Mathematical Modeling of Temperature Dynamics in Small New England Impoundments

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Abstract

Impoundments change temperature dynamics in rivers. This has been well documented, and mathematical models exist to describe these dynamics for big rivers. However, models designed for larger reservoirs may not be appropriate for the small sediment-filled impoundments with riverine characteristics common to New England. Previous work has shown that run of the river impoundments as small as 1.5 km cause statistically significantly greater heating and cooling compared to free flowing river sections.

In this research we studied two impoundments on the Westfield River in Western Massachusetts. Temperature loggers were deployed upstream and downstream of the two impoundments for a period of approximately one year.

Using regression analysis, a multivariate model was built to predict downstream river temperatures as a function of upstream river temperature, flow, and air temperature. The data used to create the model came from the upstream impoundment. The model was verified using the downstream impoundment. The model explained over 95 percent of the temperature variation of the upstream impoundment. On average it under-calculated the temperature of the lower reservoir by 1.4 degrees Celsius. This under-calculation is likely the result of increased heating in the lower reservoir due to sedimentation.

Introduction

The impacts of large dams on aquatic ecosystems are well documented and have been studied extensively. However, the impacts of these small, seemingly benign dams are less well known. At the 2004 UMass Water Resources Research Conference, David Hart, one the plenary speakers, encouraged research on the impacts of small dams on aquatic ecosystems. In this research project we create a multivariate model of small impoundments. The data used for our model come from previous student research including Allen & Perron, 2004; Palpini, 2004; Smith, 2006; and Shaw, 2006.

Figure 1: Deploying a temperature logger at Strathmore Dam (Station 26.5).

Materials and methods

There were two major steps in conducting this experiment. The first step was to collect temperature measurements. The second step was the data analysis and modeling.

Temperature Data Collection

Hobo® Instrument Temperature loggers were deployed in the Westfield River, Russell, MA (Figures 1 & 2). Loggers were deployed upstream and downstream of two small reservoirs on the river (Figure 3). The loggers were set to record data every hour or two hours depending on the season. A longer sample interval was necessary to ensure the logger memory lasted throughout the winter. Loggers were housed in waterproof cases, cabled to shore, and submerged using concrete anchors (Figure 1). These loggers were later retrieved, and the data were transferred to a computer. The data that are used in this research have been compiled from studies students carried out here at Westfield State College.

Data Manipulation

Using Microsoft Excel, the data were imported from the logger data files. Any erroneous data from the beginning and end of the data files (before or after the logger was deployed in the field) were deleted. The data files were then combined and transposed using SPSS into a form that could be used.

Model Building

The goal of this research was to build a mathematical model using multivariate regression that predicts downstream temperatures in small impoundments. The independent variables we included are incoming river temperature, air temperature, flow (CFS), and time of day (hour). The result section details the model and its fit to the data.

To verify the model, we tried it on data from a comparable reservoir (Strathmore) a short distance downstream (Figures 1 & 3). The results section also details the goodness of fit of the model to this reservoir.

Figure 2: The dam forming Russell Reservoir (Station 30).

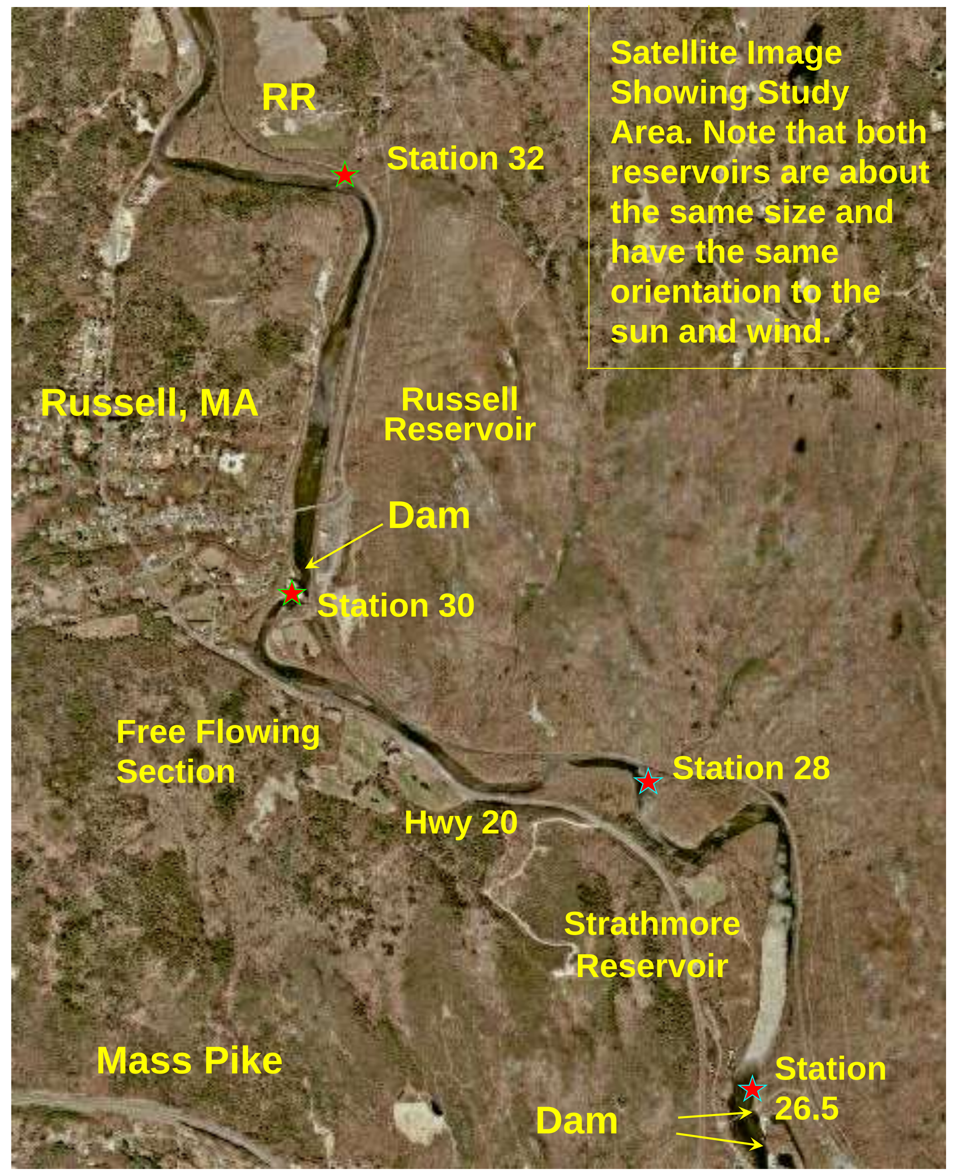


Figure 3: Aerial photo of study area (Google Earth)

Results and Discussion

The multivariate model we created estimates downstream temperature in a reservoir as a function of incoming river temperature, air temperature, flow (CFS), and time of day (hour). The model is:

$$T_{DS} = 1.107732T_{US} + 0.000261Q + 0.013777t - 2.41644,$$

Where :

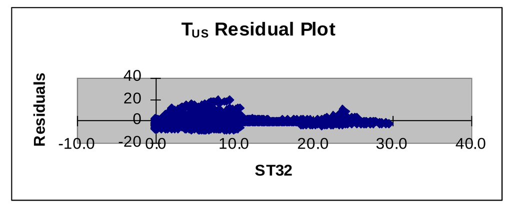
T_{DS} = Temp. Downstream (Outgoing, °C)

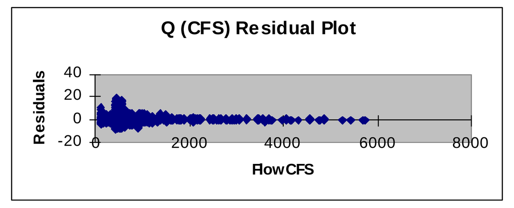
T_{US} = Temp. Upstream (Incoming, °C)

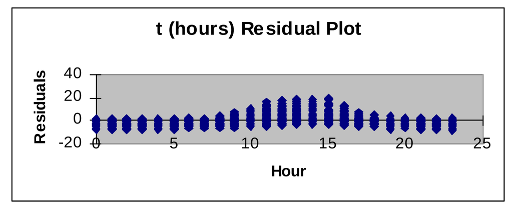
Q = Flow (cfs)

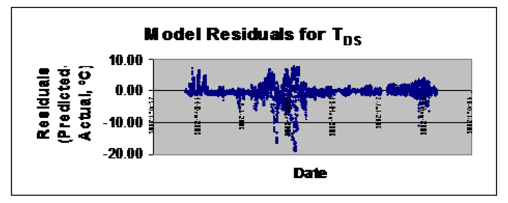
t = Time (hours)

The R^2 for the model is 0.95, meaning that 95 percent of the variation in the dependent variable was explained by the independent variables. Each of the independent variables contributed a statistically significant amount of information to the model. The residual plots do not show any perceptible trends (Figures below).



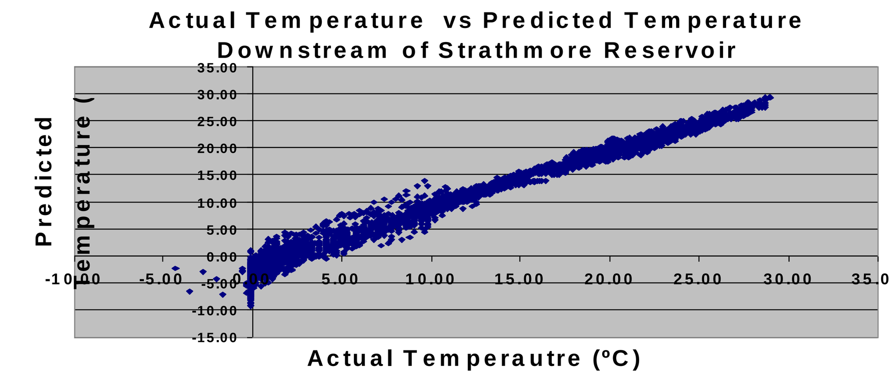




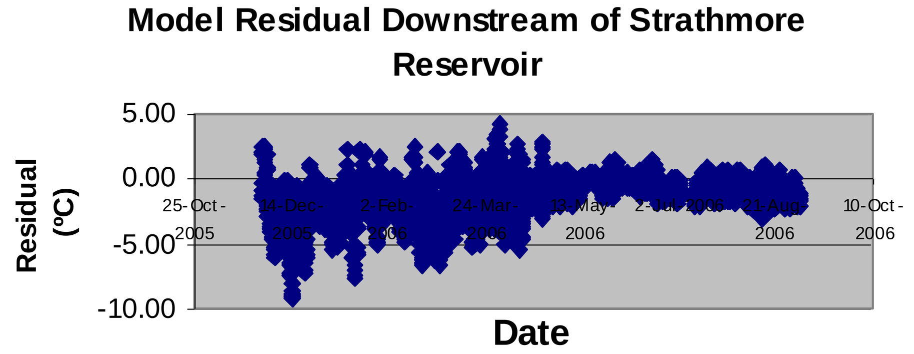


Model Validation

Using data from a comparable reservoir downstream (Strathmore Reservoir, Russell MA), we validated the model. The graph below shows the predicted values versus observed values for this reservoir.



As expected, the data illustrate a linear relationship close to a one to one ratio. The graph below shows the residuals from the predicted temperature and the actual temperature of the downstream station near Strathmore Dam.



The results of the residual graph show no trend, however the temperature in Strathmore Reservoir was consistently higher than predicted values. The average difference between the predicted temperature and the actual temperature was approximately -1.445 °C. That is, the model under predicts the temperature at the downstream station (26.5) by 1.445 °C.

One possible reason for this under calculation is direct solar heating. The Strathmore Reservoir is generally somewhat wider, and the average depth is shallower than the Russell Reservoir. [These measurements have not been accurately determined yet] It's likely that direct heating from the sun warms the river bottom more at Strathmore than at Russell. This effect could be a major influence in the under calculation of the model.

Conclusion

The model did an excellent job of predicting downstream temperature in the modeled impoundment. However, the model may not be robust enough to used for other small impoundments. In order to develop a better model, data from more small impoundments should be included in the study. By including more impoundments, a wider range of bathymetric data could be introduced which would hopefully reduce the margin of error.

Some variables that should aid the model include retention time, depth, and width of the impoundments. It is highly unlikely that any impoundments are the same depth and width, both of which can have a huge influence on water temperature. We feel that further research in small impoundment temperature dynamics is necessary to help manage these valuable aquatic ecosystems.

Acknowledgments

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