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Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin

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Keck Geology Consortium: Projects 2009-2010
Short Contributions – WISCONSIN

THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN

Project Faculty: ***SUSAN K. SWANSON***: Beloit College
MAUREEN A. MULDOON: University of Wisconsin – Oshkosh

LITHOSTRATIGRAPHIC CONTROLS ON GROUNDWATER FLOW AND SPRING LOCATION IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN

HANNAH DOHERTY: Mount Holyoke College
Research Advisor: Al Werner

ESTABLISHING PALEOCLIMATE VARIATION FROM MAJOR AND TRACE ELEMENTS AND STABLE ISOTOPES IN A TUFA DEPOSIT, WISCONSIN

ELIZABETH FORBES: Whitman College
Research Advisor: Kirsten Nicolaysen

A COMPARISON OF TECHNIQUES FOR DETERMINING SPRING SOURCE AREAS: CRAWFORD COUNTY, WISCONSIN

ASHLEY KRUTKO: Capital University
Research Advisor: Terry Lahm

WATER GEOCHEMISTRY OF TUFA-DEPOSITING SPRINGS IN THE DRIFTLESS AREA, WISCONSIN

MARY LIANG: Franklin and Marshall College
Research Advisor: Dorothy Merritts

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ETHAN MAMER: Beloit College
Research Advisor: Susan Swanson

TEMPERATURE PROFILE MODELING OF A SMALL SPRING-FED STREAM

MILES REED: DePauw University
Research Advisor: Tim Cope

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

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TEMPERATURE PROFILE MODELING OF A SMALL SPRING-FED STREAM

MILES REED
DePauw University
Research Advisor: Tim Cope

BACKGROUND & INTRODUCTION

The unglaciated region of southwest Wisconsin hosts Paleozoic limestone and dolostone that support a widely distributed network of spring systems. In addition to aiding in the understanding of the region's hydrogeology, these springs provide important habitat to a variety of stream-dwelling organisms, many of which rely on the specific associated temperature regimes to maintain homeostasis, such as the brook trout (*Salvelinus fontinalis*). Wisconsin's 2003 Act 310 legislates the prevention of environmental degradation to springs that discharge one or more cubic feet per second at least 80% of the time. As many of the springs in the region discharge significantly less than this, it is important to consider whether or not the current laws are sufficient in protecting the unique and sensitive species native to the region.

Studies have called for investigation into the physical characteristics of these springs, and their associated streams (Swanson et al., 2009), in order to better assess the conditions and the potentials for harm to small spring-fed streams. Temperature profiles are especially complex and dynamic in small streams where slight changes in a number of parameters can have effects on temperature that are difficult to predict. This study sought to gain a better understanding of a temperature profile and its associated variables by using a computer simulator (SSTEMP) to model the mean daily temperature of a small spring-fed stream network in Crawford County, WI. The findings give insight into the reliability/practicality of using SSTEMP to model small spring-fed streams; and also contribute to the ongoing debate concerning what environmental parameters play the greatest role in determining mean daily stream temperature.

Figure 1. This map of the study site in eastern Crawford County, WI shows the stream and the two springs along with the designated reaches.

The study site (Fig. 1), located on a small privately owned farm, was comprised of two small but consistently active springs which are located a little over 300 meters apart. The associated streams converge and flow into more runoff-dominated stream networks. Only about 700 meters of total stream was investigated (including both branches), over a length of about 400 meters of land. The property over which the stream flows includes both disturbed and undisturbed land and thus provided an ideal scenario for assessing the impacts of human-caused change on temperature. Disturbance is primarily due to deforestation for agricultural fields (both crops and livestock have played roles in the land's history for over 100 years). In order to consider the effects of both anthropogenic and natural variables, the stream was divided into sixteen different reaches, each with roughly homogenous characteristics – mainly streamside vegetation and stream geometry.

TEMPERATURE MODELING

SSTEMP (Stream Segment Temperature Model) was developed in 2002 by John Bartholow of the USGS, and is essentially a downscaled version of SNTEMP (Stream Network Temperature Model) which had been created by Theurer et al. (1984). It is designed to take input parameters and model a single "run" or reach of stream, outputting daily mean, maximum, and minimum temperature values. SSTEMP is really only accurate at predicting mean temperatures, as the maximum is just an estimate dependent mostly on air temperature, and the minimum is simply the difference between the mean and maximum subtracted from the mean. SSTEMP and SNTEMP have been utilized by many researchers, both for academic and management purposes (Bartholow, 2000; Blann et al., 2001; Gaffield et al., 2003; HDR Engineering Inc, 2002; Whiteledge et al., 2006).

Essentially the program performs calculations for eight individual heat fluxes involved in stream temperature modulation: 1) convective processes within the water, 2) conduction of heat along the streambed, 3) evaporation, 4) radiation reflected off the water's surface, 5) radiation reflected from the atmosphere, 6) frictional processes within the stream channel, 7) incoming solar radiation, and 8) radiation from proximal riparian vegetation. All of SSTEMP's inputs end up affecting at least one of these processes, and often more than one. Once the net energy is determined, the program applies this heat gain/loss to a theoretical unit of water that has passed (unidirectionally – an important, perhaps limiting, assumption) through the stream segment (Bartholow, 2002).

A review of the literature on stream temperature modeling demonstrates a solid, and even growing, camp of researchers who claim that shading is the dominant factor in controlling temperature (Beschta, 1997; Gaffield et al., 2005; Johnson, 2004; Whiteledge et al., 2006). Dissent does exist however - Larson and Larson (1996) argue that this is a simplistic view of a complicated system, and suggest that air temperature is a more important factor. Still others, (e.g., Johnson, 2004 and Poole et al., 2001), posit that channel substrate and morphology may play a larger role than is typically realized.

DATA COLLECTION

The measurements and descriptions taken for each stream reach were strictly dictated by the input parameters for SSTEMP, which are broken into four general classes of variables: hydrologic, geometric, meteorological, and shade.

HYDROLOGIC

Segment inflow and outflow discharges were measured on two separate days – each of which was selected due to its chronological isolation from any major recharge events – and were obtained using a standard USGS wading rod (Fig. 2a), or occasionally a surface velocity method when the channel was insufficiently deep. Inflow temperature was measured using an OakTon Con II handheld conductivity/TDS/temperature meter. Because the stream was assumed to be groundwater dominated, the measured inflow temperatures from each spring were used for accretion temperature in respective stream segments (after the confluence, an averaged temperature was calculated). Although this assumption was certainly fair to make in regions experiencing distinct discharge (the springs and the reaches immediately following them), it probably was less reliable further downstream, and should thus be considered a possible source of error.

GEOMETRIC

Latitude was determined using a handheld Garmin 12XL GPS unit, and was considered the same for all of the reaches. Segment lengths were measured by hand with a Keson 300 ft. tape measure and were taken from the center of channel downstream-up. An elevation survey was performed for each stream reach by means of a Sokkisha B2C automatic leveling device (Fig. 2b). Width was accounted for in each reach by defining a width's A term, which is a description of the width to wetted perimeter ratio, using the recommended assumed B term of 0.20 (Bartholow, 2002) and back calculating through the equation:

$$W = A * QB$$

where W is the known width and Q is discharge. Manning's n values, which provide a quantitative description of the channel surface (whether it is vegetated, rocky, sandy, etc) were estimated based on careful inspection and characterization of each reach.

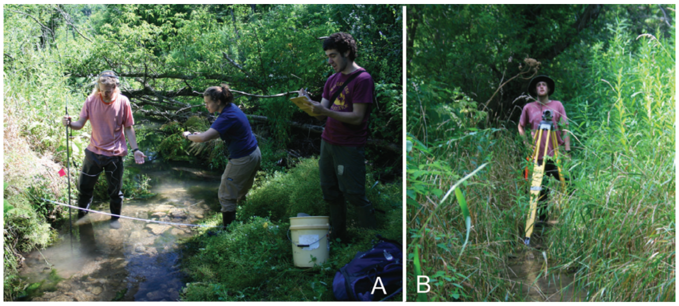

Figure 2. Data had to be collected at the end of each stream reach. A) Gauging discharge using a wading rod. B) Optical surveying of elevation.

METEOROLOGICAL

The Kestrel 2500 pocket weather meter was utilized to gather measurements on air temperature and wind speed. Although there was nearly no wind on the days during the survey, air temperature did vary by nearly six degrees Celsius in spite of the fact that measurements were taken as synchronously as possible in the middle (most thermally homogenized) part of the day. Relative humidity was determined using the Traceable humidity/temperature pen. Ground temperature was accounted for by using the mean annual air temperature of the Prairie Du Chien region (47.0 ^{0}F), based on 1971-2000 records. The ground's thermal gradient was assumed to be a constant 1.650 joules/m^2/s/^{0}C, as this parameter was beyond the scope practical measurability. Since no airborne dust was ever observed in any of the stream's reaches at any point during the study, the dust coefficient was left at a constant zero. Ground reflectivity values, a somewhat ambiguous variable that accounts for albedo of both the water and the channel surfaces together, were estimated to be between 6 and 11% (water, according to Bartholow (2002), ranges from 5 to 15%).

SHADE

Anticipated as the most crucial and difficult to describe parameter, special measures were taken to develop empirical shade percentage values. Three digital pictures were taken looking straight up at relatively regularly spaced (yet somewhat arbitrary locations) in each reach, thus providing images with clearly definable area ratios of shade to non-shade. Using sedimentary grain percentage composition diagrams to compare with the pictures, careful estimations of shade were made. The three values were averaged together for each reach to obtain reasonably accurate descriptions of shade for each segment of the stream. Clearly, one would need to break down stream reaches into even smaller divisions if exact shade values were imperative; but for the purposes of this study, this method proved effective in characterizing shade.

Table 1 summarizes the physical data, and Table 2 the meteorological data, that were used for the temperature modeling. Meteorological data were collected and modeled for two different days, one of which was significantly cooler than the other. SSTEMP does require the input of a date which, with latitude, it uses in calculating incoming solar radiation (the program is designed for use only in the northern hemisphere).

RESULTS AND DISCUSSION

Figure 3 displays the modeled temperature profiles with 95% confidence intervals alongside the measured temperature profiles for the three different segments of the stream. It was necessary to break the stream into these separate segments in order to account for the different initial temperature inputs from each spring (and the combined modeled temperatures at the confluence). Although both days' models show observable correlation with the measured temperatures, the August 1 data seemed to model more accurately. To quantify the correlations, covariance values were calculated for each of the six arrays of data. June 27's values were: 2.50 for the SW

Reach	Length (m)	Width (m)	Discharge (cfs)	Elev. (ft)	Manning's n
SW Spring			0.35	122.25	
1	50.36	2.35	0.33	119.54	0.045
3	65.8	1.59	0.38	109.97	0.045
4	52.2	2.58	0.39	106.20	0.055
5	35.5	1.98	0.43	104.06	0.055
6	18.8	3.50	0.32	104.35	0.060
7	84.8	3.73	0.37	98.68	0.045
NE Spring			0.09	108.70	
8	33.9	1.41	0.20	106.83	0.045
9	22.8	1.70	0.43	103.71	0.040
10	24.68	1.15	0.30	102.07	0.050
11	31.3	2.01	0.20	102.07	0.050
12	72	1.15	0.19	98.68	0.040
13	44	2.72	1.53	95.13	0.045
14	99.2	3.35	0.92	92.87	0.045
15	53.4	2.44	0.85	91.27	0.040
16	17.8	1.69	0.96	89.43	0.040

Table 1. This table summarizes all of the physical measurements and values used in the SSTEMP modeling.

Reach	Stream Temp.(C)		Air Tem. (F)		Humidity (%)		Wind (mph)		Pos. Sun (%)	
	7-27	8-1	7-27	8-1	7-27	8-1	7-27	8-1	7-27	8-1
1	8.9	8.8	78.4	66.7	48	68	0.0	0 - 0.8	95	25
3	9.7	9.2	78.3	67.9	64	66	2.4	0.0	95	30
4	11.0	9.8	79.7	68.5	61	57	0.0	0.0	80	35
5	11.5	10.2	83.0	68.8	52	51	1.6	0 - 2.0	90	45
6	11.7	10.5	82.5	68.0	55	43	1.0	1.5	80	30
7	12.1	10.7	82.0	68.1	56	46	0.0	1.3	25	60
8	9.5	9.5	76.7	68.8	57	55	0.0	0.0	100	25
9	9.8	9.8	78.0	70.3	59	52	1.4	0.0	25	30
10	10.2	10.5	78.9	70.6	53	51	1.2	0.0	75	30
11	11.7	12.2	79.0	68.3	56	55	1.4	0.0	85	65
12	10.3	10.3	81.1	66.6	66	47	0.0	0 - 1.2	15	30
13	12.7	11.3	80.3	67.7	62	54	1.3	2.0	30	40
14	12.6	11.3	80.2	67.2	64	54	0.0	0.0	30	25
15	13.8	12.2	85.0	68.8	51	37	0.0	0 - 2.0	80	40
16	14.5	12.5	87.0	71.0	52	42	0.0	0 - 1.0	25	35

Table 2. This table summarizes all of the meteorological measurements and values used in the SSTEMP modeling. Note the differences in air temperature between the two sampled days.

segment, 1.09 for the NE segment, and -0.07 after the confluence; while on August 1 values were 0.80, 1.34, and -0.02, respectively. This negative value for the final set of reaches may be attributed to the model's surprisingly low value for Reach 16 (Fig. 3c). The reason that this reach modeled so low (relative to the rest of the model) is likely because of an apparent 0.15 cfs increase between Reaches 15 and 16. The model accounted for this using accretion input, when in reality the increase in flow was due to agricultural drainage pipes entering the stream (which were in fact the reason Reach 16 was designated as the end of the modeling segment). This warmer, rather than colder, input of runoff water explains the negative covariance.

An obvious artifact of the modeling is the consistently higher than measured temperatures for all of the reaches on both days. Part of this can be ascribed to the fact that since input temperature is the fundamental determinant for output temperature, it only takes a slightly higher than measured temperature and the effect may propagate or even amplify throughout the rest of the model stream. Thus it is

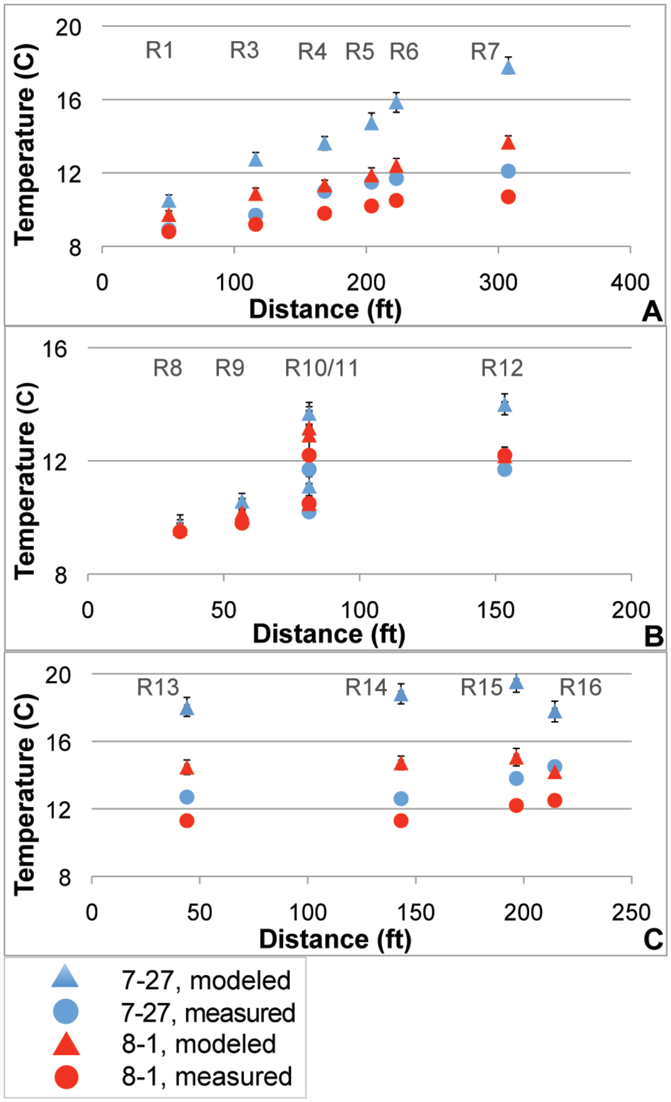

Figure 3. Graphs displaying the temperature profile as a function of distance downstream as well as the correlation between modeled and measured temperatures for two different days. 95% confidence intervals based on SSTEMP's Uncertainty Analysis function. A) SW spring to confluence (reaches 1-7); B) NE spring to confluence (reaches 8-12); C) Post-confluence (reaches 13-16).

that the final segments of the stream (Fig. 3c) have the greatest discrepancies in modeled to measured temperatures.

SSTEMP has a built in Uncertainty Analysis function that allows one to enter percentages (per value of each parameter) signifying the level of uncertainty associated with each input. Using these windows of variation, any number of tests can be quickly run with any number of random samples per test selected to provide an averaged, theoretically more realistic, temperature output. This function was utilized (set at 100 trials and 11 samples/trial) both to improve model credibility as well as to aid somewhat in calibration. The largest uncertainty factor used was for shade at 30%. In addition to the aforementioned advantages, the Uncertainty Analysis also automatically calculates 95% confidence intervals for each run, which were noted and are displayed in Figure 3 as error bars.

The only discernable reason for August 1 lower and more accurate modeling is the lower air temperature on that day. The initial inputs for the two days are nearly identical, and since shading was kept constant, air temperature is the only likely explanation. This was corroborated using the Sensitivity Analysis built into SSTEMP. This function works by altering all parameters in a single run by +/- 10% to determine which has the most influence over output temperature given the specified parameters. For nearly every run, inflow temperature dominated followed in decreasing influence by air temperature, width's A term, discharge values, humidity, shading, and possible sun. These later variables would often switch places in rank, but none of them ever came near the influence of air temperature. It was also observed that inflow had a more and more dominant role (and air temperature a correspondingly less significant role) as discharge increased.

Figure 4 shows the modeled temperature profiles alongside the air temperature and shade profiles. It is clear that while air temperature follows the general shape of the stream profile, shade has little to no correlation. Thus in regards to the prevalent air temperature vs. shade controversy in the literature, the SSTEMP model as it was employed on this specific stream suggests that air temperature is a far more important driver of stream temperature. With that said, this study did not take full advantage of the subtleties in shade modeling that are available in SSTEMP. If one is able to take the measurements, SSTEMP allows for the input of variables concerning the vegetation height, crown, offset, and density with respect to east-west direction. This sort of precision was beyond the scope of this study.

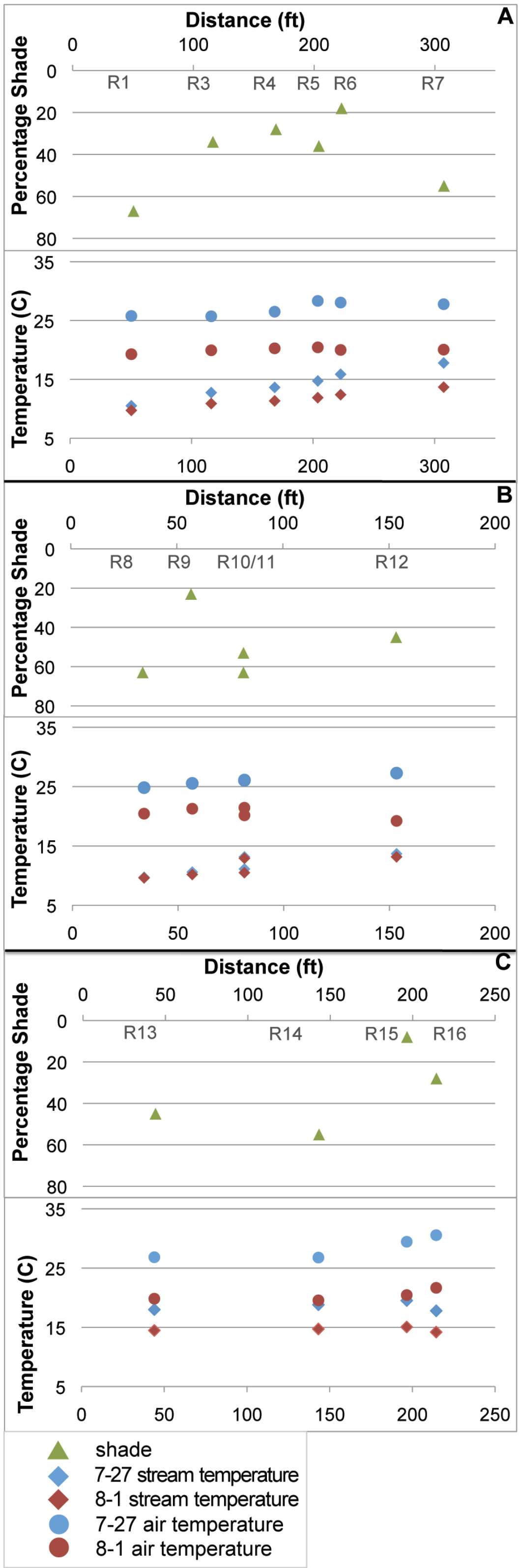

Figure 4. Graphs displaying the apparent relationship between shade, air temperature, and modeled stream temperature. Notice that shade values are somewhat random in distribution and seem to have little significance to stream temperature, while air temperature seems to have some correlation. A) Reaches 1-7; B) Reaches 8-12; C) Reaches 13-16.

The relationship between shade and air temperature needs further study if consensus is to be had on this controversy. Clearly shade effects both air and stream temperature simultaneously, while air temperature has no direct effect on shade. These dynamic relationships are difficult to understand; perhaps laboratory experimentation would be helpful in elucidating the particulars.

CONCLUSION

Although there has been obvious disturbance to this stream, the impacts do not seem to have been terribly great in terms of stream temperature. Restoration with regard to stream geometry and erosion related issues may be warranted in the deforested reaches, although as Lyons et al. (2000) point out, grassy rather than forested vegetation is more conducive to brook trout habitat in small Wisconsin streams. It is also worth noting that the measured (although not the modeled) temperatures in even the furthest reaches of the stream were well within the tolerance zones for brook trout – which is one of the most common concerns for the region's stream management. Despite disturbance, the stream is in seemingly good health; which is also supported by the property owners' claim of recent beaver activity in the stream. Overall, SSTEMP seems to be a good program for small stream modeling purposes, although for management use it would likely be wise to use either a more advanced or an additional different program.

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