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# Investigating the Relationship Between Air and Water Temperatures in Groundwater-fed Streams in Southeastern Minnesota

Steven Speltz
*Winona State University*

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Steven Speltz[1] and Jennifer Cochran-Biederman[1 2]
[1]Winona State University, Winona, MN, USA [2]University of Minnesota, St. Paul, Minnesota, USA

## Introduction

The carbonate sandstone topography of southeastern Minnesota supports a concentration of groundwater-fed streams that yield highly productive populations of brown trout (*Salmo trutta*). Climate change is expected to influence the thermal regime of these groundwater-fed systems, potentially altering the ability of trout to grow and persist in this region. Predicting the impact of climate change on groundwater-fed streams will rely on a better understanding of the relationship between air and water temperature.

To better understand the relationship between groundwater control and trout growth, this study had two main objectives:

I. First, we investigated the degree to which stream temperatures respond to air temperatures in six coldwater streams during 2012 (Year 2). We compared our results with those of a similar study conducted on the same streams during 2011 (Year 1) by [3]Krider et al. (in press).
II. Second, we aimed to evaluate the potential relationship between groundwater control and annual trout growth. Unpublished research revealed a positive relationship between groundwater control and winter growth across the study streams during Year 1 (Will French, personal communication 2013).

## Hypothesis

We expect to find differing relationships between air and water temperatures across six coldwater streams, revealing a gradient of groundwater control and thermal buffering that may affect the growth of brown trout. Based on these differences, we predict brown trout in streams classified as responsive to air temperature will achieve lower growth rates than those in non-responsive streams, because non-responsive streams maintain more optimal temperatures for brown trout growth during winter.

## Methods

### *Fish growth*

- Up to 150 brown trout were collected at each stream during January 2013 using a backpack electrofisher. Fish were marked with PIT tags and measured for total length (mm) and weight (g) (Fig. 1).
- Each site was resampled on five dates throughout the year in order to assess seasonal growth. Recaptured fish were measured for total length and weight. Instantaneous daily growth rates were calculated (mg/g/day) for all recaptured fish (Fig. 3).

### *Air temperature*

- Daily air temperatures (°C) were acquired from NOAA weather stations (Fig. 3).

### *Water temperature*

- HOBO data loggers were deployed in each stream (Fig.3) to measure water temperature (°C) (Fig. 2).

### *Data analysis*

- Linear regressions were used to investigate the degree to which average weekly stream temperatures respond to daily air temperatures during 2012 (Year 1). These relationships were compared with linear regressions completed on the same streams during 2011 (Year 1) by [3]Krider et al. (in press).
- Weekly mean water temperatures between streams and seasons were compared using student's t-test.

**Figure 1**: Example of brown trout caught at sample site.


**Figure 2**: Example of water temperature logger.


**Figure 3**: Map of study area displaying location of streams studied and air temperature loggers.

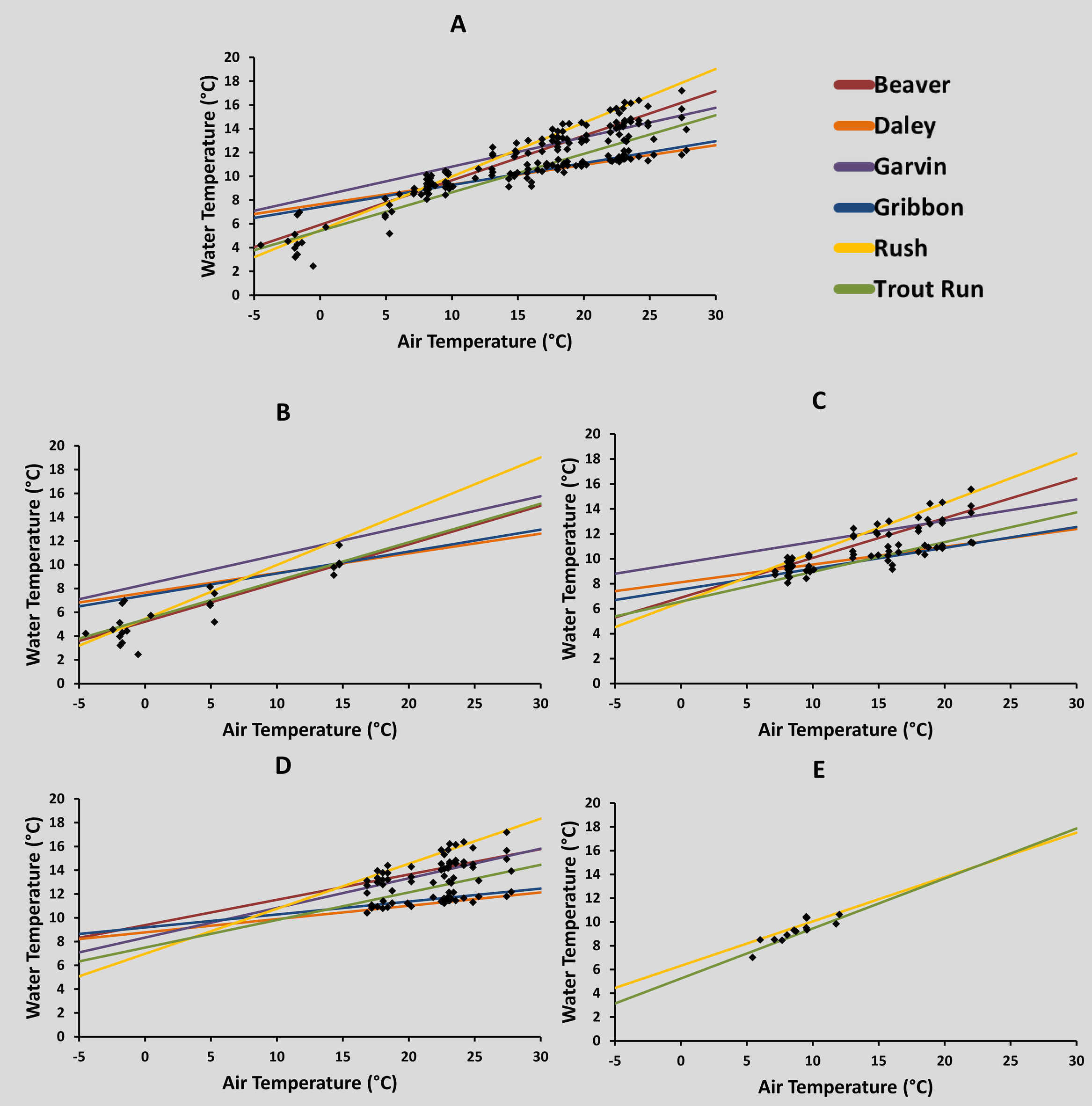


**Figure 4**: Air water temperature regressions for all streams studied, displayed by season. **A.** Annual (11/1/2011 - 10/31/2012) **B**. Winter 12/21/2011 - 3/19/2012 **C**. Spring 3/20/2012 - 6/20/2012 **D**. Summer (6/21/2012 - 9/21/2012) **E**. Fall (11/1/11 - 12/20/11) & (9/22/12 – 10/31/12)

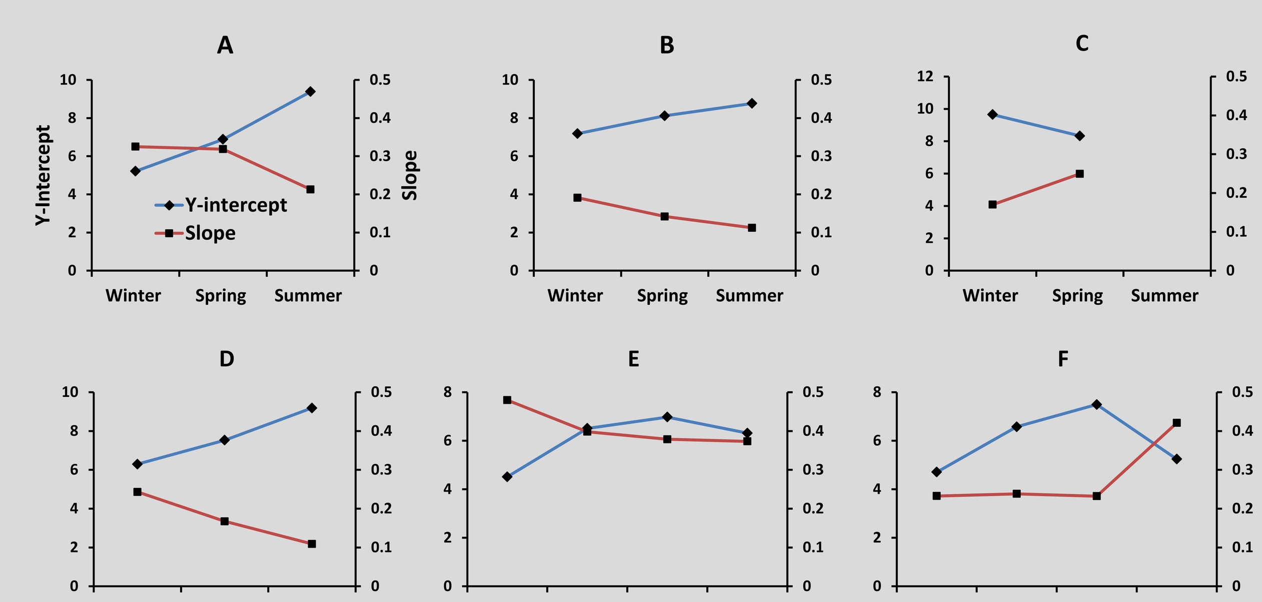


**Figure 5**: Air water regression slope and Y - intercept by season, displayed by stream. **A**. Beaver Creek **B**. Daley Creek **C**. Garvin Brooke **D**. Gribbon Creek **E**. Rush Creek **F**. Trout Run Creek

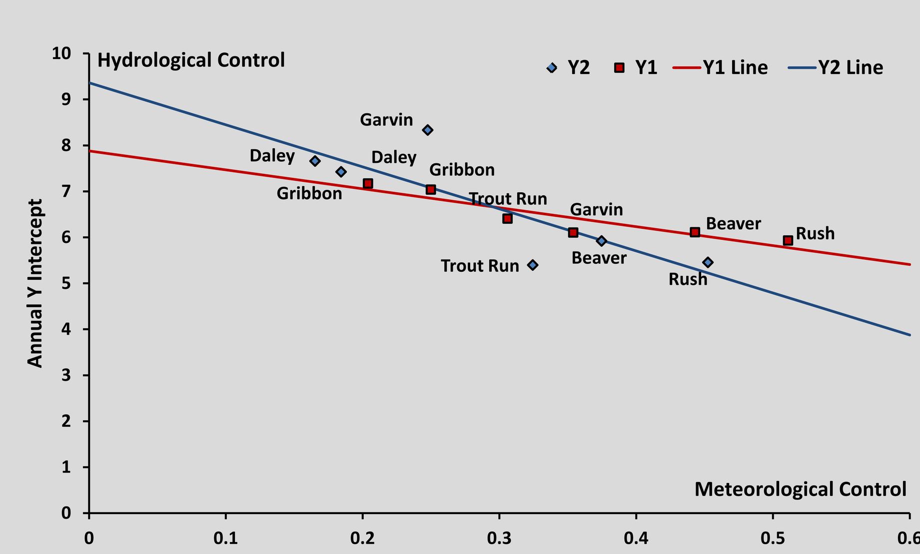


**Figure 6**: Water temperature control, displayed by responsiveness of water temperature to air temperature and average minimum annual temperature of streams studied in Y1 and Y2.
Y1 trend line: Y-intercept 7.88, slope -4.12, $R^2$ 0.835.
Y2 trend line: Y-intercept 9.36, slope -9.14, $R^2$ 0.664.

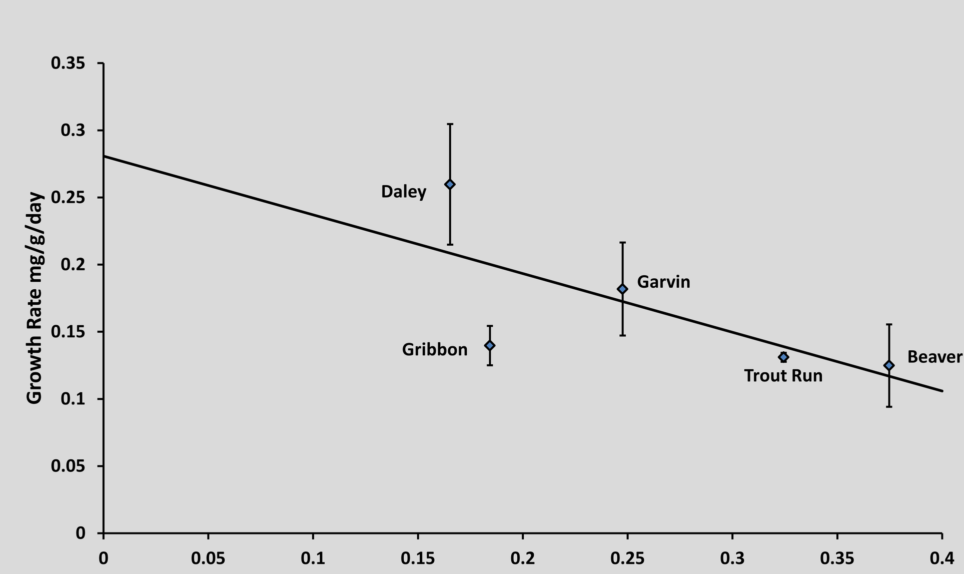


**Figure 7**: Average growth rate of brown trout across all year classes controlled by waters responsiveness to air temperature . Trend line: Y-intercept .281, slope -.437, $R^2$ 0.486.

**Literature Referenced**

[1]Carlson, A. K., W. French, L. C. Ferrington, B. Vondracek and J. Perry. Unpublished. Age Structure and Growth Dynamics of Brown Trout in Southeast Minnesota Trout Streams.
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[4]Lyons, J., J. S. Stewart and M. Mitro. 2010. Predicted effects of climate warming on the distribution of 50 streams fishes in Wisconsin, USA. Journal of Biology.
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## Results

### *Relationships between air and water temperature*

- All streams displayed a positive relationship between air and water temperature. Relationships during Y1 were similar for Y2 (Figs. 4,6).
- Among all streams, Rush Creek had the highest slopes in all seasons but fall, indicating that water temperatures rise relatively quickly in response to increasing air temperatures during these seasons (Fig. 4).
- Among all streams, Daley Creek had the lowest slopes during winter and spring while Gribbon Creek had the lowest slope during summer (Fig. 4), indicating a high degree of groundwater control.
- In general among streams, slopes decreased and y-intercepts increased from summer to winter (Fig. 5). This implies that during cold weather months, water temperatures rise at a faster rate in relation to air temperatures and that water temperatures remain higher at colder air temperatures (i.e. "winter-warm" affect).

### *Groundwater vs. meteorological control*

- In both Y1 and Y2, Rush Creek was the most meteorologically controlled stream (Fig. 6).
- In both Y1 and Y2 Daley Creek was the most hydrologically (groundwater) controlled stream (Fig. 6).
- Between Y1 and Y2, Garvin Brook displayed the greatest shift towards hydrological control (Fig. 6).
- Streams in Y1 displayed a more significant relationship ($R^2$ .835) than those in Y2 ($R^2$ .664) (Fig. 6).

### *Seasonal variation in water temperature*

- Student's t-test revealed significant differences in mean water temperature between seasons for each stream except Trout Run, where fall and summer mean water temperature were significantly similar.
- Garvin Brook, Rush Creek and Beaver Creek had a significantly different and colder annual mean water temperature than Gribbon Creek, Daley Creek and Trout Run.
- No significant difference in mean winter temperature was detected across steams.
- Mean summer water temperature did vary significantly among streams. Daley, Gribbon and Trout Run were colder than Garvin, Beaver and Rush.

### *Brown trout growth*

- In general, average annual growth rate for brown trout decreased as groundwater control increased; however, the relationship was not significant ($F_{1,5}$ =2.84, P>0.1905, $R^2$=48.6) (Fig. 7).

## Conclusions

- During winter, stream temperature is mainly influenced by hydrologic (groundwater) inputs, as much of the meteorological inputs to the landscape are frozen.
- Overall, the streams in this study feature relatively isothermic regimes, with little seasonal variation in water temperature compared to surface-fed systems.
- Despite being largely spring-fed, all streams studied have some degree of meteorological influence. Greater meteorological influence occurs in summer when rainwater can flow off the landscape into streams. The amount of influence varies between streams and is displayed by significant differences in summer mean water temperature between streams.
- Greater meteorological influence increases the degree to which a stream's average annual water temperature will be increased by the effects of climate change.
- Annual average growth rates for brown trout were slower in streams with a higher degree of meteorological control. Streams with relatively colder temperatures during winter support less growth in comparison to those with warmer winter temperatures.
- Based on current models, it is likely that stream temperatures in southeastern Minnesota will increase with rising air temperatures. Although this will lead to a widespread reduction in both abundance and distribution of trout and their prey, steams with a higher degree of groundwater control may be buffered from the immediate effects of climate change.

## Future directions

- To detect significant correlations between groundwater influence and growth rates, larger sample sizes of recaptured fish and a higher number of stream sites would be beneficial. Although it is likely that growth rates are most influenced by groundwater during winter, more intense winter sampling is needed to better understand this relationship.
- To achieve better resolution in the spatial and temporal relationship between air and water temperatures along the gradient of a stream, additional loggers of both types should be deployed.
- Streams should be thoroughly surveyed for the location of hydrological features such as springs or points where runoff enters the stream. These features can influence water temperature more than air/water contact at the water's surface.

## Acknowledgements

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