Temperature Enhancement

Introduction

The so-called "temperature enhancement" releases from the Deep Creek Hydroelectric Station into the Youghiogheny river are a bit contentious between the Youghiogheny fishermen and whitewater rafters and the Deep Creek Lake residents.

The name of the release is a bit of a misnomer, since the release does not enhance (aka increase) the temperature of the water of the Youghiogheny river, but rather it attempts to cool its waters down to 25C or below, here at the Sang Run bridge. Apparently the term "enhance" is to reflect the enhanced habitat conditions of brown trout.

The protocol used by Brookfield, owner of the Deep Creek Lake Hydroelectric Station, to determine when a "temperature enhancement release" (TER) is to be scheduled, is perhaps misunderstood.

This note attempts to clarify the process and suggests possible improvements.

Problem Analysis

The genesis of the TER is described in (Ref. 1) in support of the submittal of an "Application For A Permit To Appropriate and Use Waters of the State on June 3, 1992," referred to in the following as the "Permit Application Report (PAR)."

The information in this report was to satisfy COMAR 08.05.02.04A (NOTE: I can't find this section of the COMAR!). Penelec developed operating rules in consultation with the Maryland Department of Natural Resources.

This 469 page report, which will be referred to as the PAR, describes an extensive characterization of the "project", the "affected environment" and the "proposed changes to existing project," where the term "project" is referred to as the hydroelectric generating facilities.

The report appears to have been well researched and should be a 'read' for all those interested in this issue. A few of the highlights will be presented here.

The report states on page 3-57 that "Numerous studies have been conducted in Deep Creek Lake since 1954 (Davis 1975)

(NOTE: This reference is not described in the "List of References" of the report).

Appendix C of the report describes the Project Operational Model. From it's introduction:

"As part of the permitting process, the operation of the Deep Creek reservoir was mathematically modeled to simulate historical operation as well as scenarios of possible future operation to maximize reservoir and downstream recreation, fisheries and power benefits."

This appears to be one of the reasons for the emphasis on the downstream interests, rather than the upstream interests.

According to the PAR report, Penn State performed a study of the Upper Yough in 1989. In the Section of PAR entitled "Economic Impact" (p. 3-233) it is stated that:

```
"Whitewater boaters have a substantial impact on the economy of the State of Maryland and Garrett County."
```

Unfortunately, no such study was made of the development around the lake, although it was well recognized (See p 3-22 and 3-23 of PAR) This perhaps demonstrates an emphasis on the Upper Yough's interests.

The PAR contains a great deal of information of interest, such as:

1. Characterization of the Youghiogheny river cross section (pp. 3-165, 3-166, 3-167)
2. Drawings of the project (pp 2-6, 2-7, 2-8, 2-9)
3. Data on the project's structure (pp 2-2, 2-3)
4. Table with the characteristics of the generating equipment and controls (p 2-12)
5. The station's power capability vs. gross head (p 2-17)
6. The area-capacity curve (p 2-19, 3-221)
7. The Youghiogheny discharge curve at the tailrace (p 3-5)
8. Temperature and dissolved oxygen profiles at various lake transects (pp 3-65 thru 3-71)
9. List of fish species reported in Deep Creek Lake (p. 3-115)
10. Longitudinal profile of the Youghiogheny River between Friendsville, MD, and Oakland, MD (p.3-143)
11. List of Fish Species Reported from the Youghiogheny River Near Deep Creek, Maryland (p. 3-150)
12. Attendance at Deep Creek Lake State Park, 1980-1988 (p. 3-201)
13. Deep Creek Project average monthly inflow, generating hours and outflow, 1970 - 1989. (p. 3-238)
14. Deep Creek Project operation mode, by month, 1981-1990. (3-239)
15. and much more...

This is only a smidgen of the topics discussed in the PAR.

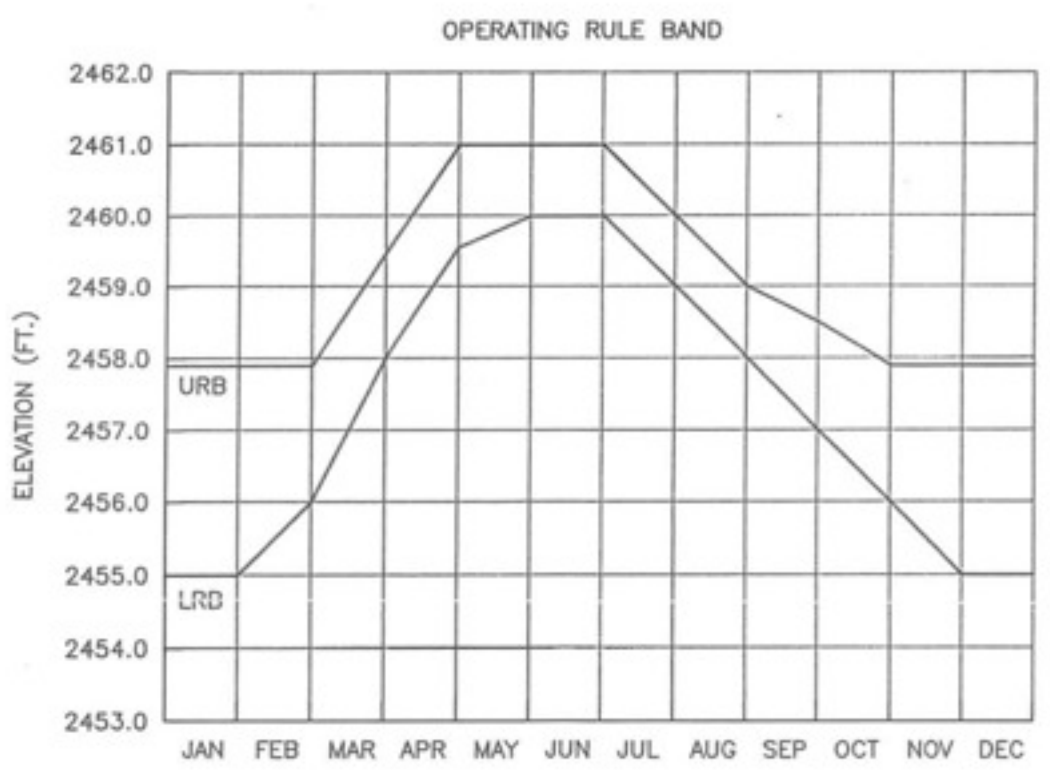
In Section 4 of the PAR, Penelec describes their proposed changes as part of the application. Their operational objectives and operating criteria were described as follows:

- (a) maintain project capacity, energy, and reliability;
- (b) support recreation on Deep Creek Lake;
- (a) enhance fish habitat in the Youghiogheny River;
- (b) enhance water temperatures in the Youghiogheny River for brown and rainbow trout;
- (c) enhance whitewater boating opportunities in the Youghiogheny River;
- (d) minimize the potential for lake shoreline erosion;
- (e) reduce the potential for entrainment of walleye and perch fry.

Their proposal for lake level was that it should be maintained above elevation 2,458 ft. from early May through mid-October. Each of these objectives were are further discussed in the report.

Penelec developed a computer model of historical lake inflow, storage, and generation to simulate historic operation and to evaluate alternative operating strategies. (water budget? Are they still using it?)

The initial rule-band was described by the following figure:



This verifies the shape of the rule band, connecting the points rather than holding a value constant for the month as implied in the current MDE permit.

Reference is also made to the procedures for temperature releases (p 4-23), referring to work done by MDNR and Versar, Inc., and white water boating opportunities (p4-24). This was from a report dating to 1992.

The history of the development of the TER protocol, as it currently stands, is not clear from the literature that I have been able to find, but it seems to start with a suggestion by Penelec and an algorithm development by Versar, Inc. for DNR.

The next chronological report is a 1995 Penelec report (Ref. 2). Quoting from the objective statement of that report:

"This plan prescribes how Pennsylvania Electric Company (Penelec) will operate Deep Creek Station to enhance water temperature in the

Youghiogheny River and to monitor river water temperature in accordance with Condition 16 of the Water Appropriation and Use Permit (Permit Number GA92S009(01}) issued by the Maryland Department of Natural Resources (MDNR) Water Resources Administration. Temperature enhancement will support MDNR's program to establish and sustain a quality brown and rainbow trout fishery in the Youghiogheny River downstream from the Deep Creek Station tailrace. MDNR is primarily concerned with the reach between the tailrace and Sang Run. To the extent possible, operation for temperature enhancement is to provide releases usable for whitewater boating."

"Prior to June 1 of each year, a water temperature monitoring instrument will be installed in the river at the Sang Run bridge and will remain in the river to record water temperatures through August 31."

"Temperatures will be recorded at intervals of not less than one half hour …"

The next report to come out is dated 1997, and is a PPRP (Power Plant Research Program) report (Ref. 3). It is the final report that describes a modeling effort with the adaptation of CE-QUAL-RIV1, a USGS first principles model for estimating river water temperatures. With a number of additions and adaptations to reflect releases from the hydroelectric facility it was designated as the YOUGH-RIV1 model. Various studies were performed with it to determine optimal release strategies. (It does not appear to have been used since)

Next in line is a 1998 report by PPRP (Ref. 4) describing the development of the regression model for TERs currently in use by Brookfield. From the report, work had been in progress since 1992 in the form of collecting data and performing simulations, presumably with the afore mentioned YOUGH-RIV1 model. The air temperature an solar radiation entering the river were identified as the most important parameters. Neither variable was measured in this section of the Youghiogheny river. Air temperature measurements were available from nearby stations and solar radiation could be approximated from cloud cover observations which were available at Elkins, WV, and Morgantown, WV.

The report describes the development of the regression model, a form of which is currently still in use. This model depends on the maximum daily air temperature predicted at Elkins, WV, and the average opaque cloud cover at the same location, in addition to the inflow water volume at Oakland and the water temperature at Sang Run.

The report has 206 data sets that are used to validate the model. This seems very small, given the period over which they were collected! (NOTE: I've extracted the data (via OCR) and are available in digital form)

Other reports in this series include Ref. 8-Ref. 11.

Ref. 11 is a survey as to how many people participate in whitewater activities. This report describes a survey performed in 1996 and 1997. When adjusted for days not surveyed it was estimated that the total number of private boaters for the entire boating season (April 15 through October 15) was 3,510 for 1996 and 4,398 for 1997.

Economic Analysis

Since the whole program of TERs is focussed on providing artificial water conditions so that brown trout can be fished it is reasonable to ask the question: "Does this make financial sense?"

To do so one would have to show that income is larger than costs, or at least equal to. No such economic analysis exists, at least not to my knowledge!

The following are some of the factors that should be evaluated in such an analysis:

Income

- Fishing license fees (exclusive for use in the Youghiogheny river)
- Area access fees (if any)
- Tax revenues from lodging, food services, equipment sales, and fishing guide services

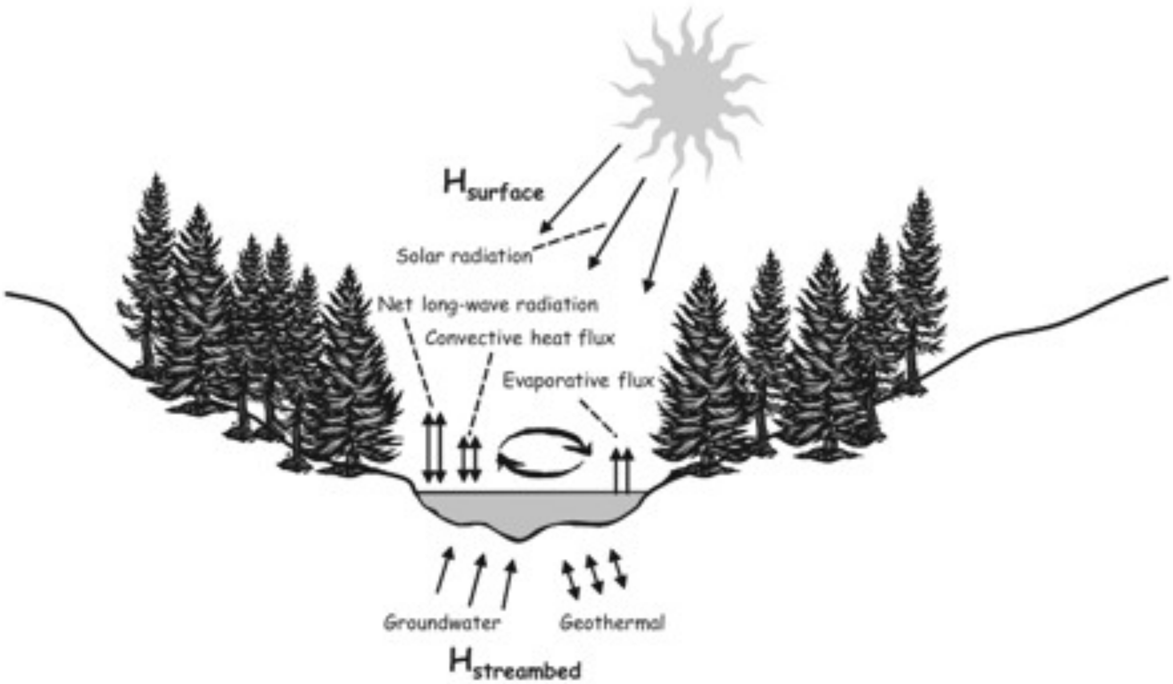
Expense

- Cost of stocking fish (hatchery costs, transportation costs, monitoring costs) (NOTE: The target is to stock annually 20,000 fingerlings, Ref. 9, p.4-7 with an annual chart on p. 4-8)
- Supervision by park rangers
- Installation and maintenance of temperature monitoring equipment
- Tracking and processing temperature measurements
- Cost of power station personnel to conduct TER conditions and make decisions.
- Cost of annual reporting and model results evaluation/improvements

Alternative Approaches

A considerable amount of work is reported in the literature on modeling river water temperature. Various approaches are available that have the potential of better predictability than the current regression model.

There are a couple of excellent articles by Caissie (Ref. 5 and 6) describing the phenomenology and the work done by others. A simple diagram, shown below, and taken from the first reference, describes the variables. (BTW, I have emailed the author for updated information)



The following are my thoughts as to how better predictions can be made. In my past, I've worked with such techniques for other types of problems.

Neural Networks

Neural Networks (NN) is a mathematical technique analogous to multiple linear and non-linear regression, except that a model does not need to be specified a priory. It can describe complex non-linear relations between input and output data. It is well suited as an interpolative or predictive scheme when there is lots of data that encompasses the operating regime of its variables. It generally does very well at recognizing patterns. This should therefore be highly applicable to the case of predicting the river water temperature since plenty of data should exist since 1995, and even prior to that.

NN techniques have been applied to predicting river temperatures (Ref. 6). The Youghiogheny situation is ideal for developing a NN model. Once developed it's calculations should be as easy to use as the current protocol.

The process envisioned is to try several models, each with a different input data stream. The output is always the same, the temperature at the Sang Run bridge.

Genetic Programming

Evolutionary computing using genetic algorithms, is widely used in hydraulics and hydrology. An important characteristic of GP is that both the model structure and coefficients are simultaneously optimized; as with NN, the specific model formulation is not needed and the algorithm can be trained with lots data.

Physical Modeling

Physical modeling involves the the use of the fundamental laws of conservation of mass, momentum and energy. One of the initial modeling efforts of the Youghiogheny river was done with a modified version of QUAL-RIV1 as described in (Ref. 3). There are other such modeling tools available, such as PHIM (Penn State Integrated Hydrologic Modeling System) (Ref. 7)

With the capabilities of today's computers doing a full-fledged simulation should be easily done, and should present an alternative to the regression model. The protocol could be simplified significantly, since the simulation needs to be run only once a day, since it can be setup to run for many hours of real river flow time. The simulation could be run even at night time, automatically, and provide the necessary decision data by early morning.

Additional Considerations

Because of the importance of this issue, getting real data at the appropriate location and use that data in simulations should be high on the list of priorities

Since solar radiation is an important factor in making forecasts installing a solar radiation gage somewhere along the river stretch of interest should enhance the reliability of the protocol. There is no need to separate diffuse from direct radiation, and hence a simple, inexpensive, photovoltaic panel should be sufficient to measure the incident energy on the water. All we're interested in is 'relative' contributions.

It's not clear to me why there should be "operator error." The equations are simple, the data inputs are simple; all could easily be implemented for automatic, operator-free, processing.

NOTE: In Ref.8, Table 2-2, the regression coefficient for the cloud cover factor in the 7:00 am equation is -0.019 while in Ref. 9, Table 2-2 this coefficient is listed as -0.019, while, strangely, the Partial R-square and Model R-square values are the same. Note that Table 2-4 in the same document list the number as -0.019! Which one should it be? In prior documents, the number was always -0.019, which is probably the right one.

I found many other articles with relevant titles and abstracts, but to get a copy of the whole article would require payment. I did not consider them.

Conclusions

Given all the years of data, experience and improvements to equipment and sensors, it is somewhat surprising that no more precise and reliable methodology has evolved.

Statements such as: `"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."` (Ref 8, p.2-4) are no longer valid. Our forecasts, especially in the summertime when high river temperatures are expected, are quite accurate.

High river water temperatures are most likely to occur when there is little cloud cover (maximize solar radiation) which tends to coincide in the summertime with higher air temperatures.

It's strongly suggested that a fresh approach be taken of predicting the river water temperature. My personal opinion is that the procedure should be based on:

- Use a first principles river water temperature predictor (no regression) such as PIHM
- Assemble all of the measurements from past years for model verification purposes
- Add sensor(s) as required
- Do a single prediction nightly, that does not require operator intervention
- NN based predictions could be used as a check on the model prediction (simple to implement)

PLV: 11/1/2014 (First Version)

Updated: 11/2/2014

List of References

1. Pennsylvania Electric Company, SUPPORT DOCUMENT FOR PERMIT APPLICATION TO APPROPRIATE AND USE WATERS OF THE STATE DEEP CREEK STATION, PENNSYLVANIA ELECTRIC COMPANY, Revised Section 4.0, April 1994. {DeepCrSupportDocument-Rev1994Apr.pdf}
2. "Youghiogheny River Water Temperature Enhancement Plan," Deep Creek Station, Youghiogheny River, May 1995 {2995-0002A.pdf}
3. Stephen P. Schreiner and Geoffrey D. Birky, (Versar Inc.) "A TEMPERATURE SIMULATION MODEL OF THE YOUGHIOGHENY RIVER FROM DEEP CREEK STATION TO SANG RUN", PPRP-DC-1, June 1997 {pprp-dc-1.pdf}
4. Stephen P. Schreiner Versar, Inc., "YOUGHIOGHENY RIVER TEMPERATURE ENHANCEMENT PROTOCOL: MODEL DEVELOPMENT AND RESULTS FOR 1995 AND 1996 , PPRP-DC-2 , 1998 {pprp-dc-2.pdf}
5. D. CAISSIE, "The thermal regime of rivers: a review,"Freshwater Biology (2006) 51, 1389–1406, The thermal regime of rivers: a review - CAISSIE - 2006 - Freshwater Biology - Wiley Online Library {j.1365-2427.2006.01597.x.pdf}
6. Loubna Benyahya, Daniel Caissie, André St-Hilaire, Taha B.M.J. Ouarda and Bernard Bobée, "A Review of Statistical Water Temperature Models ," Canadian Water Resources Journal, Vol. 32(3): 179-192 (2007)www.bio.ulaval.ca/cirsa/Publications/Benyahyaetal07_review_CWRJ.pdf {Benyahyaetal07_review_CWRJ.pdf}
7. Penn State Integrated Hydrologic Modeling System (PIHM) Penn State Integrated Hydrologic Modeling System
8. Stephen P. Schreiner Jodi R. Dew and Craig M. Bruce, Versar, Inc., "YOUGHIOGHENY RIVER TEMPERATURE ENHANCEMENT PROTOCOL FOR OPERATING DEEP CREEK HYDROELECTRIC STATION: MODEL DEVELOPMENT AND RESULTS FOR 1995-2005, PPRP-DC-5, August 2006. {pprp-dc-5.pdf}
9. Stephen P. Schreiner, Jodi Dew-Baxter, Versar Inc, and Alan W. Klotz, DNR, "TEMPERATURE AND TROUT HABITAT ENHANCEMENT FOR OPERATING DEEP CREEK HYDROELECTRIC STATION: OPERATING PROTOCOL DEVELOPMENT AND RESULTS FOR 1995-2008", PPRP-DC-6, March 2011. {pprp-dc-6.pdf}
10. Stephen P. Schreiner, Versar, Inc., "YOUGHIOGHENY RIVER TEMPERATURE ENHANCEMENT PROTOCOL FOR OPERATING DEEP CREEK HYDROELECTRIC STATION: MODEL DEVELOPMENT AND RESULTS FOR 1995-2000," PPRP-DC-4, February 2001.{pprp-dc-4.pdf}
11. Stephen P. Schreiner, Versar, Inc., "SURVEY OF NONCOMMERCIAL RECREATIONAL USE OF WHITEWATER IN THE UPPER YOUGHIOGHENY RIVER, 1996-1997," PPRP-DC-3, June 1998. {pprp-dc-3.pdf}

1. Cindie Hébert, "MODELING OF HOURLY STREAM TEMPERATURES WITHIN TWO FORESTED CATCHMENTS," PhD Thesis, DALHOUSIE UNIVERSITY DEPARTMENT OF CIVIL AND RESOURCE ENGINEERING, 2013. {Hebert-Cindie-PhD-March-CIVL-2013.pdf}
2. M. Arganis, R. Val, J. Prats, K. Rodríguez, R. Domínguez and J. Dolz, "WATER TEMPERATURE MODELING BY MEANS OF GENETIC PROGRAMMING," 11th International Conference of Urban Drainage, Edinburgh, Scotland, UK., 2008 {114.pdf}
3. CE-QUAL-RIVI: A Dynamic, One-Dimensional (Longitudinal) Water Quality Model for Streams,User's Manual, US Army Corps of Engineers, 1990 {a230794.pdf}
4. W. Czernuszenko, "THERMODYNAMICS OF RIVERS," RESH SURFACE WATER – Vol. II {E2-07-03-02.pdf}
5. W.A. Perkins, M. C. Richmond, "Long-term, One-dimensional Simulation of Lower Snake River Temperatures for Current and Unimpounded Conditions," PNNL-13443, February 2001 {PNNL-13443.pdf}
6. Michael L. Deas, Cindy L. Lowney, "Water Temperature Modeling Review", California Water Modelling Forum, September 2000. {BDMFTempReview.pdf}
7. Ruochuan Gu, "A simplified river temperature model and its application to streamflow management," Journal of Hydrology (NZ) 37(1):35-54, 1998 {JoHNZ_1998_v37_1_Gu.pdf}
8. V. Kothandaraman and R.L. Evans, "Use of Air-Water Relationships for Predicting Water Temperature," Report of Investigation 69, State of Illinois, 1972 {ISWSRI-69.pdf}
9. Corbitt Kerr, Joe Kasprzyk, David Vargas, and Keith Sawicz, "Integrated Modeling Using PIHM GIS for the Shavers Creek Watershed," CE 555- Final Report, Penn State University, 12/19/07 {CE555_Shavers_Creek_Final_Report.pdf}