Report for 2002OR2B: Temperature Effects of Streambed Heating

There are no reported publications resulting from this project.

Report Follows:

Title: Modeling Streambed Heating in Shallow Streams

Problem and Research Objectives:

The goal of this research is to examine the influence of streambed heating on stream water temperatures and incorporate a dynamic streambed heating algorithm in the CE-QUAL-W2 water quality model.

The objectives of this research are:

- Monitor streambed temperatures in the Lower Bull Run River to characterize vertical, longitudinal and lateral temperature gradients in different substrates.
- Monitor environmental factors influencing the river heat budget such as meteorological conditions, vegetation characteristics, light attenuation, and substrate geologic characteristics.
- Collect bathymetric cross section data to support model development.
- Conduct experimental work in a controlled environment to reduce the influence of wind, variable flow, and uncertainties with the substrate material.
- Develop a three-dimensional streambed heating algorithm for incorporation in the water quality model, CE-QUAL-W2 model.
- Implement the modified W2 model and calibrate it for the time period when field data were collected.

Methods, Procedures, and Facilities:

There research work involved two components: A field component which was conducted during the summer of 2002 and an experimental lab component conducted during the fall of 2002.

Field Work

Bathymetric Data

Bathymetric cross-sections were collected at nine locations in the field study reach on July 25th and July 26th 2002. Cross-section elevations were tied to a benchmark located on the Rt. 14 Bridge in the middle of the field study reach. The river channel cross-sections were combined with the stream bank topography from a U.S. Geological Survey (U.S.G.S.) Digital Elevation Model (DEM) to generate a contour plot of the river bathymetry. The contour plot was then sliced into 10 pieces to develop the CE-QUAL-W2 model segments.

Stream Temperature Data

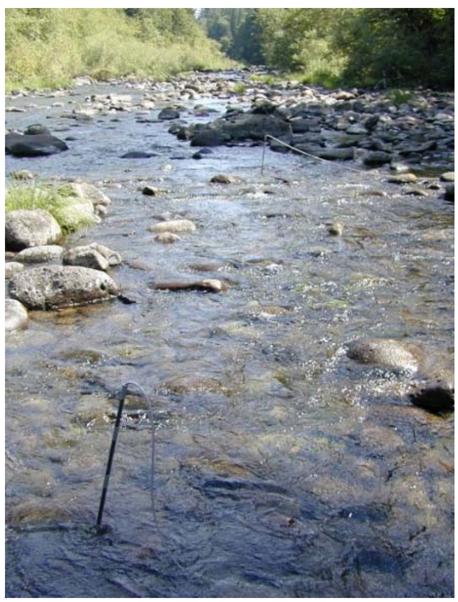
Stream temperature data were collected at two locations upstream of the Rt.14 Bridge using OnSite StowAway temperature logger, recording at 10-minute intervals. The U.S.G.S. monitored one location downstream of the bridge at 15-minute intervals using a thermocouple. The two upstream monitoring sites upstream included replicate thermistors. The data collected at the sites were used for the model upstream boundary condition and for calibrating the model.

Streambed Temperature Data

Streambed temperatures were monitored at five locations in the study reach. Three locations were monitored above the Rt. 14 Bridge in cobble substrate (Probes 1 to 3) and two locations were monitored below the bridge were in bedrock substrate (Probes 4 and 5). The temperature probes were constructed using 6.35 mm diameter PVC pipe with a length of 1.25 m with 6 glass bead thermistors, spaced 20 cm a part. The probe was filled with silicone for waterproofing. Figure 1 shows one of the completed probes. Two probes were placed in the field and after a week or more they were moved to a new location.

The probes placed in the cobble reach were placed at a maximum depth of 0.50 m due to the compact nature of the substrate and the inability of equipment to effectively penetrate deeper. The probe was placed in the hole, and the substrate replaced in the reverse order that it was removed. Figure 1 shows two probes placed in the streambed after the holes were filled. The substrate then settled around the probes, which was confirmed when the probes were removed a few weeks later. Only the bottom three thermistors were buried in the substrate.

Two probes, Probes 4 and 5, were placed in bedrock using holes drilled by the City of Portland, Water Bureau. The holes were drilled to depths of 1.05 and 1.0 m with diameters between 25 and 32 mm (1.0 to 1.25 in). The probes were placed in the holes so the top thermistor was just below the substrate – water interface as shown in Figure 1. The probe was pressed against the side of the drilled hole with a long narrow piece of wood, and then sand was used to fill in the backside of the hole.



Probe 3 and 1, looking upstream

Hole for Probe 3

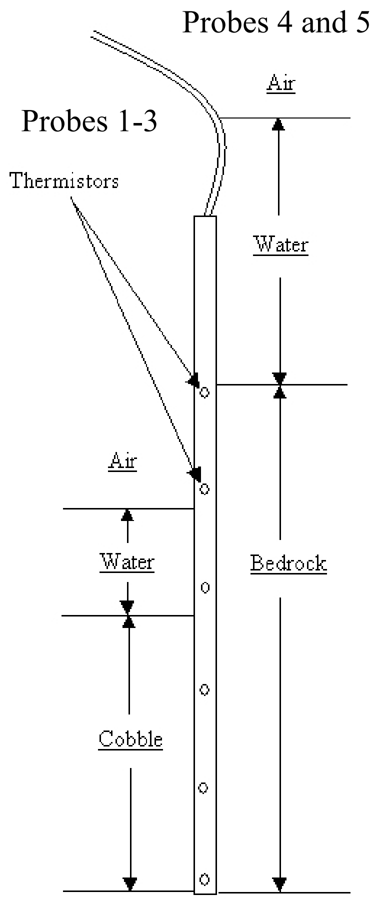


Figure 1. Streambed temperature probes, probes in the cobble went to a depth of 0.5 m below the sediment-water interface, probes in the bedrock were placed to a depth of 1 m.

Probes 1 and 2 were placed for two weeks to examine lateral variability on streambed temperatures. Probe 2 was then removed from the substrate and was placed downstream of Probe 1 to investigate longitudinal variability in streambed temperature (re-designated as Probe 3). After 2 weeks the two probes were removed and placed at the two bedrock sites Probes 4 and 5.

Streambed Substrate and Geology

The streambed in the reach transitioned from cobble and boulder at the upstream end to primarily bedrock at the downstream end. The streambed substrate in the study area can be characterized by three reaches. Reach 1 is characterized primarily by boulders and large cobble and represents the toe end of a plane-bed reach with riffle to run unit characteristics in low flow. Reach 2 substrate is characterized primarily by boulders and bedrock with a very uneven bottom surface capturing some cobble. The reach is a turbulent cascade with a slope of 2.4%. Reach 3 is characterized as a mid-channel pool reach with the deepest parts of the pool closer to head of the reach. The substrate is primarily bedrock with boulders and large cobbles predominately on the sides and banks. The toe of the reach slopes upward and is dominated by large cobble and boulders overlying the bedrock.

- Bedrock substrate

The underlying river channel geology has been discussed by the U.S.G.S. (1996), Baldwin (1981) and Beeson and Moran (1979). The U.S. Forest Service mapped the river channel geology in 1997 as Columbia River Basalts. The bedrock substrate in the Reaches 1 and 2 (and elsewhere in the basin) are where the Columbia River Basalts have been exposed and remain resistant to fluvial erosion (U.S.F.S., 1997). In Reach 3 the holes were drilled in the bedrock to place two temperature probes. Samples of the bedrock substrate were collected during drilling. The bedrock particles are dark gray and appear to be fine grained indicating the substrate is likely part of the Columbia River Basalt Formation.

- Boulder/Cobble substrate

Three temperature probes were placed in Reach 1 for the first few weeks of the field study. Boulders and large cobble substrate dominated this reach and are believed to by lying over the Columbia River Basalt seen in Reaches 2 and 3. On August 18, 2002 Ground Penetrating Radar was used on two cobble substrate sites to determine the depth of the cobble overlying the bedrock. When digging the holes to place the temperature probes the particle size was observed to decrease with depth.

Meteorological Data

Meteorological data were collected at two locations in the lower river: the U.S.G.S. gage station (14140000) and on the Rt. 14 Bridge. The monitoring site on the bridge measured solar radiation at 10-minute intervals. The monitoring site at the U.S.G.S. gage station was maintained by the City of Portland, Water Bureau and measured air temperature, relative humidity, wind speed and wind direction at 15-minute intervals.

Light Attenuation Data

Light attenuation data was collected on July 25th and September 20th, 2002 at 21 monitoring sites. Data collected on July 25th used a spherical photosynthetic active radiation (PAR) sensor and measurements were taken above the water surface and at the bottom of the water column. Data collected on September 20th used an incident PAR sensor and measurements were taken just below the water surface and at several depths below the surface. The incident sensor was also inverted to measure radiation reflecting off the substrate.

Flow and Dye Study Data

The large cobbles and boulders characterizing Reach 1 indicate there is the possibility of hyporheic flow. If hyporheic flow exists then the water would emerge at the end of Reach1 where the cobble and boulder layer overlying the bedrock ends in Reach 2. A dye study was conducted on September 5th and surface water and groundwater levels were measured to investigate this issue.

- Dye study

A dye injection probe was placed in the streambed by digging a hole similar to the holes used for the streambed temperature probes. The probe consisted of a 1.27 cm diameter PVC with a hole drilled one cm from the bottom where a small tube with inner diameter of 3 mm was inserted and run on the inside of the PVC pipe to the top. The probe was placed in the streambed on August 30th and air was injected to ensure the tube was not blocked at the buried end. The dye study was conducted on September 5th to allow the substrate surrounding the probe to settle. The injection tube was a depth of 0.47 m below the surface of the substrate, similar to the deepest thermistors buried in the streambed. 48 ml of Rhodamine WT dye was injected in the tube at 8:15 am and then flushed with 20 ml of water. Based on visual observations in the tube there was no red dye present after flushing. Water samples were then taken downstream of the injection point at the three locations. Site “A” was located 7.6 meters downstream of the injection point. Site “B” was located 33 m downstream of the injection point, where the cobbles overlying the bedrock end. If the dye was to be transported downstream in the substrate then it would emerge near this monitoring site. Site “C” was located 0.3 m downstream of the injection point to monitor if the dye immediately surfaced.

- Water Level Measurements

The dye injection probe was also used to measure the water levels in the substrate and the river water level to determine if there was a gradient. The dye injection PVC pipe had a large enough diameter to place a rod in the pipe and measure the water level relative the top of the pipe. The river water level on the outside of the pipe was also measured relative to the top of the pipe.

Vegetative and Topographic Shade Data

- Vegetation data

The vegetation data collected consisted of vegetation (tree) heights and the distance from the river centerline to the vegetation. A field person walked along the middle of the stream channel and used a laser range finder to measure both tree heights and the vegetation offset distances. The vegetation heights were converted to vegetation top elevations by adding the bank elevation to the tree height. The distance from the river centerline to the vegetation for each bank was used directly in developing the model file.

Lab work

Several lab experiments were conducted to demonstrate streambed heating processes in a more controlled environment to reduce the influence of topographic and vegetative stream shading, cloud cover, atmospheric dust and moisture attenuation, wind, and variable flow. The results of the experiments will be used with the streambed heating algorithm to test the algorithm's ability to handle a more simplified streambed heating case and to demonstrate the basic streambed heating processes.

Experimental Design

The experiment was designed to monitor the temperature of substrate material in 2 buckets (5 gallons each) with overlying water exposed to constant radiation during the day and none at night. Each bucket had 4 temperature probes embedded in the substrate and 1 in the water above the substrate. The buckets were placed in a larger tub, which was filled with sand to provide a heat sink. The outside of the buckets and the air were also monitored with thermistors to better understand the buckets' boundary conditions. All thermistors recorded temperature at 5-minute intervals. The radiation was supplied by a narrow spot beam stage light, which produced approximately 1010 W/m^2 at 2.3 m above the experiment. Radiation was measured at 10-minute intervals with a pyranometer placed between the two buckets. The lamp was turned on for 8.5 hours a day using a timer. Figure 2 shows a drawing of the experimental design with thermistor locations identified by numbers and letters.

Each bucket was filled with substrate material to a depth of 20 cm and then filled with water to a depth of 6 cm. Evaporated water from the buckets was replaced with water at room temperature. The first experiment used one bucket filled with sand and the other with gravel. The second experiment used one bucket with sand and gravel and the other with sand. The third experiment had both buckets filled with concrete, one painted white and the other painted black.

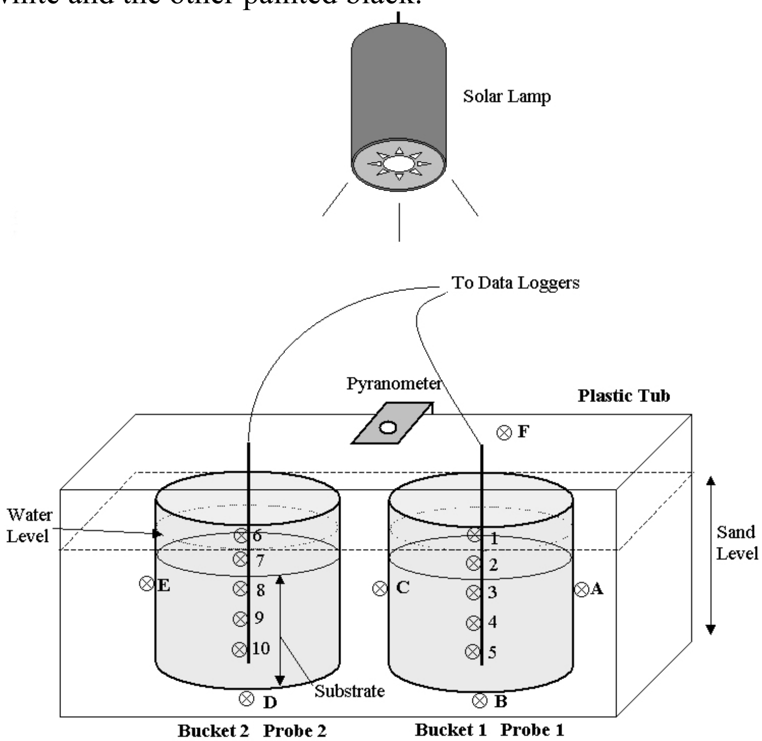


Figure 2. Experimental lab design

Principal Findings and Significance:

The research work is currently still in progress with completion anticipated by the end of 2003. The field and lab work have been completed but the modeling work is still in progress. The fieldwork results show there is a vertical temperature gradient in both the cobble and boulder streambed and the bedrock streambed. Figure 3 shows an 8-day period for one of the probes placed in the cobble and boulder streambed. The figure shows cooler temperature further down in the streambed material. Figure 4 shows a similar plot for the bedrock material. Temperature measurements near the sediment-water interface are similar to the water temperature measurements but deeper in the streambed the diurnal fluctuations are minimized and several degrees cooler. The lab experiments conducted also showed decreasing temperatures with depth. Figure 5 shows temperature measurements recorded in the sand and gravel media experiment conducted in the lab. The plot shows diurnal fluctuations in temperatures but the results indicate there are slightly different processes influencing the temperature measurements at larger depths. Because the lab experiment is based on a small amount of "substrate" material the sand surround the bucket may be influencing the temperatures recorded in the bucket. The data collected in the field and in the lab will be used to test the streambed heating algorithm.

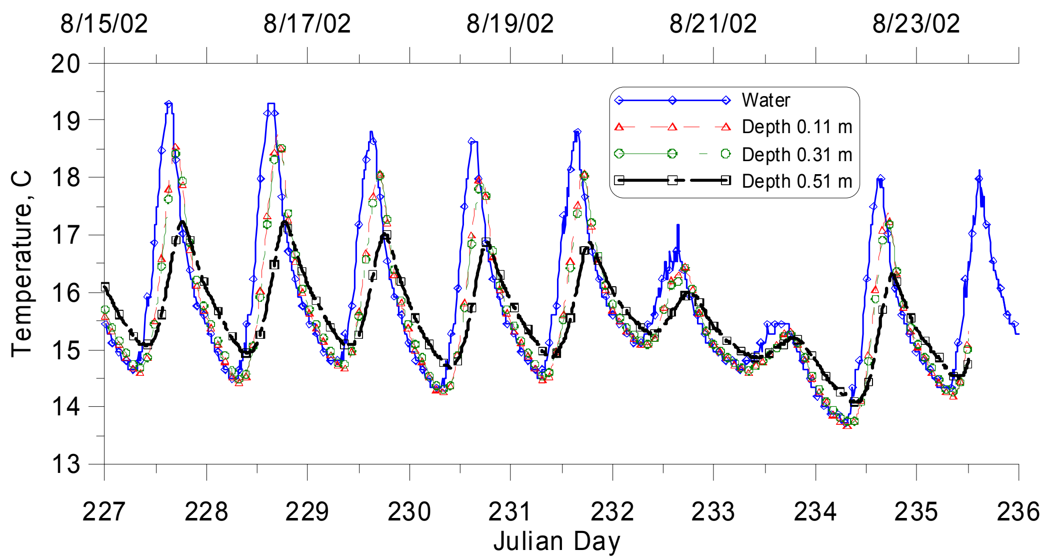


Figure 3. Streambed temperature Probe 1, cobble substrate

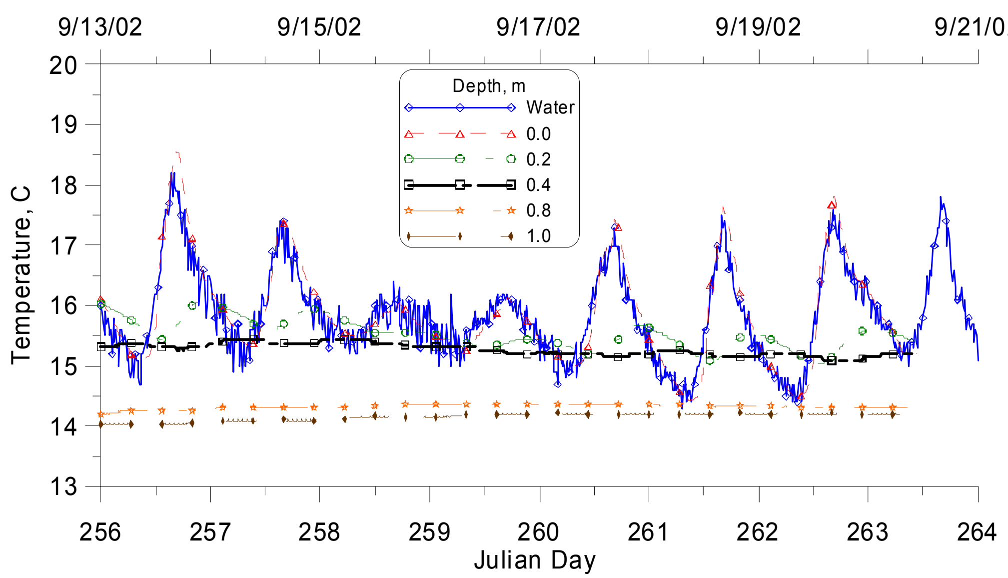


Figure 4. Streambed temperature Probe 5, bedrock substrate

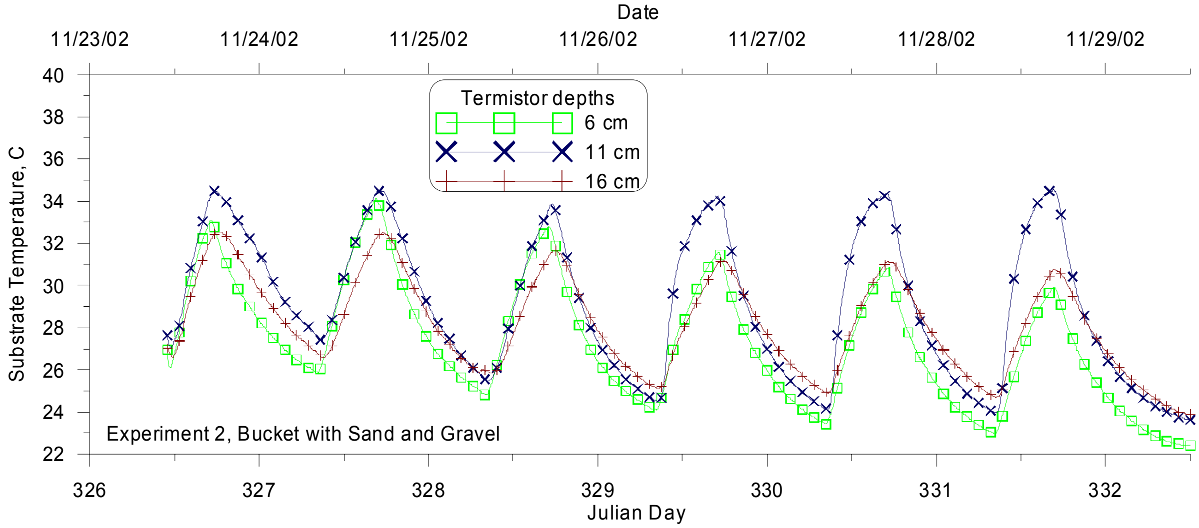


Figure 5. Experiment 2, measured temperatures in Sand and Gravel media bucket.

Training and publications:

Two abstracts for the research work have been submitted to conferences in the fall of 2003. The first abstract was submitted to the Pacific Northwest Clean Water Association Annual Conference in September and was recently accepted. The second abstract was submitted to the American Institute of Hydrology Conference in October.

When the work is completed papers will be submitted to various journals such as *Environmental Modeling and Software* and the *International Journal of River Basin Management*. In addition, a longer report will be submitted to the Center for Water and Environmental Sustainability.

References

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