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TEMPERATURE AND TROUT HABITAT ENHANCEMENT FOR OPERATING DEEP CREEK HYDROELECTRIC STATION: OPERATING PROTOCOL DEVELOPMENT AND RESULTS FOR 1995-2008

March 2011

MARYLAND POWER PLANT RESEARCH PROGRAM

Martin O'Malley, Governor ♦ Anthony G. Brown, Lt. Governor

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TEMPERATURE AND TROUT HABITAT ENHANCEMENT FOR OPERATING DEEP CREEK HYDROELECTRIC STATION: OPERATING PROTOCOL DEVELOPMENT AND RESULTS FOR 1995-2008

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FOREWORD

This report, entitled “Temperature and Trout Habitat Enhancement for Operating Deep Creek Hydroelectric Station: Operating Protocol Development and Results for 1995-2008," was prepared by Steve Schreiner and Jodi Dew-Baxter of Versar, Inc., as part of Biology Integrator Contract No. K00B0200109 and by Alan Klotz of Maryland Department of Natural Resources, Fisheries Service, at the request of Shawn Seaman, Power Plant Assessment Division, Maryland Department of Natural Resources.

ABSTRACT

The Maryland Department of Natural Resources (DNR) Power Plant Research Program evaluated the use of flow releases from a hydroelectric facility to moderate elevated temperatures in the Youghiogheny River to enhance habitat for trout. A model 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. During June, July, and August, DCHS personnel use an operating protocol developed based on the results of the model to determine whether to release water to maintain tolerable temperatures for trout. This report outlines model development, parameters of the protocol, and assessments of the effectiveness of the protocol as it was implemented from 1995 through 2008.

The applied temperature enhancement protocol was successful at maintaining lower temperatures than would otherwise have occurred in the river without the releases. Some system failures in implementing the protocol at the facility, including some operator errors, resulted in water temperatures that occasionally exceeded the target value. Other exceedances were due to some of the protocol's thresholds. More effective training for operators and minor adjustments of the protocol may improve the ability to use releases from DCHS to control temperature in the river. The improvements of fish habitat attained by implementing the protocol are reflected in the increased survival of stocked trout and the robustness of the trout fishery in the river.

EXECUTIVE SUMMARY

The Deep Creek Hydroelectric Station 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 driven primarily by the economics of power generation and water availability in Deep Creek Lake. As part of relicensing by the Federal Energy Regulatory Commission and Maryland's permitting processes, Maryland Power Plant Research Program and the station owner, now Brookfield Power (formerly, Pennsylvania Electric Company), evaluated the uses of hydroelectric releases to provide minimum flows for fish habitat, flows for whitewater boating, and flows to moderate elevated river temperatures specifically to address the needs of resident trout. They identified temperature as the primary factor that influences the quality of fish habitat and that can be moderated by operation of the power plant; thus, the term *temperature enhancement* denotes improving conditions for fish by lowering water temperature to within a suitable range. Previous studies indicated that appropriately timed power-generation releases would be the most cost-effective and balanced use of releases to lower river temperature, thereby enhancing fish habitat over a distance of at least 5.8 km (3.6 miles) downstream from the tailrace. This report describes (1) the development of a model to predict river temperature; (2) an operating protocol for determining when temperature-enhancement releases are needed; and (3) the results of the first 14 years of implementing the protocol.

A model and protocol for predicting maximum daily river temperature during the warmest time of the year was developed using daily measurements of river flow, 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) that power plant operators can use during the morning and early afternoon to predict maximum river temperature for the day and determine if a release is needed to lower it. Releases are then announced to the public via a telephone recording. Target maximum river temperature is 25°C, which is considered to be the upper threshold for suitable brown trout habitat. Model equations were based on historical measurements of average daily river flow, hourly river temperatures, maximum daily air temperature, and mid-day cloud-cover fraction from 1987 through 1993. When applied to the historical data, the equations showed that the rate of unnecessary releases (i.e., releases that were not needed to lower water temperature to a suitable level for trout) was 14%, and the rate of failure to make releases needed to improve temperature was about 4%. That is, during an average historical year in which the model would have prompted 17 releases for temperature enhancement, only 2 or 3 of those releases would have been unnecessary. The protocol requires personnel managing the facility to gather a set of regional data early each day to predict the maximum water temperature likely to occur in the river later that day and determine if a release will be necessary to offset an expected increase that would exceed acceptable levels. The regional data to be collected were determined based on the results of the model and include river flow as measured at Oakland, Maryland; the weather forecast; and early morning river temperatures. The protocol established thresholds for specific parameters that were intended to indicate the need for a release to moderate the predicted increase in river temperature.

Temperature levels were monitored in the Youghiogheny River during summer months to assess the effects of the applied protocol and the conditions under which it failed to maintain the target temperature range. The area upstream and downstream of the hydroelectric facility was monitored at nine temperature sampling stations. The most upstream station, Swallow Falls, is approximately 3.5 kilometers above the tailrace; the most downstream station, Sang Run, is approximately 5.8 kilometers below the tailrace. During the first 14 years of using the protocol to operate the Deep Creek Project, the total number of days when river temperature exceeded 25°C at Sang Run ranged from 3 in 1996 to 25 in 2005. If the Deep Creek Project had not been operating, the estimated number of days on which temperature might have exceeded 25°C at Sang Run ranged from 4 to 10 days in 1996, to 27 to 44 days in 2002. Maximum river temperature rarely exceeded 27°C at Sang Run, and on days when river temperature exceeded 25°C, it rarely exceeded 26°C. In contrast, actual maximum temperature at Swallow Falls exceeded 27.5°C on 32 days in 1999 and on 22 days in 1995. Maximum temperature at Swallow Falls exceeded 30°C on 7 days during the 14-year study period; 6 of those days were in 1995 and 1999. Data from the Swallow Falls station suggest that days when temperature-enhancement releases would have been unnecessary were few.

The effectiveness of the protocol was assessed by evaluating the conditions that existed, the parameters that were monitored, and the actions of personnel at the facility associated with each episode when river temperature exceeded 25°C at the downstream station (i.e., Sang Run). Causes of exceedances can be grouped into 3 main categories: (1) failure to implement the protocol correctly (i.e., operator error); (2) protocol exception parameters that indicated that no release was necessary; or (3) uncertainty in forecast data, river monitoring data, or the regression model equations.

Implementation of the temperature-enhancement protocol between 1995 and 2008 was largely successful at maintaining lower temperatures than would otherwise have occurred in the river. The success rate could be improved by adjusting several factors. More effective training for operators who implement the protocol would improve its success for enhancing temperature. In 2009, the protocol was modified by extending the thresholds slightly to account for unusual conditions. The early morning temperature threshold (below which the protocol is not implemented) was lowered to 20°C because nine of the past exceedances could have been prevented by a lower threshold for the predicted maximum river temperature for the day. Similarly, the flow threshold (above which the protocol is not implemented) was raised to 4.25 m^3/s (150 cfs) because the higher flow threshold would have prevented temperature exceedances on 15 additional days during the 14-year period.

The effects of implementing the temperature-enhancement protocol on the resident fish populations can be estimated by measuring changes in the abundance and health of trout during the 14-year period; however, changes in fishing regulations (i.e., catch-and-release beginning in 1993) during the same period make these results less definitive for evaluating the effectiveness of the temperature-enhancement protocol. Populations of stocked trout in the Youghiogheny River have been monitored since 1988. Catch-and-release records indicate a significant increase in the numbers of quality-size trout ($\geq$ 305 mm) during the study period. Measured factors of the condition of trout were within the optimal range for both brown trout and rainbow trout during the 14-year, post-temperature-enhancement period. Overall, stronger survival and vigor of the trout population have been documented since the implementation of the temperature-enhancement protocol for Deep Creek Hydroelectric Station.

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1.0 INTRODUCTION

Deep Creek Hydroelectric Station (DCHS) is operated to comply with a Water Appropriations Permit for power generation issued by the Maryland Department of the Environment. Condition 16 of the permit requires the operator to submit a plan for operating DCHS 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, the term *temperature enhancement* denotes improving conditions for fish by lowering water temperature to within a suitable range.

The DCHS operator outlined a general temperature-enhancement protocol (Penelec 1994) to (1) operate the DCHS as necessary to prevent water temperatures from exceeding 25°C in the Youghiogheny River between the tailrace and Sang Run; (2) minimize unnecessary releases; (3) provide maximum advance notice of releases to those interested in whitewater recreation; and (4) provide simple, automated implementation. Maryland Department of Natural Resources' (DNR) Power Plant Research Program (PPRP) worked with the operator to use available historical data to develop and test a model and operating protocol to meet those goals.

This report describes the development of a model and operating protocol for predicting the maximum daily river temperature during summer based on daily measurements of river flow and water temperature in the river, and 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 maximum river temperature. Operators use these predictions to determine if a release is needed to maintain the desired temperature. The public is then notified of planned releases via a telephone recording. This report also presents results of the first 14 years of implementing the protocol during the summers of 1995 through 2008, followed by an analysis of trout populations during those years.

DNR's Fisheries Service develops strategic plans to manage, monitor, assess, and provide access to commercial and recreational fisheries in the state. DNR designated the portion of the Youghiogheny River (Garrett County, Maryland) from the tailrace at DCHS downstream to the bridge at Sang Run as a Catch and Release Trout Fishing Area (C&R TFA) in 1993. Regulations limit terminal tackle to artificial lures and flies. Fishing is permitted year-round. Prior to 1993, this portion of the river was managed under Maryland's Designated Trout Stream regulations, which specified a two-fish-per-day creel limit with no restrictions on minimum size, bait, or tackle. The fishery in the C&R TFA is maintained by put-and-grow stockings of fingerling brown trout, *Salmo trutta*, and rainbow trout, *Oncorhynchus mykiss*, annually during the fall. The goal is to maintain the density of the population of adult trout at 621 trout/km and a standing crop of 25 kg/ha, as

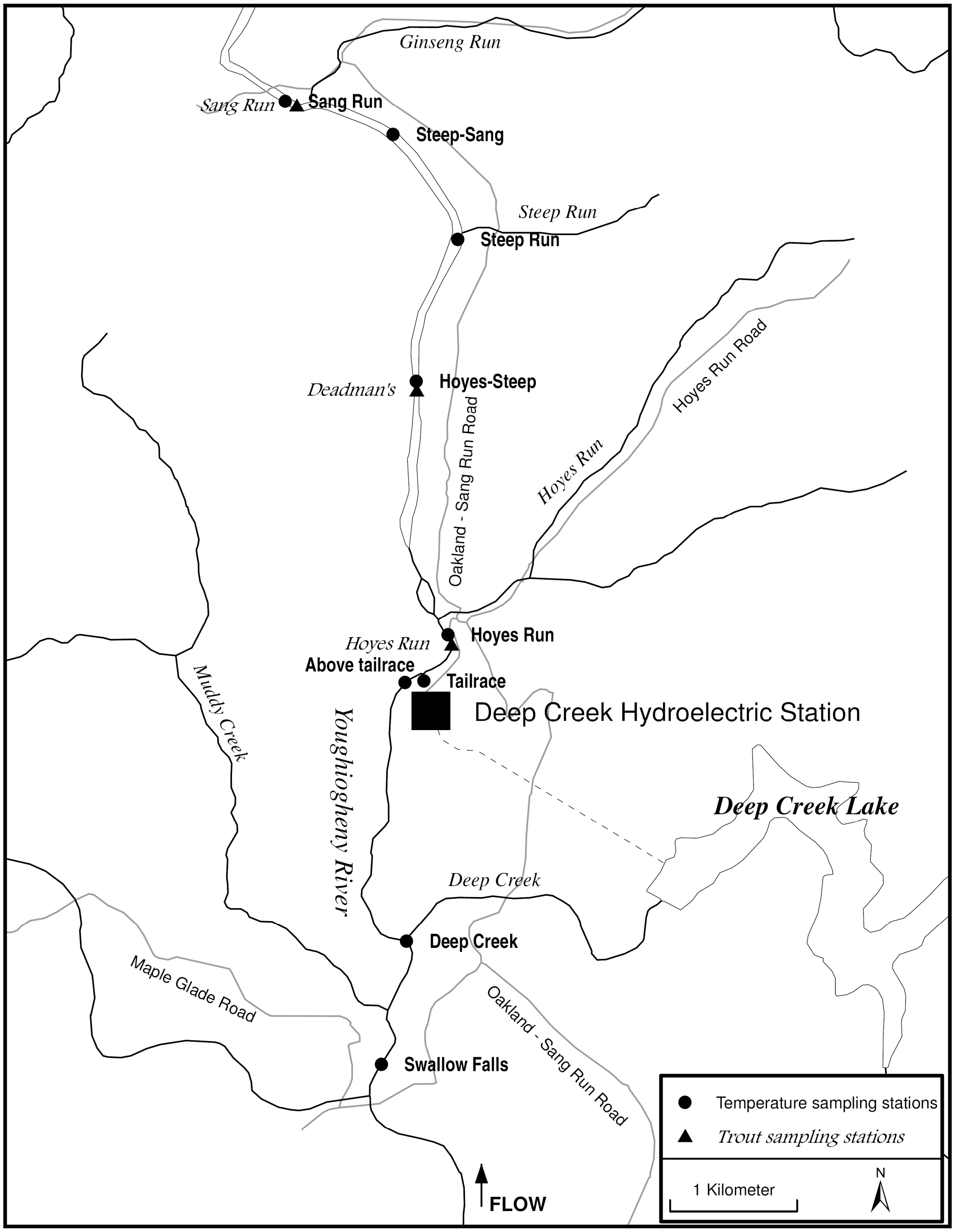


Figure 1-1. Map of the Youghiogheny River between Swallow Falls and Sang Run, Maryland, showing the locations of the tailrace of Deep Creek Hydroelectric Station, temperature-logging and fish-sampling stations, and major tributaries.

measured during fall sampling efforts. Trout populations within the C&R TFA have been surveyed at two sampling stations annually since 1988: (1) the Hoyes Station located near the upper boundary of the C&R TFA, and (2) the Sang Run Station located near the lower boundary (Figure 1-1). Beginning in 1999, trout populations were sampled at a third location known as Deadman's Station, which is about midway in the C&R TFA.

2.0 MODEL AND PROTOCOL DEVELOPMENT

2.1 INPUT DATA

Schreiner (1997 a, b) used a combination of simulation modeling and test releases from DCHS to show that a 2-hour, 2-unit release beginning at 1100 hours would be sufficient to maintain temperatures cooler 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 cfs) or a series of pulsed operational releases, a two-hour, two-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 a means of predicting when river temperatures would be likely to exceed a certain target. In this case, 25°C was used to trigger a temperature-enhancement release because it is near the upper end of the temperature tolerance range of brown trout (Raleigh et al. 1986). The power company was assumed to use a two-hour, two-unit release to maintain the desired temperature whenever at least three hours' advance notice could be provided to potential whitewater boaters. Under less severe conditions (maximum river temperatures of less than 26°C to 27°C), only a one-hour, two-unit release would be required and would be used whenever more than three hours' notice was not feasible.

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 measured flow rate. DNR's Fisheries Service has monitored summer water temperature in the Youghiogheny River from locations above the tailrace to Sang Run since 1987. Multiple regressions of data from 1987 to 1993 were used to develop a set of equations for predicting maximum river temperature based on river flow, temperature, and meteorological variables. Historical data showed no occurrences of river temperatures warmer than 25°C before June 1 or after August 31 during these years; therefore, only data for June through August were used in the analysis.

The two most important meteorological factors affecting diurnal increase in river temperature are air temperature over the river and solar radiation entering the river (Brown and Barnwell 1987). These parameters are not measured at or near this section of the Youghiogheny River, although minimum and maximum daily air temperatures are recorded nearby in McHenry and Oakland, Maryland. 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 data are Elkins and Morgantown, West Virginia. Hourly air-temperature and cloud-cover data for those locations are available from the National Climatic Data Center. Since air temperature and cloud cover are the readily available parameters for estimating the expected increase in water temperature during the day a temperature-prediction model must be based on forecasts of this information.

Forecasts were available for Elkins and Morgantown, West Virginia, but not for Oakland or McHenry, Maryland.

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, West Virginia, 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, West Virginia, 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, Maryland.

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 the Morgantown station is with regard to air temperature. These results, combined with a greater similarity in elevation between Elkins and the Youghiogheny River site, showed that data from the Elkins station were the most suitable 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 was less than 2.8 m^3/s (100 cfs) at Oakland, which is equivalent to 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 threshold for an enhancement release and, thereby, to minimize monitoring costs. The tailrace flow value was calculated using the following equation (Penelec 1994):

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

where

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

The relationship between average daily river flow and maximum daily water temperature in the Youghiogheny River near Sang Run during the summer was analyzed using data from 1987 to 1993, when the station was not operating. River temperature exceeded 25°C only when flows at Oakland were less than about 2.8 m^3/s (100 cfs). There was little relationship between flow and river temperature at low flows [i.e., from less than 0.85 m^3/s to 1.1 m^3/s (30-40 cfs)]. Successive regressions between flow and temperature over a range of flows that varied from 0.57 m^3/s to 1.1 m^3/s (20-40 cfs) up to 4.8 m^3/s (170 cfs) showed a maximum correlation in the range of 0.85 m^3/s to 4.8 m^3/s (30-170 cfs).

2.2 REGRESSION EQUATIONS

Data for river flow, water temperature, air temperature, and cloud cover and information about the operation of the station 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 used only the data for days when river flow at Oakland did not exceed 2.8 m^3/s (100 cfs) and when DCHS did not generate power (or when generation occurred after 1500 hours because generation after that time would not affect maximum river temperature).

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; however, the greater uncertainty in earlier forecasts probably would 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 0900 hrs 1100 hrs	1200 hrs 1400 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^2, and increased importance of measured river temperatures from 1200 hours through 1500 hours. 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.

The data could be classified into two distinct groups with respect to the relationship between flow and river temperature. 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 operational complexity of using two formulas based on river flow, regressions for models to be used before 1100 hours 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:

$$\text{SMAXADJ} = \text{SMAX} - 0.04\ (\text{OFLOW} - 30)$$

where

SMAXADJ = Sang Run adjusted temperature,
SMAX = 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. Implementing the protocol involves using predicted air temperature and cloud cover instead of measured data; consequently, daily predictions of maximum river temperature are less certain than is suggested in Table 2-2, which is based on actual historical data rather than forecasts. 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 often are given as a range (e.g., upper 80s could be 87°F 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 Service1995)

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 hours (PSANG6 and PSANG7), maximum air temperature and cloud cover are less important predictors of maximum river temperature than measured temperatures; therefore, no adjustments were made for to account for uncertainty in developing those models.

PSANG1 is intended for use only when measured water temperature data are not available (e.g., due to sensor failure). In that case, estimates cannot be conservative 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 hours, based on sensor readings at 0700 and 0900 hours, and 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 hours (to reach Sang Run at 1430 hours 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 = 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 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 4 of the 16 "unnecessary" releases and 24.9°C for 3 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, 2 to 3 additional releases would be made during an average year that required 17 temperature enhancement releases.

2.4 PROTOCOL EXCEPTIONS

To minimize unnecessary monitoring, the protocol was designed to discontinue monitoring if the predicted maximum temperature determined at 0700 hours was less 23°C. As described previously, historical data (1987-1993) indicated that river temperature exceeded 25°C only when river flows were less than 100 cfs as recorded in Oakland, Maryland; therefore, the protocol was not implemented whenever river flows were less than 100 cfs. A flow diagram showing the steps of the final protocol is shown in Figure 2-1.

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.

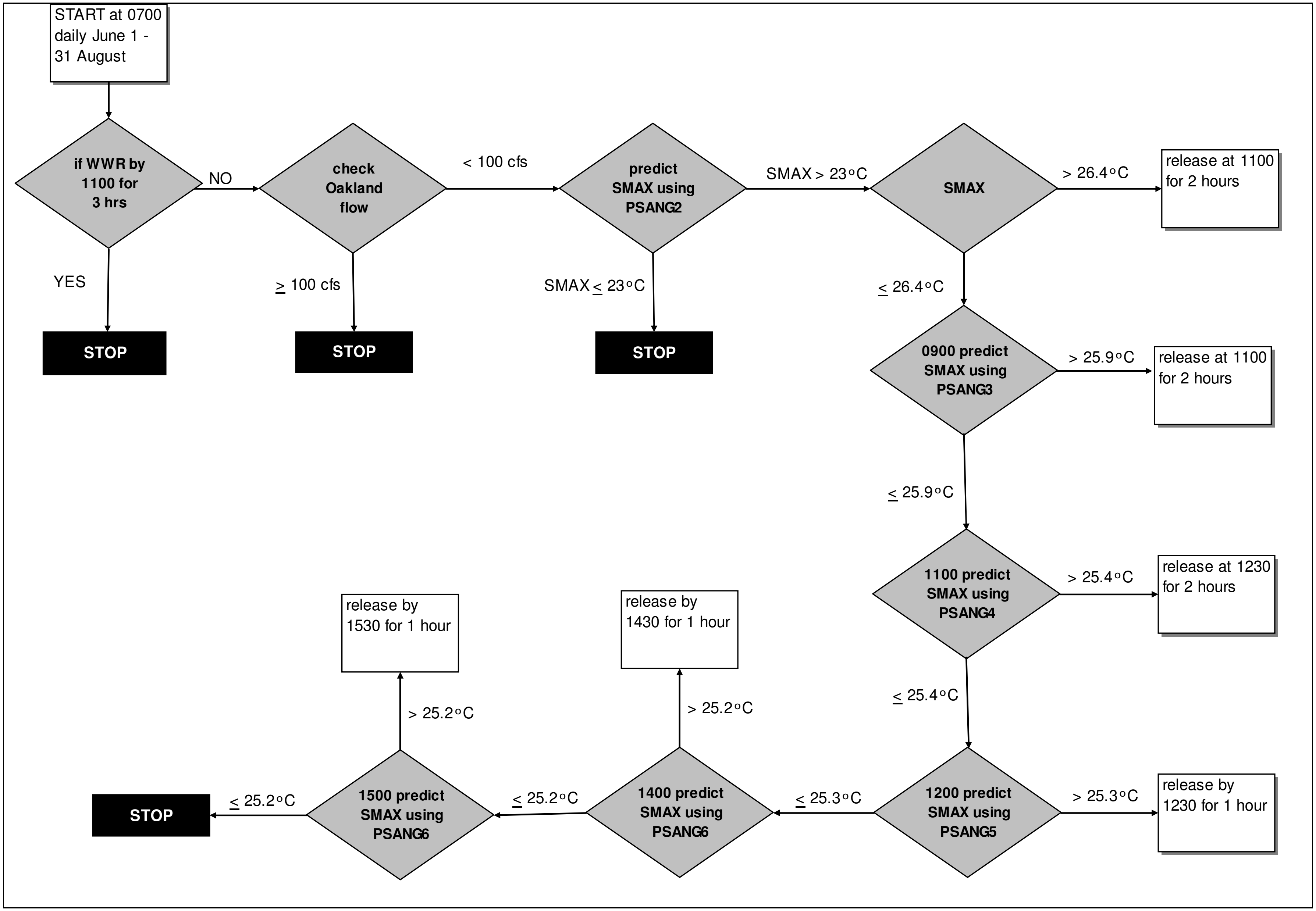


Figure 2-1. Deep Creek Hydroelectric Project: diagram of protocol for temperature enhancement releases, as originally developed and implemented in 1995. Notes: WWR = White Water Release

3.0 PROTOCOL TESTING

3.1 DATA SOURCES

The power company recorded water temperature at the bridge over Sang Run at 2-minute to 10-minute intervals from June through August in 1995 through 2008. Station operators used these data in real time to decide whether to release water for temperature enhancement according to the protocol described in Section 2 of this report. In our analysis, one measurement was extracted from the 2-minute to 10-minute data set at half-hour intervals for comparison with data that DNR collected using temperature sensors[1] placed at several locations (Figure 1-1) between Swallow Falls (4.3 km or 2.7 miles downstream of the tailrace) and Sang Run (6.8 km or 4.2 miles downstream). DNR's probes recorded water temperature at half-hour intervals on various dates in June through sometime in September of each year from 1995 through 2008. These data were available after the summer season to evaluate the relationship between actual river temperature and releases from Deep Creek Hydroelectric Station (DCHS). The power company's temperature data sometimes were missing or invalid; therefore, the average of DNR's data from two sensors at the Sang Run station was used to determine if the target temperature of 25°C was maintained. Data from the upstream stations at Swallow Falls or the confluence of the Deep Creek tributary with 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, West Virginia, as part of the temperature-release protocol on days when no releases were planned for any purpose other than temperature enhancement. Hourly records of actual meteorological data from Elkins Station 13729 were obtained from the National Climatic Data Center in Asheville, North Carolina, after the summer season to compare actual daily measurements of cloud cover and minimum and maximum daily air temperatures with predicted values.

Prior to 1996 and after 2003, cloud cover information from the Elkins station was available as cloud cover fraction in tenths (i.e. values ranging from 0 to 10). As shown in Table 2-3, those numerical values correspond with descriptive terms for cloud cover. From 1996 to 2003, cloud cover fraction was reported using terms describing sky cover. Those descriptive terms were converted to an average numerical value on the same scale as the other numerical data as follows: CLR or FEW = 0.5; SCT = 3; BKN = 7.5; OVC = 9.5. Those values were used for analyses that required measured cloud cover fractions.

The power company obtained instantaneous, early morning flow readings for the Youghiogheny River at Oakland, Maryland, from the U.S. Army Corps of Engineers' river bulletin board (http://waterdate.usgs.gov/md/nwis/uv/?site_no=03075500). Flow information recorded at 15-minute intervals was obtained from the U.S. Geological Survey (station

[1] Ryan TempMentors from 1995-2001, and StowAway TidBiT temperature data loggers (onsetcomp .com) since 2001.

number 03075500) after each summer season and summarized to provide daily averages. Table 3-1 shows average flow for June, July, and August, in 1995 through 2008.

Table 3-1. Average flow in m^3/s (cfs) in the Youghiogheny River for June through August, 1995-2008, compared with the long-term average flow (1942 through 2008) at Oakland, Maryland (USGS station 03075500)

Year	Rank (67 = wettest)	June	July	August	June-August
1995	18	3.1 (111)	1.0 (37)	3.3 (116)	2.5 (88)
1996	65	7.7 (273)	16.1 (567)	10.3 (362)	11.4 (401)
1997	37	6.8 (240)	2.1 (75)	4.2 (150)	4.4 (155)
1998	51	11.8 (417)	5.8 (205)	2.2 (78)	6.5 (231)
1999	3	0.7 (23)	0.6 (20)	0.4 (14)	0.5 (19)
2000	44	7.2 (254)	7.3 (257)	2.1 (75)	5.5 (195)
2001	55	7.7 (273)	12.4 (438)	3.3 (115)	8.4 (296)
2002	15	1.1 (38)	4.1 (145)	1.2 (41)	2.4 (84)
2003	67	21.7 (766)	15.3 (539)	10.1 (358)	15.7 (554)
2004	41	10.4 (368)	1.6 (58)	3.1 (110)	5.0 (176)
2005	34	2.9 (101)	8.2 (290)	1.5 (54)	4.2 (149)
2006	28	6.7 (238)	3.5 (125)	0.7 (23)	3.6 (127)
2007	38	1.2 (44)	4.5 (159)	8.0 (284)	4.5 (160)
2008	46	9.7 (343)	8.5 (301)	2.1 (75)	5.8 (205)
Average		6.0 (212)	4.9 (174)	3.7 (131)	4.9 (172)

3.2 RESULTS

Releases from the DCHS were summarized as the annual percentage of days between June 1 and August 31 on which releases were scheduled and announced at least one day in advance. Announced and scheduled whitewater releases accounted for 15% to 40% of the total (Table 3-2). Whitewater releases are scheduled for Mondays, Fridays, and one Saturday per month, water levels permitting. Announced and scheduled releases for power generation accounted for 0% to 27% of the total. Unscheduled releases accounted for 14% to 49% of the total; 1% to 32% of unscheduled releases were for temperature enhancement and 2% to 48% were for unscheduled power generation. No water was released for any purpose on 16% to 51% of summer days during the 14-year study period.

Table 3-2. Summary of releases from Deep Creek Station during implementation of the temperature enhancement protocol (June 1 through August 31) during 1995-2008

Release Type	**Percentage of days**													
Year	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**
Announced and scheduled whitewater	37	36	36	34	15	32	30	34	29	30	34	31	36	40
Announced and scheduled power	11	27	9	1	0	1	12	0	0	7	7	8	9	25
TOTAL announced and scheduled	**48**	**63**	**45**	**35**	**15**	**33**	**42**	**34**	**29**	**37**	**41**	**39**	**45**	**65**
Not announced or scheduled (for power)	9	12	8	35	2	23	22	14	48	16	2	5	4	7
Temperature enhancement	26	9	14	10	32	9	12	23	1	2	15	26	14	8
TOTAL unscheduled	**35**	**21**	**22**	**45**	**34**	**32**	**34**	**37**	**49**	**18**	**17**	**31**	**19**	**14**
Days with no release	17	16	34	21	51	36	24	29	22	45	42	30	36	21

The percentage of days on which water was released to enhance temperature was largest during dry years (1995, 1999, and 2002), and smallest during the wettest year (2003). The percentage of days with whitewater releases remained fairly consistent from 1995 through 2008, except in 1999, when the frequency of releases for whitewater boating decreased because of drought conditions. The percentage of announced releases for discretionary power generation was largest in 1996 (27%) and smallest during 1999, 2002, and 2003 (0%). Unannounced releases for generation ranged from 2% in 1999 and 2005, when lack of rainfall resulted in the loss of nearly all discretionary generation during the summer, to 48% in 2003, which was the wettest summer in the 67-year flow record.

Days on which river temperature at Sang Run exceeded 25°C (at either DNR's sensors or the power company's) were evaluated by reviewing 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 the protocol parameters used that day. The primary causes of exceedances can be grouped into three categories: (1) failure to implement the protocol correctly (i.e., operator error); (2) conditions that failed to trigger the use of the protocol according to original thresholds [i.e., flow at Oakland greater than 2.8 m^3/s (100 cfs), or temperature prediction at 0700 hours less than or equal to 23°C]; or (3) uncertainty in one or more components of the protocol (e.g., forecast data, measured data, the regression model equations).

Table 3-3 provides details about seven primary causes of exceedances. Specifically, 16% of exceedances resulted from operators failing to follow the protocol correctly or from problems with equipment. Conditions that failed to trigger the use of the protocol [i.e., flow greater than 2.8 m^3/s (100 cfs) at Oakland] accounted for 14% of exceedances.

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 of Temperature Exceedance Per Year															
	95	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**Total**	**% of Total**
Operator error	4						4	3		7	6		1	1	26	16.0
Flow > 2.8 m^3/s (100 cfs)	5	1	1			1	3	2	1		4	2	3		23	14.2
Predicted max. temp. < 23°C	1						1	4	1		1			1	9	5.6
Forecast Uncertainty	4	1	3	1	2		1	4			5	7	5	4	37	22.8
Monitoring Uncertainty			2	3	1	2									8	4.9
Forecast and Monitoring Uncertainty			3	5	4			4	1						17	10.5
Regression Model Uncertainty	4	1	2	1	5		1	6		1	9	9	3		42	25.9
Total	18	3	11	10	12	3	10	23	3	8	25	18	12	6	162	100.0

The historical data (collected from 1987 through 1993) showed no instances of actual maximum temperature exceeding 25°C when river flow was greater than 2.8 m^3/s (100 cfs); however, that occurred five times in 1995, four times in 2005, three times in 2001 and 2007, twice in 2002 and 2006, and once each in 1996, 1997, 2000, and 2003. In 18 of those 23 cases, raising the flow threshold from 2.8 m^3/s (100 cfs) to 4.2 m^3/s (150 cfs) would have resulted in maintaining temperature below 25°C. Raising the flow threshold would not necessarily trigger a release but would prompt the operator to continue to monitor the need for a release. Such additional monitoring would have been required approximately once in each of the 14 years during which the original protocol was in effect. In the remaining 5 cases, river flow was considerably greater than 4.2 m^3/s (150 cfs) at the time the protocol would have been implemented. Raising the flow threshold further or eliminating it entirely probably would not have resulted in maintaining river temperature below 25°C in those cases because the increased volume of stormwater runoff in the river would have displaced a temperature-enhancement discharge from the hydroelectric station relatively quickly, unless the release was maintained for a much longer period than is practicable.

Once in 1995, 2001, 2003, 2005, and 2008 and four times in 2002, the predicted maximum temperature for the day (based on information available at 0700 hours) was below 23°C (see Section 2.4), but actual maximum temperature eventually exceeded 25°C, which suggests that lowering the predicted-maximum-temperature threshold would improve results. Lowering the predicted maximum temperature required to trigger a release to 20°C would have eliminated most of those nine exceedances. The benefits of lowering the predicted-maximum- temperature threshold and raising the high-flow threshold may be additive for improving the performance of the temperature-enhancement protocol. Two of the nine dates on which the predicted-maximum-temperature threshold failed to trigger a necessary temperature-enhancement release occurred on dates with an average river flow greater than 2.8 m^3/s (100 cfs) at Oakland, Maryland. Maximum temperature was not predicted on the 14 dates when river flow clearly exceeded the threshold for proceeding to the next step of the protocol; consequently, no data were collected from which to determine if the predicted maximum temperature for the day would have triggered a release.

The remaining 64% of exceedances were due to uncertainty in forecast or measured data used in the protocol equations, or to uncertainty inherent in the regression model itself. Different values of the parameters were used in the protocol equations to pinpoint the likely time and cause of each exceedance (i.e., to identify the parameter or other factor that led to a predicted maximum temperature lower than 25°C on days when the actual maximum temperature exceeded 25°C). If all test combinations resulted in the same predicted time of exceedance, inherent uncertainty in the regression model was assumed to be responsible for the observed exceedance, rather than uncertainty in forecast or measured data. This usually occurred when exceedance temperature was very close to the threshold value of 25°C. When forecast uncertainty was the only reason for an exceedance, a combination of uncertainty in cloud cover and air temperature together, or cloud cover separately accounted for the exceedance with equal probability.

Uncertainty could be reduced to some extent by revising the protocol to use local weather data, but the expense to collect necessary data, revise the protocol, and provide a site-specific weather forecast would be considerable. Uncertainty in the cloud forecast could be reduced by adjusting the cloud cover factor used for certain descriptions. For example, the originally approved protocol document did not list values corresponding to thunderstorms and showers, but these terms were assigned high cloud cover factors as the protocol was implemented by the power company, which may have resulted in under-predicting maximum daily temperature until later in the day. The benefit of this correction cannot be quantified easily, but the cost should be minimal because the protocol does not use the cloud cover factor after 1100 hours. Using more accurate values would result in earlier releases only on days when releases probably would have been made later in the day. Uncertainty in measured data could be separated into uncertainty in temperature measurements and natural spatial and temporal variability in river temperature. Natural variability is greater than measurement uncertainty, suggesting that there is no simple way to reduce this component of uncertainty in the protocol. 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.

Most temperature exceedances occurred when river temperatures were between 25.1°C and 26.0°C, except for those caused by operator error and flow greater than 2.8 m^3/s (100 cfs) at Oakland (Table 3-4; Figure 3-1). The number of temperature exceedances caused by operator error fluctuated little with increasing temperature. The number of exceedances associated with flow greater than 100 cfs at Oakland was greatest when the temperature ranged from 26.1°C to 26.5 °C (7 exceedances); the second greatest number occurred between 25.1°C and 25.5°C (5). Increasing the flow threshold to 4.2 m^3/s (150 cfs) could decrease the number of exceedances in the higher temperature ranges.

Figure 3-2 illustrates 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. Temperatures at Swallow Falls provide an estimate of predicted river temperature at Sang Run in the absence of releases from DCHS. Maximum daily temperatures at Swallow Falls or the Deep Creek tributary confluence and those at Sang Run were evaluated to determine the average difference between them. Data used for this evaluation were from June through August of 1987 through 2008 on days when the DCHS was not operated and when river flow as measured at Oakland, Maryland, was less than 2.8 m^3/s (100 cfs). Based on these data, the average upstream river temperature was 0.7°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 releases from DCHS. In 2001 and 2003, data from the Deep Creek confluence station were used in place of data from Swallow Falls because the sensor at the Swallow Falls station failed. Although river temperatures exceeded 25°C at Sang Run between 3 and 25 days per year, maximum temperature rarely exceeded 27.5°C. In contrast, actual maximum temperature

Table 3-4. Summary of causes for temperature exceeding 25°C at DNR's sensors in the Youghiogheny River at Sang Run based on distribution of temperatures greater than 25°C between June and August (1995-2008)

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	7	4	4	4	2	0	1	4	26
Flow > 2.8 m^3/s (100 cfs) at Oakland	5	4	7	4	2	1	0	0	23
Predicted max. temperature < 23°C	4	2	0	1	0	0	1	0	8
Forecast Uncertainty	14	13	8	1	0	2	0	0	38
Monitoring Uncertainty	2	4	2	1	0	0	0	0	9
Forecast and Monitoring Uncertainty	5	5	2	3	0	1	0	0	16
Regression Model Uncertainty	18	12	8	2	1	1	0	0	42
Total	55	44	31	16	5	5	2	4	162

Note: Seven temperature exceedances are not included in this table but are listed in the appendix because the temperature at Sang Run did not exceed 25.1°C at DNR's sensors, but did exceed 25.1°C according to the power company's sensor.

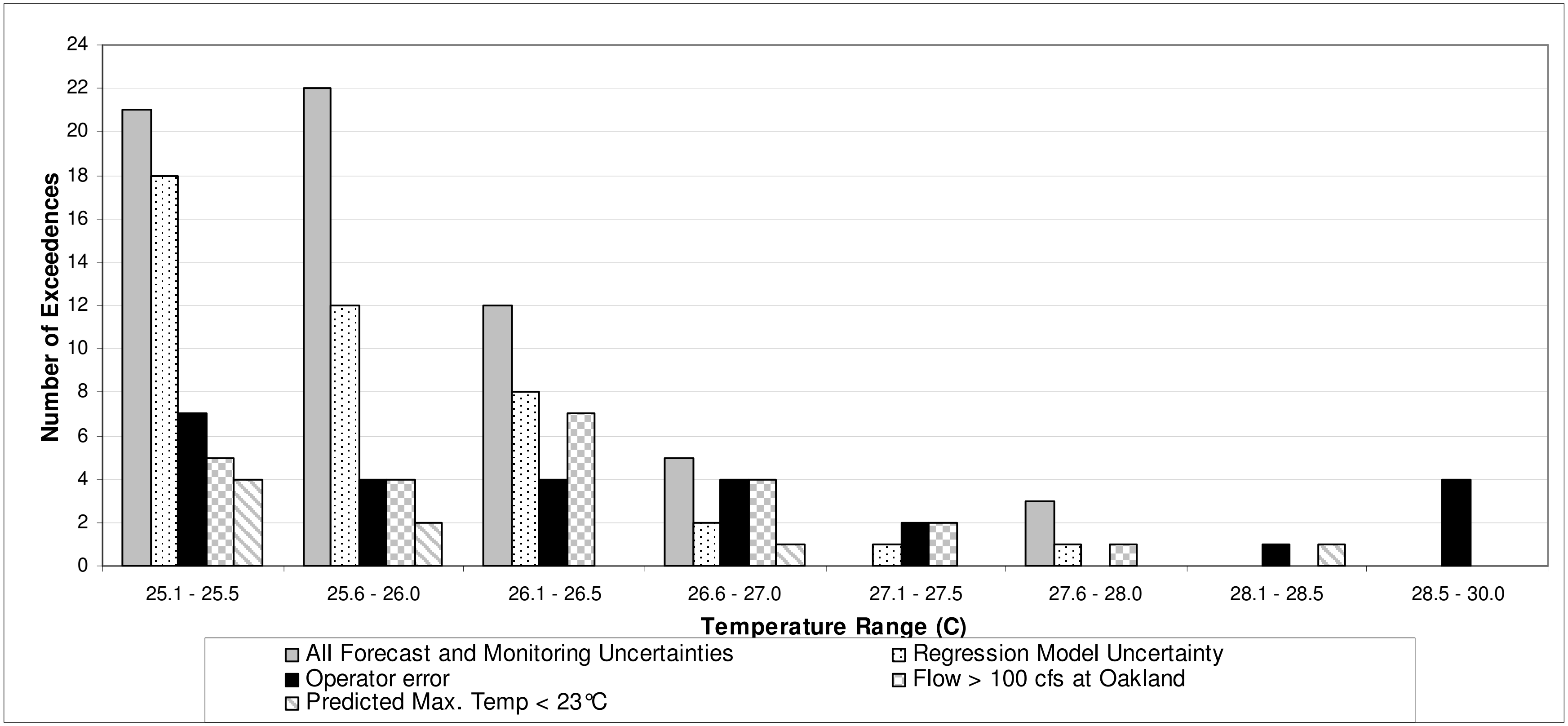
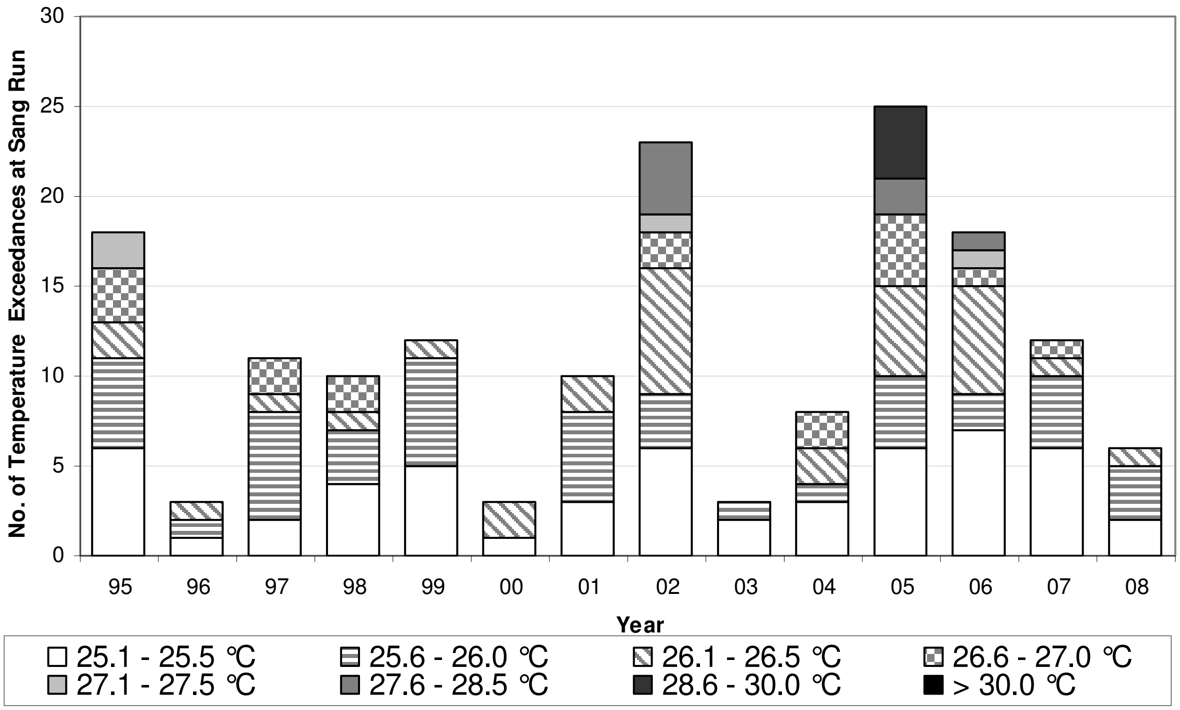


Figure 3-1. Summary of causes for temperature exceeding 25°C at DNR's sensors in the Youghiogheny River at Sang Run based on distribution of temperatures greater than 25°C between June and August (1995-2008)



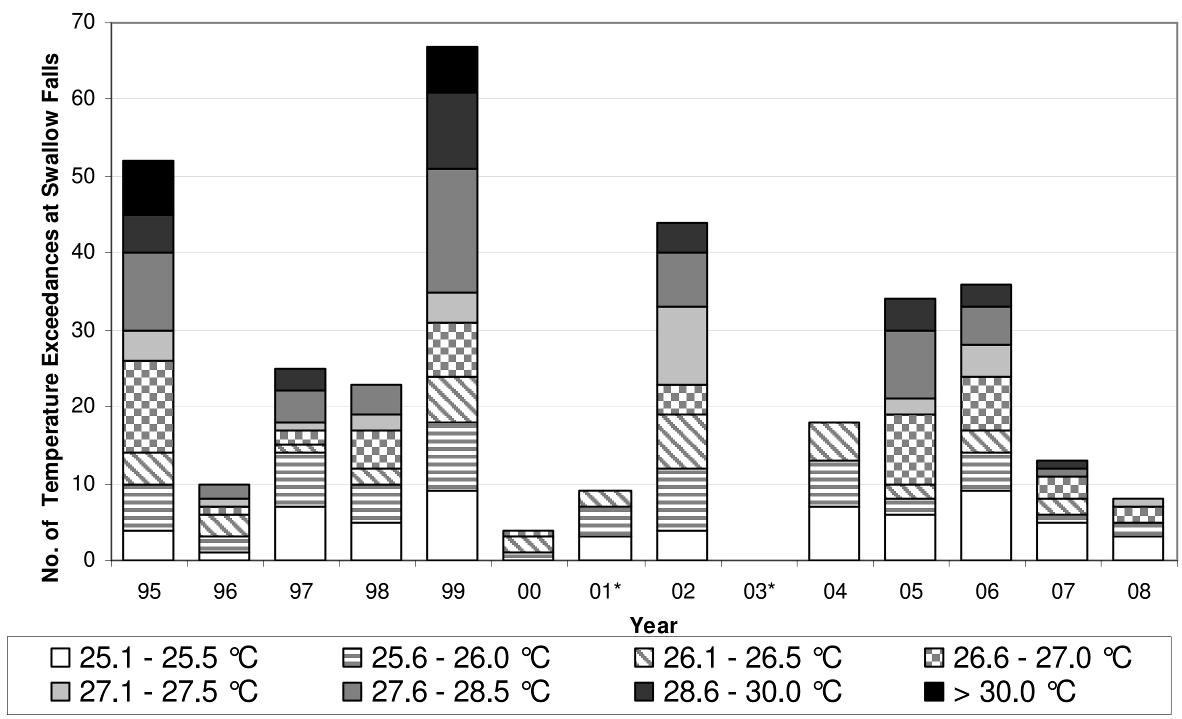


Figure 3-2. Distribution of temperatures greater than 25°C in the Youghiogheny River at Sang Run and Swallow Falls between June and August, 1995-2008. Data from the station at the Deep Creek tributary confluence replaced Swallow Falls data (due to sensor failure) in 2001 and 2003.

at Swallow Falls exceeded 27.5°C on 22 days in 1995 and on 32 days in 1999. Maximum temperature exceeded 30°C on 7 days and 6 days in those years, respectively.

In summary, the total number of days on which temperature exceeded 25°C at Sang Run ranged from 3 in 1996, 2000, and 2003, to 25 in 2005 (Table 3-5). 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 occurred on a minimum of 0 days in 2003 to a maximum of 67 days in 1999. Maximum river temperature at Sang Run exceeded 27°C 16 times from 1995 through 2008; maximum temperature exceeded 25°C 162 times, and 64 of those days exceeded 26°C; 61% 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 3-5. Summary of temperature enhancement releases from Deep Creek Station over the 14-year period from 1995 through 2008

River Conditions	**Year**													
	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Total releases for temperature	24	8	13	9	29	8	11	21	1	2	14	23	13	7
Days > 25 °C at Swallow Falls	52	10	25	23	67	4	9[a]	44	0[a]	18	34	38	13	8
Days > 25 °C at Sang Run[b]	18	3	11	10	12	3	10	23	3	8	25	18	12	6
Days < 25 °C at Swallow Falls on temperature enhancement release day[c]	1	1	1[d]	1[d]	0	4	5[a]	0	1[a]	1	3	6	1	3

[a] Data from Deep Creek tributary confluence were used due to sensor failure at Swallow Falls.
[b] False negatives, meaning needed release not made or not made in time.
[c] Potential false positives, meaning release made but may not have been needed.
[d] Sang Run exceeded 25°C on these days even though Swallow Falls did not.

4.0 TROUT STUDIES

4.1 OBJECTIVES

The purpose of this part of the study was to monitor parameters of the trout population in the Youghiogheny River Catch and Release Trout Fishing Area (C&R TFA) in response to catch and release regulations and coldwater enhancement measures working in concert since 1995. The objectives were to document fish species composition and abundance, estimate trout population densities and standing crops at three established sampling stations annually, and calculate indices of physical condition for trout species.

4.2 PROCEDURES

Figure 1-1 shows fish sampling locations; Table 4-1 lists the coordinates of those locations. Sampling stations were selected to include all kinds of habitat present in the stream reach to be surveyed (pool, riffle, run). The total length and width of the station were measured to the nearest tenth of a meter. The surface area of the stream reach was computed and expressed in hectares. Trout were collected using a model no. 2.5-Generator Powered Pulsator (GPP), Smith-Root, barge-mounted electro-fishing unit equipped with three anodes and dip nets. The survey was initiated at the downstream end of the station, and three electro-fishing passes were made through the entire station. During each pass all trout were collected and placed in live boxes. All trout were anesthetized with a 1:10 solution of clove oil and ethanol alcohol, identified to the species level, measured for total length (TL) to the nearest millimeter, weighed to the nearest gram, and returned alive to the stream at the completion of the survey. Trout populations were estimated using the three-pass regression technique described by Zippin (1958), and population densities and standing crops were estimated using the MICROFISH 2.2 software package (Van Deventer and Platts 1985). Statistical analyses of population means were interpreted as described by Motulsky (2003). The coefficient of condition (K) described by Lagler (1952) was used as a measure of fish condition. Other species of fish were collected in the third pass, identified to the species level, rated on their general abundance, and then released back to the river. The general number of fish of a particular species in each sample was rated as abundant (> 100 individuals), common (5-100 individuals), or scarce (< 5 individuals).

Trout populations were not estimated in 1996 and 2003 because of high river flows during the scheduled sampling period. In 2004, high river flow precluded estimating populations at the Hoyes and Deadman's stations; therefore trout population data for that year were insufficient for use in this analysis.

Table 4-1. Youghiogheny River trout sampling stations 1988–2008		
Station Name	**Start location**	**End location**
Hoyes Run	N39°31.681 W79°24.684	N39°31.584 W79°24.619
Deadman's	N39°32.756 W79°24.891	N39°32.655 W79°24.866
Sang Run	N39°33.918 W79°25.643	N39°33.888 W79°25.519

4.3 RESULTS

Table 4-2 presents a list of the common and scientific names of fishes collected in the Youghiogheny River within the C&R TFA during this study period. The assemblage of species is indicative of a coldwater/coolwater fish community (Steiner 2000), and species composition remained relatively unchanged during the study period.

Table 4-2. Common and scientific names and relative abundance of fish species collected in the Youghiogheny River Catch and Release Trout Fishing Area, 1988-2008		
Common Name	**Scientific Name**	**General occurrence**
River chub	*Nocomis micropogon*	Abundant
Blacknose dace	*Rhinichthys atratulus*	Scarce
Longnose dace	*Rhinichthys cataractae*	Common
White sucker	*Catostomus commersoni*	Abundant
Northern hog sucker	*Hypentelium nigricans*	Common
Margined madtom	*Noturus insignis*	Scarce
Chain pickerel	*Esox niger*	Scarce
Brook trout	*Salvelinus fontinalis*	Scarce
Rainbow trout	*Oncorhynchus mykiss*	Abundant
Brown trout	*Salmo trutta*	Abundant
Mottled sculpin	*Cottus bairdi*	Abundant
Bluegill	*Lepomis macrochirus*	Scarce
Rock bass	*Ambloplites rupestris*	Common
Smallmouth bass	*Micropterus dolomieu*	Common
Johnny darter	*Etheostoma nigrum*	Scarce

Trout densities and standing crops (Figures 4-1 and 4-2) were significantly greater from 1995 through 2008 than during the period before temperature enhancement (i.e., 1988 through 1994; t-test, $P = 0.053$ and $P = 0.0009$, respectively). The mean trout density and standing crop increased by about two-fold during the period of combined temperature enhancement and special fishing regulations.

During 2005 DCHS failed to comply with the temperature enhancement protocol on a record number of occasions (see Tables 3-2 and 3-4 and Figure 3-2), which may have affected the trout population adversely. The mean trout population densities and standing crops were significantly smaller during 2005 through 2008 than during 1995 through 2002 (t-test $P = 0.0034$ and $P = 0.0009$, respectively). Mean trout densities decreased by about 58% between those periods, and mean standing crops decreased about 42% (Figures 4-1 and 4-2). The management objectives of 621 trout/km and 25 kg/ha were not achieved during the period from 2005 through 2008.

Figure 4-3 shows the estimated number of quality-size trout ($\geq$ 305 mm) per kilometer in the Youghiogheny River C&R TFA from 1988 through 2008. The number of quality-size trout is a useful descriptor of the age and size structure of the population. Generally, stocked fingerling trout attain 305 mm by Age 3 in the Youghiogheny River C&R TFA. The number of quality-size trout in the C&R TFA increased significantly after catch-and-release regulations and temperature enhancement measures were implemented (t-test $P = < 0.0001$). The mean number of quality-size trout increased 3.2 times after the initiation of temperature enhancement measures. Despite significant decreases in the densities of trout populations between the 1995–2002 period and the 2005–2008 period, there was no significant difference in the number of quality size trout between those intervals (t-test $P = 0.10$), suggesting that larger trout ($\geq$ 305 mm) are more tolerant of periodically warmer water temperatures. The frequency distributions of the length of brown and rainbow trout during 2002 (Figures 4-4 and 4-5, respectively) show a typical pattern of trout-population size structure that achieves management goals. The length frequency distributions of brown trout in 2006 and rainbow trout in 2007 (Figures 4-6 and 4-7, respectively) show that fewer young age classes were present, and the management goal of 621 trout/km was not achieved during those years.

DCHS followed the temperature enhancement protocol more closely during 2006, resulting in a 36% increase over estimated trout densities during 2005, even though only 50% of the recommended number of fingerlings was stocked during the fall of 2005. The mean estimated standing crop (Figure 4-2) approached the desired management goal of 25 kg/ha in 2006. That 62% increase from 2005 is an indication that older, larger fish constituted a large portion of the trout population. DCHS followed the temperature enhancement protocol closely in 2007; however, the trout population declined from its 2006 abundance. The mean, combined-species density of trout decreased 38%, and standing crops decreased 33% in 2007. The density of rainbow trout decreased the most, measuring 47% less than in 2006.

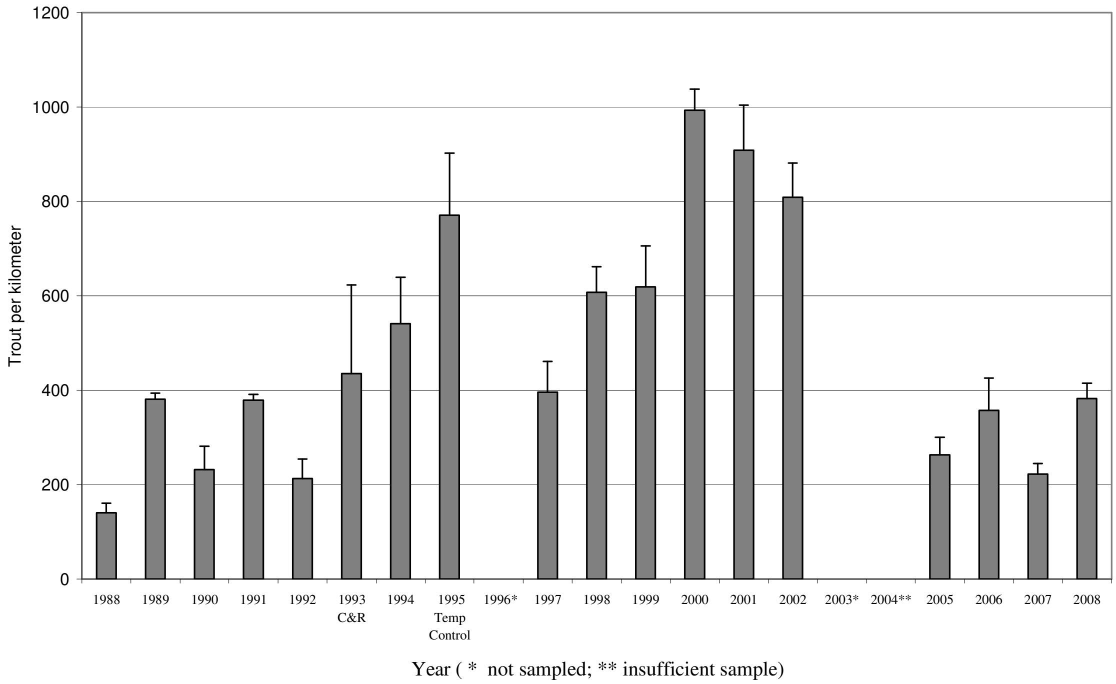


Figure 4-1. Mean trout densities in the Youghiogheny River Catch and Release Trout Fishing Area, 1988–2008

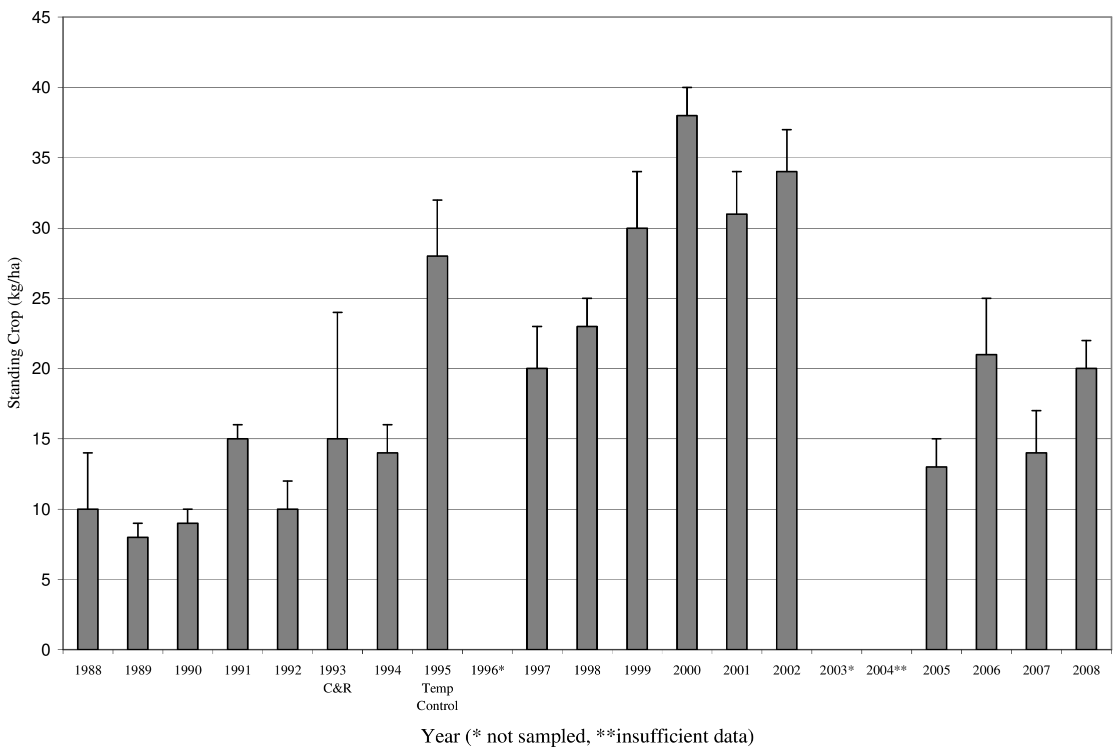


Figure 4-2. Mean trout standing crops in the Youghiogheny River Catch and Release Trout Fishing Area, 1988–2008

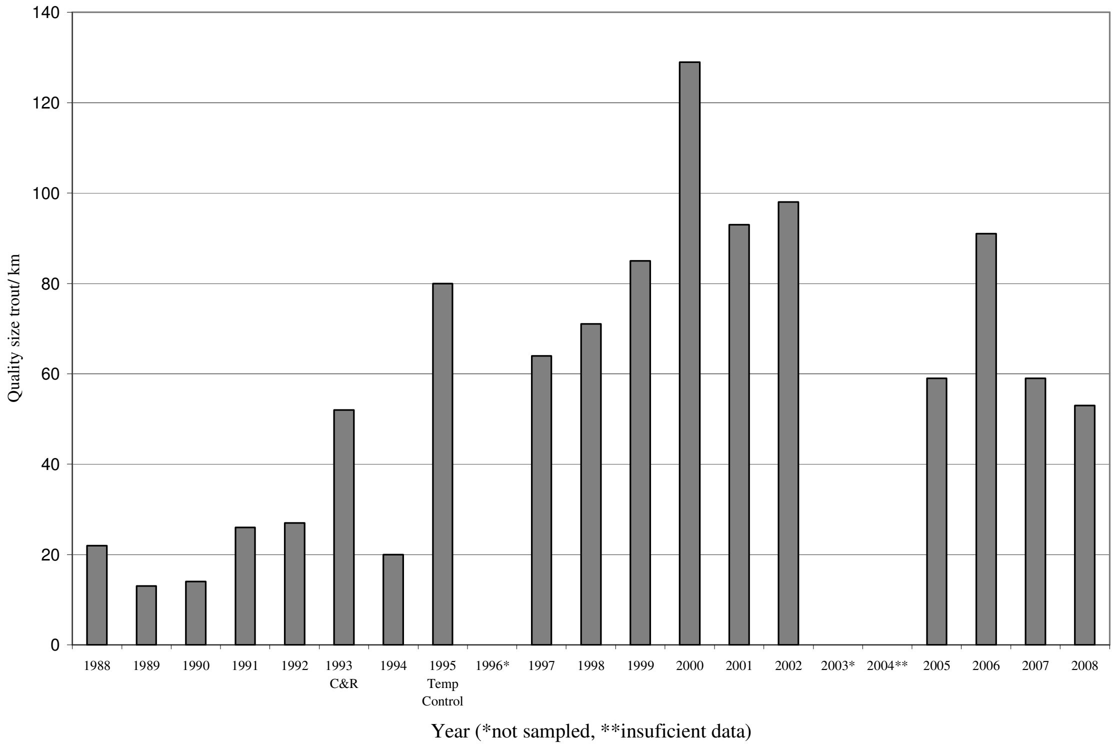


Figure 4-3. Estimated quality-size trout (≥ 305 mm) in the Youghiogheny River Catch and Release Trout Fishing Area, 1988–2008

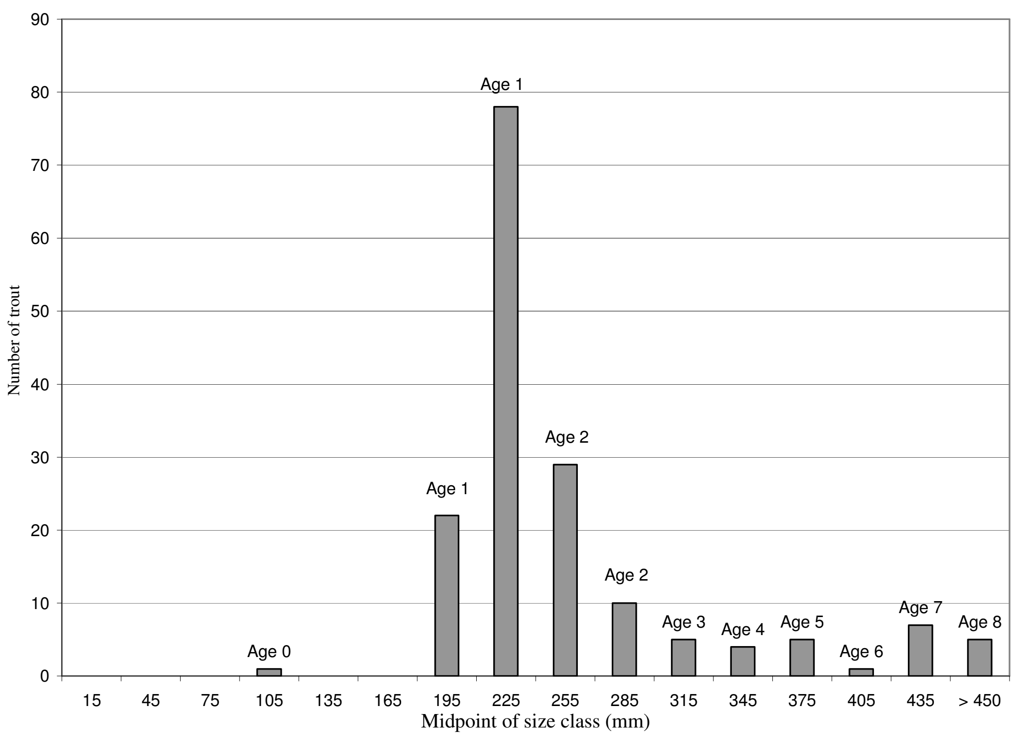


Figure 4-4. Length frequency distribution of brown trout (n = 167) in the Youghiogheny River Catch and Release Trout Fishing Area, 2002

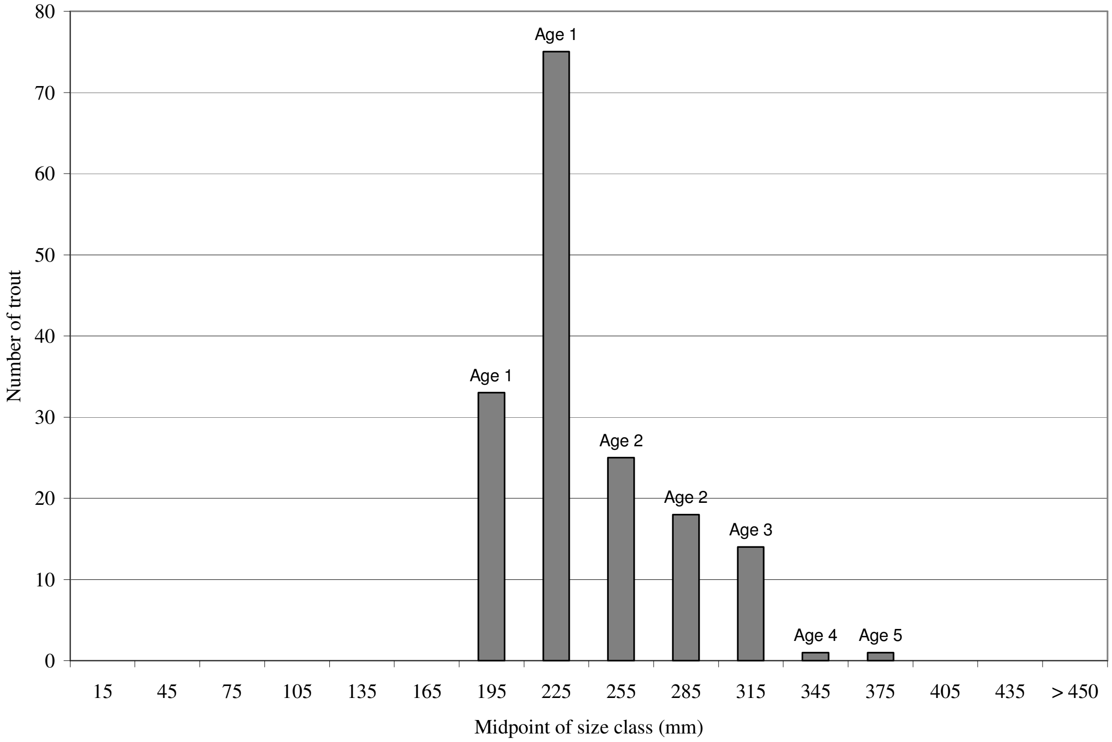


Figure 4-5. Length frequency distribution of rainbow trout (n = 167) in the Youghiogheny River Catch and Release Trout Fishing Area, 2002

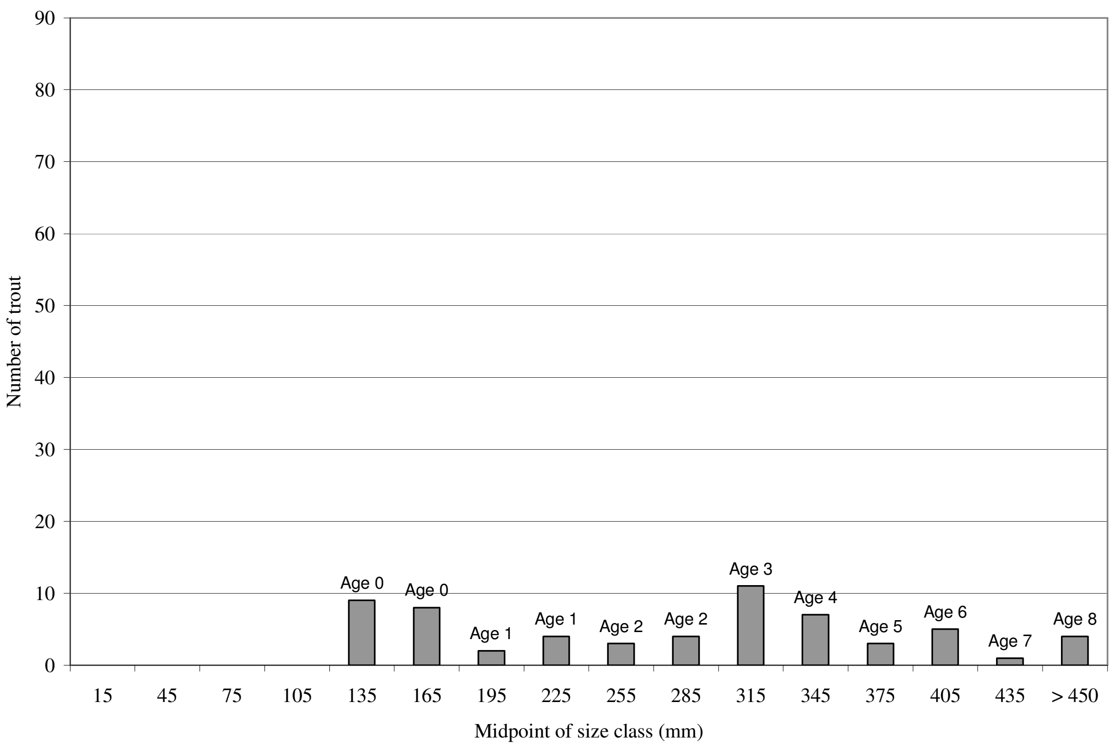


Figure 4-6. Length frequency distribution of brown trout (n = 61) in the Youghiogheny River Catch and Release Trout Fishing Area, 2006

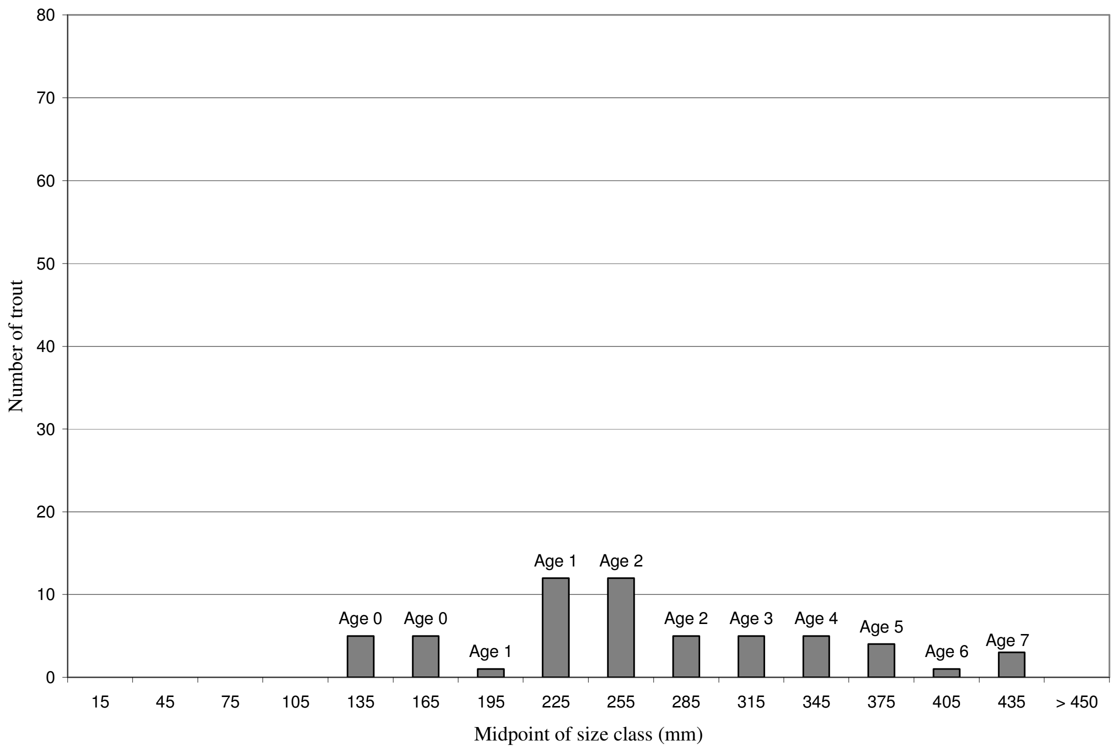


Figure 4-7. Length frequency distribution of rainbow trout (n = 58) in the Youghiogheny River Catch and Release Trout Fishing Area, 2007

Figure 4-8 shows a record of fingerling trout stocking from 1988 to 2008. The annual stocking objective is to release 20,000 fingerlings (10,000 brown trout and 10,000 warmwater rainbow trout) in the fall. Stocking at that annual rate generally achieves the management goal of 621 adult trout per kilometer within the management area; however, the number of stocked fingerlings was less than the recommended objective during 9 years of the 14-year period of this study. During 2006, 16,000 fingerling brown trout were released within the C&R TFA in the spring; however, few of those early-stocked fish survived to Age 1 compared with typical survival of fall-stocked fingerling trout, and the early-stocked fish have contributed little to the adult population in the Youghiogheny River C&R TFA. The management goal was achieved in 2007, and by 2008 trout densities and standing crops increased to levels similar to those observed in 2006 (Figures 4-1 and 4-2).

Tables 4-3 and 4-4 present the average total length, weight, and condition factors for trout in the Youghiogheny River. Condition factors were generally within the optimal range (0.90 - 1.10) for both brown trout (Table 4-3) and rainbow trout (Table 4-4) during this study period. The Youghiogheny River C&R TFA has produced quality-size ($\geq$ 305 mm) and trophy-size ($\geq$ 457 mm) trout consistently since 1995. Species composition of adult trout in the Youghiogheny River C&R TFA has averaged 47% brown trout and 53% rainbow trout since 1994, when rainbow trout became part of the management scheme.

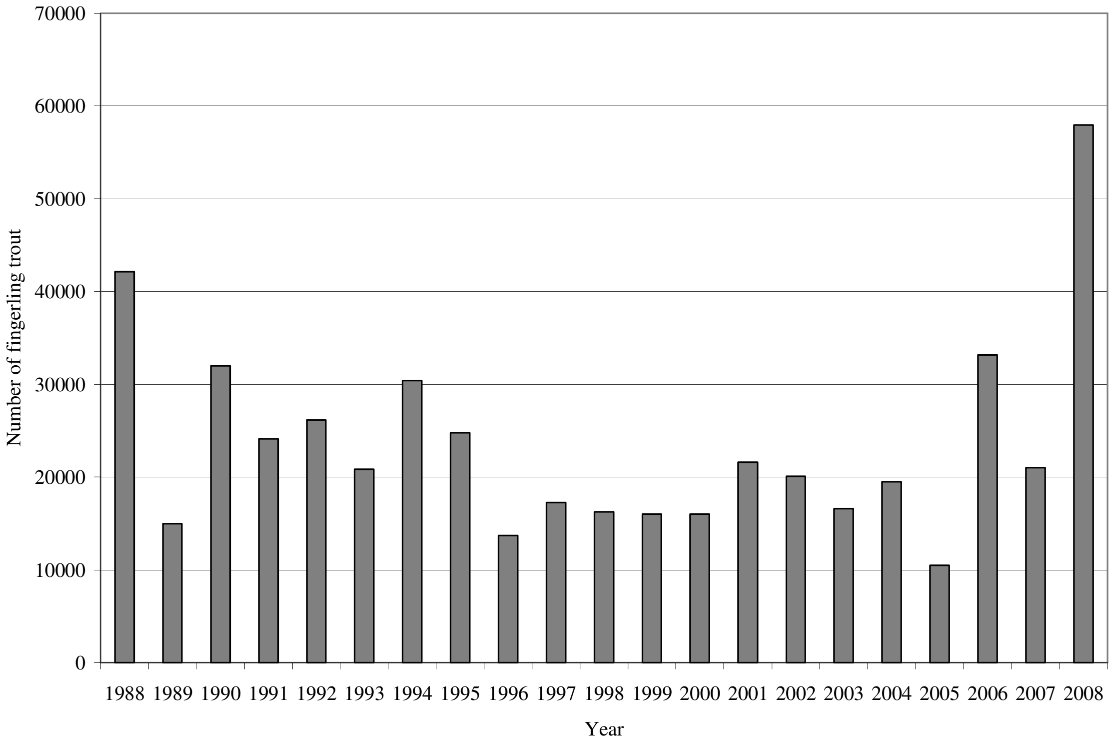


Figure 4-8. Fingerling trout stocking record for the Youghiogheny River Catch and Release Trout Fishing Area, 1988–2008

Table 4-3. Mean total length, weight, and condition factor (K) with ranges for adult brown trout in the Youghiogheny River Catch and Release Trout Fishing Area, 1988–2008

Year	N	TL(mm)	W(g)	K
1988	42	261 (162-470)	214 (40-1200)	1.00 (0.79-1.52)
1989	119	216 (161-343)	98 (38-408)	0.88 (0.68–1.15)
1990	48	250 (182-381)	154 (50-500)	0.93 (0.68-1.14)
1991	116	234 (172-660)	171 (34-3451)	0.96 (0.61-1.75)
1992	88	236 (161-491)	161 (46-1189)	1.02 (0.82-1.26)
1993	73	239 (147-349)	142 (31-499)	0.95 (0.63-1.42)
1994	75	236 (122-385)	144 (14-655)	0.96 (0.74-1.48)
1995	154	256 (135-442)	177 (31-877)	0.94 (0.66-1.26)
1997	61	275 (150-392)	247 (34-678)	1.07 (0.90-1.35)
1998	108	269 (197-395)	209 (71-630)	0.97 (0.76-1.19)
1999	141	272 (203-610)	236 (77-2441)	0.99 (0.80-1.26)
2000	109	294 (190-595)	307 (56-2565)	1.00 (0.74-1.22)
2001	154	218 (128-560)	162 (23-1777)	0.99 (0.72-1.24)
2002	167	257 (115-622)	206 (17-2348)	0.97 (0.70-1.23)
2004*	22	314 (142-600)	438 (27-2116)	0.95 (0.71-1.11)
2005	54	296 (194-682)	300 (70-3039)	0.94 (0.74-1.29)
2006	61	288 (130-585)	330 (17-1848)	0.99 (0.66-1.63)

Table 4-3. (Continued)				
Year	**N**	**TL(mm)**	**W(g)**	**K**
2007	54	285 (214-560)	285 (95-1530)	1.00 (0.83-1.26)
2008	46	295 (125–555)	315 (13-1172)	0.94 (0.67-1.14)
* Sample from the Sang Run Station only				

Table 4-4. Mean total length, weight, and condition factor (K) with ranges for adult rainbow trout in the Youghiogheny River Catch and Release Trout Fishing Area, 1988–2008				
Year	**N**	**TL (mm)**	**W (g)**	**K**
1988	7	224 (187-288)	105 (75-200)	0.92 (0.82-1.15)
1989	0			
1990	2	272 (237-306)	185 (110-260)	0.87 (0.82-0.91)
1991	3	213 (198-231)	96 (82-116)	1.00 (0.87-1.17)
1992	4	278 (262-290)	192 (159-227)	0.88 (0.75-0.98)
1993	7	332 (304-375)	345 (275-508)	0.92 (0.87-0.99)
1994	76	191(125-303)	70 (28-261)	0.97 (0.56-2.20)
1995	66	245 (141-311)	141 (28-289)	0.92 (0.60-1.09)
1997	83	237 (190-392)	149 (74-678)	1.05 (0.80-1.42)
1998	95	248 (150-405)	147 (34-681)	0.90 (0.63-1.13)
1999	104	252 (175-345)	158 (46-376)	0.96 (0.80-1.11)
2000	251	225 (160-370)	129 (38-495)	1.02 (0.80-1.27)
2001	231	209 (130-390)	110 (18-630)	1.00 (0.70-1.25)
2002	167	240 (185-355)	137 (62-451)	0.95 (0.65-1.24)
2004*	18	254 (215-317)	153 (95-252)	0.95 (0.65-1.15)
2005	53	240 (141-330)	139 (31-346)	0.95 (0.56-1.25)
2006	104	261 (201-475)	180 (68-1089)	0.94 (0.62-1.13)
2007	58	268 (124-445)	251 (22-968)	1.03 (0.74-1.23)
2008	147	202 (133-365)	94 (20-486)	0.95 (0.52-1.63)
* Sample from the Sang Run Station only				

4.4 DISCUSSION

Prior to 1995, water temperature in the Youghiogheny River often exceeded 25°C in mid-summer and reached as high as 29°C in the C&R TFA, reducing available trout habitat to cool-water refugia created by tributaries, spring seeps, groundwater flow interface, and shaded areas (Pavol and Klotz 1991). Standing crops of trout, densities of adult trout, and numbers of quality-size trout in the Youghiogheny River C&R TFA have increased since 1995, when catch-and-release regulations were implemented and the operators of DCHS adopted minimum flow, dissolved oxygen augmentation, and temperature enhancement protocols. Maintaining water temperature and flow volume within the range that brown trout and rainbow trout can tolerate has increased habitat available in the Youghiogheny River C&R TFA during critical mid-summer periods, resulting in increased survival, a larger population, and a high-quality fishery. An adult trout population of 621/km (1,000/mile) throughout the Youghiogheny River C&R TFA should maintain a high-quality trout fishery. The number of quality-size trout in the Youghiogheny River C&R TFA in the post-enhancement period is comparable to the very high-quality trout population of Maryland's Savage River Trophy Trout Fishing Area (Klotz 2008).

The 2005 estimated trout population decreased significantly from previous post-temperature-enhancement years. River temperatures during the summer of 2005 reached the critical thermal maxima, or the temperature at which trout lose their ability to escape lethal conditions (Lee and Rinne 1980). The Maryland Department of the Environment issued a Notice of Violation of State Water Appropriation Permit to the operators of DCHS. The notice charged that the operators had violated Condition 16 of the permit on six dates during June-August 2005 (MDE 2005). The DCHS operators acknowledged the non-compliance occurrences and reported that they were caused by protocol software problems and operator error (Becker 2005). These problems were subsequently corrected and have not recurred.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Implementation of the temperature enhancement protocol between 1995 and 2008 was largely 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. Maintenance of water temperature and flow volume within a range that brown trout and rainbow trout can tolerate increased available habitat in the Youghiogheny River Catch and Release Trout Fishing Area during critical mid-summer periods, resulting in increased survival, a larger population, and a high-quality fishery. Minor changes to the protocol could further improve its performance, as described below.

The ability to maintain river temperature below 25°C could be increased by improving training for operators responsible for implementing the temperature-enhancement protocol. Based on the 14-year course of the protocol, the following changes in specifications of the protocol could improve the effectiveness of the temperature-enhancement plan: (1) reduce the predicted-minimum temperature threshold for triggering a release to 20°C from 23°C; (2) raise the flow threshold to 150 cfs from 100 cfs; and (3) revise the cloud-cover factor (CCF) guidelines in the protocol to include additional forecast variables. Additional costs of operation related to these small changes should be minimal. These changes were implemented for 2009 and subsequent summer seasons.

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