monitoring Uncertainty
8/4/1998	1.0	15.4	26.4	26.0	14.3	14	14	NE	14	14	11	11		1	Monitoring Uncertainty
8/5/1998	3.0	15.1	26.6	27.1	15.4	15	15	11	9	9	11	9		1	Forecast (cloud) and monitoring
8/6/1998	0.5	14.5	25.2	24.5	12.5	11	11	11	7	7	9	7		2	Forecast (cloud) and monitoring
8/13/1998	2.5	15.4	25.5	25.5	none		NE	NE	12	NE	11	11		none	Forecast (cloud) and monitoring
8/23/1998	0.5	14.0	25.2	24.8	13.0	11	11	11	9	11	11	11		2	Forecast (cloud)
8/26/1998	0.5	13.8	25.6	25.2	12.5	11	11	NE	11	NE	11	11		5	Model - Protocol Uncertainty
6/9/1999	0.5	14.4	26.0	25.3	12.5	11	11	11	9	9	9	9		2	Forecast (cloud) and monitoring
6/10/1999	0.5	14.4	25.7	24.9	12.5	11	11	7	7	7	11	7		2	Forecast (cloud/ air)
6/23/1999	2.5	17.4	25.2	25.8	none		NE	NE	NE	NE	15	15		none	Monitoring Uncertainty
7/1/1999	2.5	17.2	25.0	25.3	none		NE	NE	NE	9	NE	9		none	Forecast (cloud/air) (Power Co. only)
7/5/1999	0.5	12.9	25.8	25.4	11.0	7	7	7	7	7	7	7		2	Model - Protocol Uncertainty
7/8/1999	0.5	18.0	24.7	25.3	none		NE	NE	NE	NE	9	11		none	Monitoring Uncertainty (Power Co. only)

Table A-1. (Continued)

Date	Duration of Exceed-ance (decimal hours)	Time of Exceed-ance (decimal hours)	Max Temp (EC) MDNR	Max Temp (EC) Power Co.	Actual Start Time of Release (decimal hours)	Start Time Variables and Time of Predicted Exceedance (decimal hours)								Duration of Release (decimal hours)	Reasons for exceedance
						A (Log file)	A (cal-culated)	B	C	D	E	F	G		
7/11/1999	2.5	17.7	25.2	25.7	none		NE	NE	NE	NE	NE	NE		none	Model - Protocol Uncertainty
7/15/1999	3.0	17.7	25.2	25.6	none		NE	NE	NE	NE	NE	11		none	Model - Protocol Uncertainty
7/18/1999	0.5	15.9	25.3	25.5	14.0	14	14	NE	14	11	14	7		1	Forecast (cloud/air) and monitoring
7/27/1999	1.5	15.2	26.5	26.9	14.0	14	14	NE	7	7	14	7		1	Forecast (cloud)
8/3/1999	0.5	15.9	25.7	25.8	14.0	14	14	NE	14	14	14	14		1	Model - Protocol Uncertainty
8/4/1999	2.0	16.2	25.9	26.2	15.0	15	15	11	15	11	12	11		1	Forecast (air) and monitoring
8/12/1999	1.5	16.7	25.9	26.1	15.0	15	15	NE	15	15	11	15		1	Model - Protocol Uncertainty
8/16/1999	3.5	17.7	25.3	26.0	none		NE	7	NE	11	11	11		none	Forecast (air) and monitoring
7/2/2000	2.0	15.1	26.3	26.4	15.5	15	15	NE	15	15	11	11		1	Monitoring Uncertainty
7/8/2000	1.0	15.8	25.5	26.2	15.5	15	15	NE	15	15	14	14		1	Monitoring Uncertainty
8/2/2000	4.5	13.8	26.3	26.7	none		NE	NE	NE	NE	11	11		none	Flow > 100 cfs
6/19/2001	3.0	15.5	26.2	ND	none		NE	ND	NE	ND	ND	ND		none	Flow > 100 cfs
6/26/2001	3.5	15.5	25.6	25.9	none		NE	NE	NE	NE	NE	12		none	Operator error
6/28/2001	5.0	14.5	26.4	26.9	none		NE	NE	NE	NE	11	11		none	Flow > 100 cfs
6/30/2001	1.0	14.3	26.0	26.3	13.8	11	11	11	11	11	11	11		3	Operator Error (Units failed)
7/1/2001	0.5	16.0	25.1	25.3	17.5	14	14	NE	14	14	15	15		1	Operator error
7/24/2001	0.5	14.5	25.2	24.7	12.5		11	7	7	7	9	7		5.5	Operator Error (Sensor reading error)
8/7/2001	1.5	14.0	25.9	25.9	none*		NE	NE	NE	NE	11	11		6	Flow > 100 cfs
8/8/2001	1.0	14.0	25.7	25.6	12.5	11	9	11	9	11	11	11		6	Model - Protocol Uncertainty
8/9/2001	1.0	13.5	25.6	25.3	12.0	11	11	11	9	9	11	11		8.5	Forecast (cloud)
8/11/2001	0.5	17.0	25.1	25.9	none		NE	NE	NE	NE	NE	11		none	Low morning temperature
6/22/2002	5.5	14.5	27.1	27.1	none		ND	ND	ND	ND	11	11		none	Operator error
6/23/2002	2.0	14.5	26.8	26.5	12.5	11	11	11	11	11	11	9		2	Forecast and monitoring
6/25/2002	1.5	14	25.9	25.2	12.3	12	11	9	9	7	9	7		5.5	Forecast and monitoring
6/26/2002	1.5	13.5	27.6	26.2	12.5	11	11	11	9	7	11	7		2.5	Forecast and monitoring
6/29/2002	6.5	14	26.6	26.4	none		ND	ND	ND	ND	11	11		none	Operator error (no T7 reading)
7/2/2002	1.0	13	26.2	24.8	11.0	9	9	7	7	7	9	7		3.25	Forecast and monitoring
7/3/2002	1.0	12.5	27.6	25.5	10.9	9	9	9	7	7	9	7		2	Model - Protocol Uncertainty

Table A-1. (Continued)

Date	Duration of Exceed-ance (decimal hours)	Time of Exceed-ance (decimal hours)	Max Temp (EC) MDNR	Max Temp (EC) Power Co.	Actual Start Time of Release (decimal hours)	Start Time Variables and Time of Predicted Exceedance (decimal hours)								Duration of Release (decimal hours)	Reasons for exceedance
						A (Log file)	A (cal-culated)	B	C	D	E	F	G		
7/4/2002	1.0	13	26.2	25.4	11.0	7	7	7	7	7	7	7		2.5	Model - Protocol Uncertainty
7/9/2002	0.5	14.5	25.2	24.8	12.6	11	11	11	9	9	11	9		2	Forecast (cloud/ air)
7/16/2002	5.0	14	26.4	26.4	none		NE	NE	NE	NE	11	11		none	Flow > 100 cfs
7/17/2002	1.8	13.5	26.4	25.5	12.5	11	11	11	9	11	11	11		2	Forecast (cloud)
7/20/2002	1.0	13.5	26.1	25.5	12.5	11	11	11	11	11	11	11		2.5	Model - Protocol Uncertainty
7/23/2002	0.3	13	25.2	24.3	11.0		7	NE	7	NE	7	9		2.5	Model - Protocol Uncertainty
7/31/2002	8.5	12.5	27.8	27.8	none		NE	NE	NE	NE	11	11		none	Flow > 100 cfs
8/4/2002	8.5	13	28.4	28.5	none		NE	7	NE	7	14	9		none	Low morning temperature
8/6/2002	3.5	14	25.9	26.2	none		NE	NE	NE	NE	14	12		none	Low morning temperature
8/8/2002	1.5	17	25.2	25.7	none		NE	NE	NE	NE	NE	NE		none	Low morning temperature
8/10/2002	0.5	15	25.4	24.3	none		NE	NE	NE	NE	14	11		none	Operator error (no T9 reading)
8/11/2002	1.0	14.5	26.1	24.5	12.5	12	12	9	9	7	11	7		none	Forecast (cloud/ air)
8/13/2002	0.3	16.5	25.2	25.3	8 & 14.5	7	7	7	7	7	7	7		3	Model - Protocol Uncertainty (Early Release)
8/18/2002	1.0	15.5	26.1	26.2	14.0	14	14	12	12	9	14	9		1	Forecast (cloud/ air)
8/20/2002	0.5	17	25.2	25.8	15.0	15	15	NE	15	15	NE	NE		1	Model - Protocol Uncertainty
8/25/2002	4.5	14	25.9	25.4	none		NE	NE	NE	NE	11	11		none	Low morning temperature
7/3/2003	4.0	15	25.9	25.8	none		NE	NE	NE	NE	14	12		none	Flow > 100 cfs
7/26/2003	3.0	16	25.4	25.2	none		NE	11	NE	11	11	11		none	Forecast and monitoring
7/27/2003	0.8	18	24.9	25.1	none		NE	NE	NE	NE	NE	11		none	Monitoring Uncertainty
8/23/2003	3.0	15	25.5	25.5	none		NE	NE	NE	NE	14	11		none	Low morning temperature
8/24/2003	1.2	16.5	25.0	25.2	none		NE	NE	NE	NE	15	15		none	Monitoring Uncertainty
7/1/2004	2.0	16	25.4	25.2	none		NE	NE	NE	15	15	12	15	none	Operator error
7/4/2004	3.5	15.5	26.1	25.8	none		15	12	15	14	15	12	15	none	Operator error
7/6/2004	5.5	15	26.6	26.8	none		14	NE	14	14	14	14	9	none	Operator error
7/7/2004	1.0	15.5	25.6	25.1	14.0		15	NE	15	7	15	7	14	3	Operator error
7/11/2004	5.0	15	27.0	27.0	17.0		15	NE	15	14	15	14	12	3.3	Operator error
7/24/2004	1.5	17.5	25.2	25.5	none		NE	NE	NE	NE	NE	NE	NE	none	Model - Protocol Uncertainty
7/25/2004	3.5	16	26.1	26.2	12.3		15	NE	15	14	14	14	14	10.1	Operator error

Table A-1. (Continued)

Date	Duration of Exceed-ance (decimal hours)	Time of Exceed-ance (decimal hours)	Max Temp (EC) MDNR	Max Temp (EC) Power Co.	Actual Start Time of Release (decimal hours)	Start Time Variables and Time of Predicted Exceedance (decimal hours)							G	Duration of Release (decimal hours)	Reasons for exceedance
						A (Log file)	A (cal-culated)	B	C	D	E	F			
7/29/2004	2.0	16	25.5	ND	none		ND	NE	ND	14	ND	14	11	none	Operator error (missing sheet)
6/11/2005	ND	ND	ND	25.2	none	7	7	9	7	9	ND	ND		none	Operator Error
6/12/2005	ND	ND	ND	26.9	none		NE	NE	NE	NE	ND	ND		none	Flow > 100 cfs
6/23/2005	4.5	15.5	26.3	26.6	none		NE	NE	NE	NE	NE	14		none	Operator Error
6/25/2005	9	14	28.8	28.9	none		NE	NE	NE	7	11	7		none	Operator Error
6/26/2005	10.5	13.5	29.5	29.8	none		NE	NE	7	7	7	7		none	Operator Error
6/27/2005	0.5	12	25.2	24.9	10	7	7	7	7	7	7	7		3	Model - Protocol Uncertainty
6/28/2005	0.5	13	26.5	ND	11	7	7	NE	7	7	7	7		2	Model - Protocol Uncertainty
6/29/2005	10.5	13.5	28.5	ND	none		NE	NE	NE	7	9	7		none	Operator Error
6/30/2005	1	12.5	27.1	ND	11	9	9	7	7	7	9	7		2	Model - Protocol Uncertainty
7/6/2005	4.5	15.5	26.3	ND	none	9	NE	NE	NE	NE	12	12		none	Flow > 100 cfs
7/12/2005	3.5	13.5	27.0	26.7	none		NE	NE	NE	NE	12	9		none	Low morning temperature
7/26/2005	1	14.5	25.2	25.4	13		NE	NE	NE	NE	11	11		3	Flow > 100 cfs
7/27/2005	6	13	26.9	26.7	none		NE	NE	NE	NE	11	11		none	Flow > 100 cfs
7/30/2005	1	14	25.9	25.8	12.5	11	11	11	11	11	11	11		2	Model - Protocol Uncertainty
7/31/2005	1.5	13.5	26.6	26.5	12.5	11	11	11	11	11	11	11		2	Model - Protocol Uncertainty
8/2/2005	9.5	13.5	28.9	29.4	none	11	11	11	9	7	11	7		none	Operator Error
8/3/2005	11	13	29.7	30.2	none	11	11	11	7	7	11	7		none	Operator Error
8/4/2005	0.5	13	26.1	25.8	11	7	7	NE	7	7	7	7		2	Model - Protocol Uncertainty
8/7/2005	0.5	14.5	25.3	25.7	12.5	11	11	11	7	9	11	9		2	Forecast (cloud)
8/9/2005	0.5	14	25.5	25.5	12	11	11	11	11	11	11	11		3	Model - Protocol Uncertainty
8/10/2005	0.5	13	25.1	23.9	11	11	11	11	11	11	11	11		3	Model - Protocol Uncertainty
8/11/2005	0.5	14	25.5	24.9	12	11	11	11	9	7	11	9		3	Forecast (cloud)
8/14/2005	2.5	14.5	27.9	28.3	15	15	15	9	7	7	14	7		1.5	Forecast (cloud/ air)
8/17/2005	0.5	14	25.5	24.9	12	11	11	9	9	7	11	9		3	Forecast (cloud/ air)
8/20/2005	0.5	14.5	26.4	25.7	12.5	11	11	11	9	7	12	7		2	Forecast (cloud)
8/21/2005	4	14	25.9	26.4	none	7	NE	NE	7	NE	9	9		none	Flow > 100 cfs
8/23/2005	NE	NE	24.5	25.2	none		NE	NE	NE	NE	NE	NE		none	Model - Protocol Uncertainty
8/24/2005	0.5	17	25.6	25.6	15	15	15	NE	15	15	15	15		1	Model - Protocol Uncertainty