Assessing the Value of Intermittent Stream Temperature Data for Kings Creek at Konza Prairie Biological Station, KS.

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Introduction

Streams located in the Great Plains are essential for ecological health. Prairie streams serve multiple purposes even under constant stress. These streams are exposed to extreme heat, precipitation, harsh winters, and agricultural fragmentation. Such conditions shape the way organisms react and survive. Studying the dynamics of prairie stream characteristics can help ecologists understand the responses of prairie stream organisms to habitat changes and how life downstream is affected.

The Konza Prairie Biological Station is an ideal location to research prairie streams. It is located in the Flint Hills of Kansas and is maintained and studied by Kansas State University. There are two streams that flow across the Konza, the largest of which is Kings Creek, where water temperature data have been recorded at multiple stations since 1987. Generally speaking, climate plays a major part in intermittent prairie streams. We hypothesize that the water temperature of Kings Creek will generally follow air temperature patterns over the study period of 1987 to 1997.

Factors that Influence Stream Temperature

Understanding what environmental factors affect stream temperature can help in conservation efforts to maintain or repair ecosystems. The following stream temperature controls are some of the most influential, but this is by no means an exhaustive list.

Riparian Vegetation

Management practices can have a major impact on ephemeral streams and the biotic life within them. One of the most common ways that streams are altered by human practices is the removal of riparian vegetation. The importance of riparian vegetation lies primarily in its ability to shield the stream from incoming solar radiation, thereby reducing diurnal and seasonal water temperature fluctuations (Johnson, 2004). Removal of streamside vegetation is followed by an immediate increase in stream temperature (Brown and Krygier, 1970; Dunham et al., 2007). Plants also keep the soil of the flood plain in place so as to reduce sedimentation of the channel and maintain bank stability, which have subtle but long-term effects on temperature (Poole and Berman, 2001). The degree to which riparian vegetation regulates stream temperature is based on factors such as plant species and density, width of riparian corridor, stream orientation, sinuosity, and channel entrenchment (LeBlanc and Brown, 2000). Thicker, larger plants provide better shading and channel stability, and are most effective in wide strips along the stream. Plants on the west side of a stream provide the most insulation against solar radiation, as this is the direction the Sun is located when its heating effects are most intense. Sinuous streams have low rate of flow and so are in need of vegetation to shade them. Finally, a deep-set channel is more structurally protected from solar radiation, so less vegetation is necessary to maintain cool stream temperatures.

Fire is a unique and powerful occurrence in prairie biomes, so it is necessary to understand its effects on prairie stream temperatures. These manifest in several ways, in both the short- and long-term (Dunham et al., 2007). In the years immediately following a wildfire, average stream temperature significantly increases, and summer maximums can remain elevated for at least a decade. This increase is likely due to the effects that burning has on riparian vegetation, which alter incoming solar radiation and precipitation run-off. Longer-term changes are a result of a fire's ability to reorganize the channel itself. When precipitation follows a fire event, left-over debris flows into the stream. This debris is capable of slowing stream flow and widening the channel, which can cause stream temperature increases. These changes to the channel will not right themselves as quickly as vegetation loss, so temperature elevation can last for decades.

Grazing can have both positive and negative effects on streams. Grazing provides many nutrients such as available nitrogen to both the stream and the riparian zone. However, when cattle or bison cross a stream or climb down banks, they disrupt the riparian zone causing changes in geomorphology and sediment concentrations (Whiles et al., 2015). Additionally, over grazing is common in drought stressed periods and creates a greater possibility for erosion of sediments into ephemeral streams. Changes in riparian management especially with grazing can greatly impact the community respiration rates of a stream as well (Van Horn, 2012).

Precipitation

The importance of precipitation lies in the fact that stream temperature is proportional to heat energy divided by water volume (Poole and Berman, 2001). As an inverse relationship, any increase or decrease in water discharge will result in a decrease or increase in stream temperature, respectively. Since precipitation patterns vary widely around the world, the degree to which precipitation influences stream temperature varies depending on factors such as latitude, altitude, and topographic features (Dodds et al., 2015). As with solar radiation, precipitation is seasonal at higher latitudes. Prairie streams tend to be intermittent, so they are especially vulnerable to precipitation changes. Additionally, precipitation controls the amount of riparian vegetation growing around the channel and the sediment load of the stream, which are both factors that influence stream temperature (Poole at al., 2001).

Groundwater

As with precipitation, groundwater's role in stream temperature stems from water volume inputs. Additionally, it has a moderating effect on stream temperature. Groundwater tends to have a constant, relatively low temperature, so as it seeps into the stream, it acts as a buffer against the influence of other stream temperature controls (Poole and Berman, 2001). To fully understand the interactions at play, it's important to understand the below-ground structure of a stream (see Figure 1). Alluvial groundwater can be subdivided into hyporheic and phreatic. Hyporheic groundwater is water that enters the aquifer from the stream, flows through the alluvium, and reemerges into the stream. Phreatic groundwater is water derived from the catchment aquifer that enters the bottom of the alluvial aquifer and mixes with hyporheic water. As a rule, the temperature of the phreatic aquifer is the baseline of the stream temperature, with deviations occurring downstream from where the phreatic water entered the channel. Alternatively, the hyporheic zone allows for an exchange of water through substrate, which has a cooling effect throughout the stream channel (Johnson, 2004).

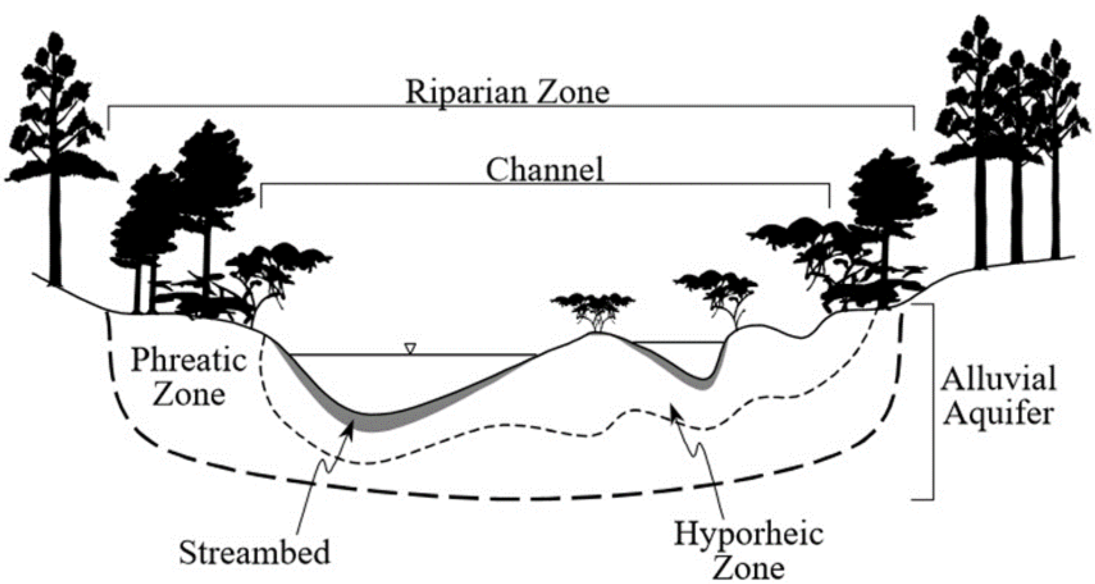

Figure 1. The generalized structure of a stream (Poole and Berman, 2001).

Discharge

To understand the importance of discharge, one must consider the common understanding that precipitation causes flow in intermittent streams. It has been demonstrated that mean annual temperature will lead to more precipitation, in turn creating more runoff and stream flow in these intermittent streams (Lauwo, 2007). There are other sources of stream change that maybe wouldn't seem as obvious but must be considered, such as stream flow vs intermittency based on fluctuations in the groundwater table rather than just precipitation (Costigan, 2013). These hydrologic impacts, such as groundwater fluctuations and flooding events, are significant in maintaining intermittent stream connectivity (Franssen et al., 2006). Stream connectivity (surface water connectivity) is an important factor to stream temperature and flow because a poorly connected stream is going to have pools that are stagnant and more susceptible to temperature fluctuations in response to air temperature. Additionally, current groundwater storage, dynamic infiltration paths, and soil moisture content can all cause variability with results of precipitation depending on their statuses at the time of a given precipitation event (Costigan, 2015).

Sediment

Sediment load is indirectly responsible for altering stream temperature in a variety of ways (Poole and Berman, 2001; Kaushal, 2013). As sediment load increases, channels tend to widen and shallow, which has been shown to increase stream susceptibility to temperature changes. Sedimentation also occurs on the streambed, clogging the alluvium and inhibiting groundwater exchange with the hyporheic zone. Sediment fluxes also change water emissivity, and more sediment mixing into the stream lowers the stream's ability to reradiate solar energy back to the atmosphere. As a general rule, activities that contribute to a high sediment load will foster stream temperature variation and water quality reduction.

Why Stable Stream Conditions Matter

We've shown that there are a multitude of factors that influence stream temperature, intermittency, and channel shape. Any variation in these stream conditions can result in changes to stream nutrient levels and biodiversity. Since these two factors are crucial to a healthy ecosystem, it's important to understand the effects that stream temperature has on them.

Nutrients

It has been shown that total nitrogen in intermittent streams in higher than that of perennial streams, as well as a connection that these concentrations during storm flows were directly related to the magnitude of storms and inversely related to the frequency of storm events (Tate, 1990). Further study has confirmed that decay rates of organic matter is slower in intermittent streams, due to the typically drier conditions (Tate and Gurtz, 1986). Additionally, warmer streams have higher decay rates, leading to higher nutrient contents. This acknowledges that the nutrients can be largely affected by the decomposition of vegetation in the intermittent system. Along with being a large source of potential nutrient input, vegetation also provides a large source of filtration for stream and groundwater recharge (Craine, 2011). This suggests that changes made to the stream environment can negatively impact vegetation life and abundance, potentially affecting the rates of runoff and leading to a total change in stream behavior and nutrient load.

Biodiversity

Studying the dynamics of prairie stream characteristics can help ecologists understand the resistance and resilience of prairie stream organisms and how biodiversity is affected. Resistance is the ability of an organism to protect itself from disturbances, and resilience is how that organism recovers. The organism's ability to rebound is based on the physical characteristics of the habitat and the history of the organisms. The most resilient and fastest to rebound are the microbial organisms, followed by the stream fish. (Dodds et al., 2004). One disturbance under study is the ability of prairie streams to respond to droughts and floods. Kings Creek and other prairie streams exist in an ever-changing balance between flood and drying stages. Both flood and drought remove organisms from streams, which can be detrimental to stream biodiversity.

Each species of fish have different ranges of water temperatures that they find optimal. Their reactions to temperatures outside their ideal range vary with habitat and evolutionary traits. Both extreme increase and decrease in stream temperatures are detrimental to the aquatic life that reside there (Ross et al., 1985). Although warmer waters are usually considered more harmful, water that is not warm enough can be dangerous too. Nonetheless, both can affect growth, survival rate, and the ability for fish to tolerate diseases. Spontaneous increases in water temperature can stress fish with excessive respiration rates. This is due to lower availability of oxygen for uptake because warm water cannot hold as much dissolved oxygen compared to cool water. On the other hand, a rapid decrease in stream temperatures can affect metabolic rates and biological processes in stream organisms (Brungs and Jones, 1977).

Critical Thermal Maximum (CTM) has been used as a tool to measure thermal tolerance of fish and other ectotherms. Critical thermal maximum is defined as the "collected thermal points at which locomotor activity becomes disorganized to the point at which the organism loses its ability to escape conditions that will promptly lead to its death" (Fessell et al., 1995). There are indicators of fish that surpass their CTM. The most important are muscle spasms, loss of equilibrium and finally death. Farless and Brewer (1997) conducted an experiment that tested the CTMs of 15 prairie fish from Oklahoma. They collected samples of the 15 fish and acclimated them to a water temperature 20 ^{0}C for two weeks. After acclimation, Farless and Brewer increased the water temperature 2^{0}C until fish exhibited signs of equilibrium loss. Out of the 15 samples found in the Oklahoma stream, the following four fish are also found in Konza's Kings Creek: bluegill, bluntnose minnow, stoneroller, and redbelly dace. They experienced loss in equilibrium at 36^0 C, 35.5^{0}C, 34.2^{0}C, and 34.8^{0}C respectively.

Due to temperature's effect on altering the development of juvenile fish, it can also affect how the juveniles survive predator attacks. At lower temperatures, fish growth rates decrease thus exposing them to a vulnerable time for longer periods. Furthermore, fish have a reduced likelihood of surviving predator encounters since lower temperatures can also reduce swimming speeds. Swimming speed variation decreased with higher temperatures and fish swam closer to the bottom at these temperatures. It has been shown juvenile guppies display a difference in depth at higher temperatures. (Kent and Ojanguren, 2015).

Data and Methods

Kings Creek is the main stream that provides drainage for The Konza Prairie. The Konza Prairie is located in North East Kansas, United States, and covers part of both Riley and Geary Counties (see Figure 2). This region is highly variable in both temperature and precipitation. Winter is usually cold and dry while summer is wet and warm. The average annual precipitation is 835mm. or 32.9 in. with 75% of the total precipitation falling in the growing season. The Konza consists of more than 60 watersheds and 34 km^2 of the northern part of the Flint Hills. It is a protected native range with study areas that are minimally affected by humans outside of controlled studies, and is dominated by tall grass prairie. The nearest agricultural disturbance is located 5km away and is a separated local watershed. Kings Creek empties into McDowell Creek and is a tributary to the Kansas River (Macpherson, 2012).

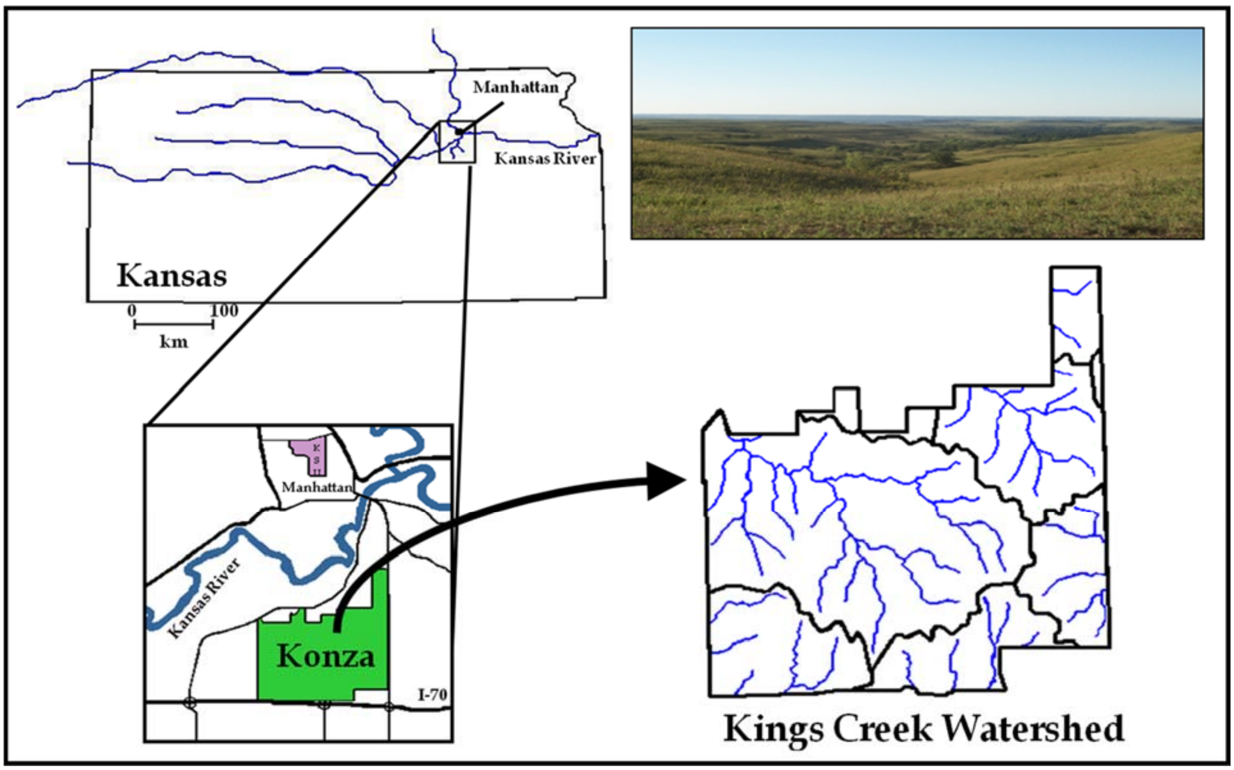

Figure 2. The location of the Konza Prairie Biological Station

There are four stations along Kings Creek with data loggers that have recorded stream temperature since 1987. For simplicity, we chose to look at one station in watershed N20B (see Figure 3), which is grazed by bison and burned every twenty years. Monthly data are collected and available in the Konza Long-Term Ecological Research database.

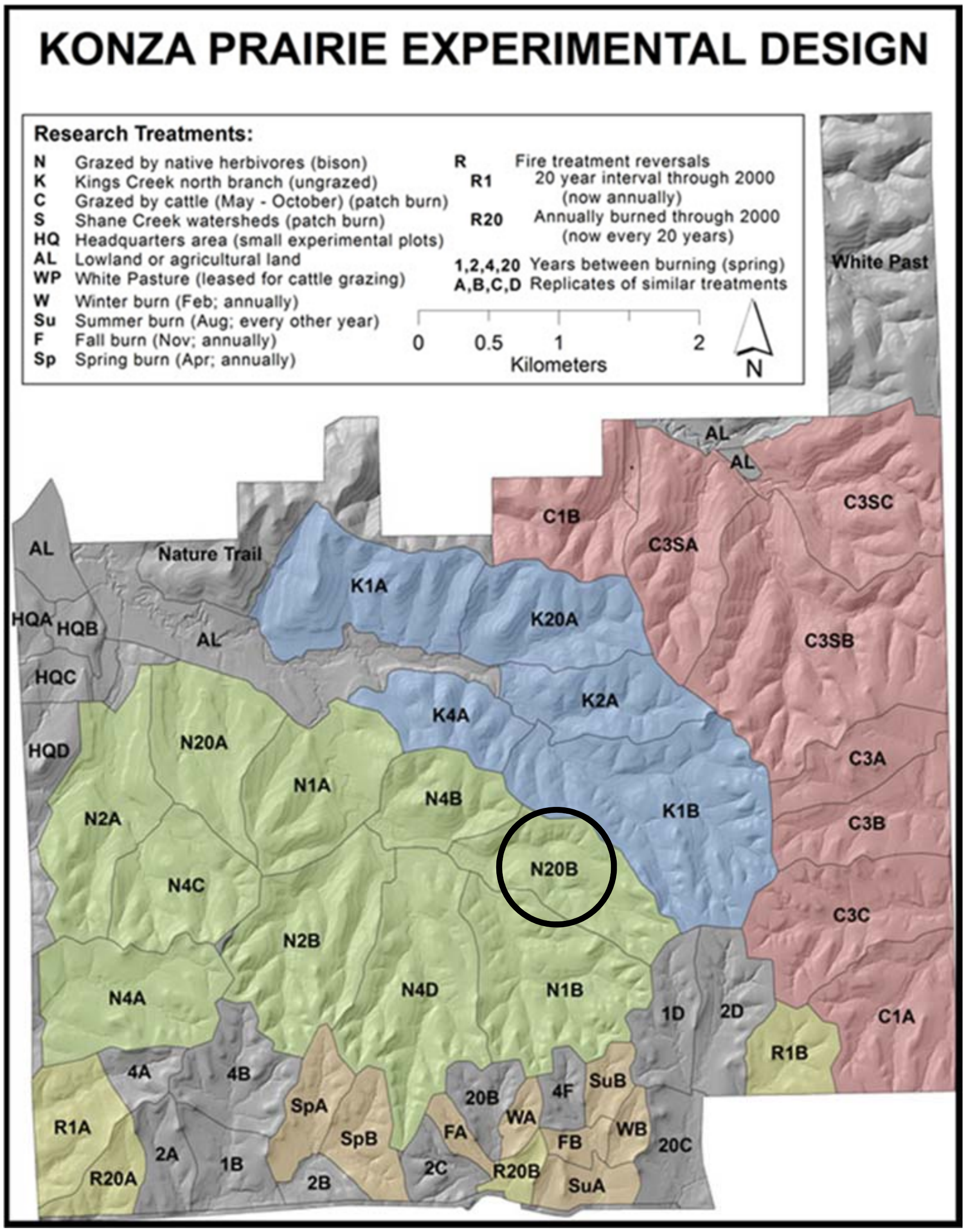

Figure 3. The location of the N20B watershed, the focus of this study.

Monthly air temperature data for this region were gathered from the National Climatic Data Center's Weather Underground database. From here, we graphed the monthly stream and air temperature data for each year they were available during our study period. During certain times of the year, there is no stream temperature data because Kings Creek was not flowing, as it is an intermittent creek. In 1995, the creek was dry all year, so there are no values for this year. Additionally, air temperature data were not available for 1992. This left us with nine years of data. Correlation values for these years were then calculated based on how close the air and stream temperature values are to one another.

Results and Discussion

Our end result was nine graphs displaying monthly air and stream temperature trends in degrees Celsius, with annual correlation values (see Figure 4). Air and stream temperature did in fact correlate closely with each other as we hypothesized, with just a few variations. These were likely due to the previously discussed factors that influence stream temperature, such as fire, precipitation, and groundwater influence.

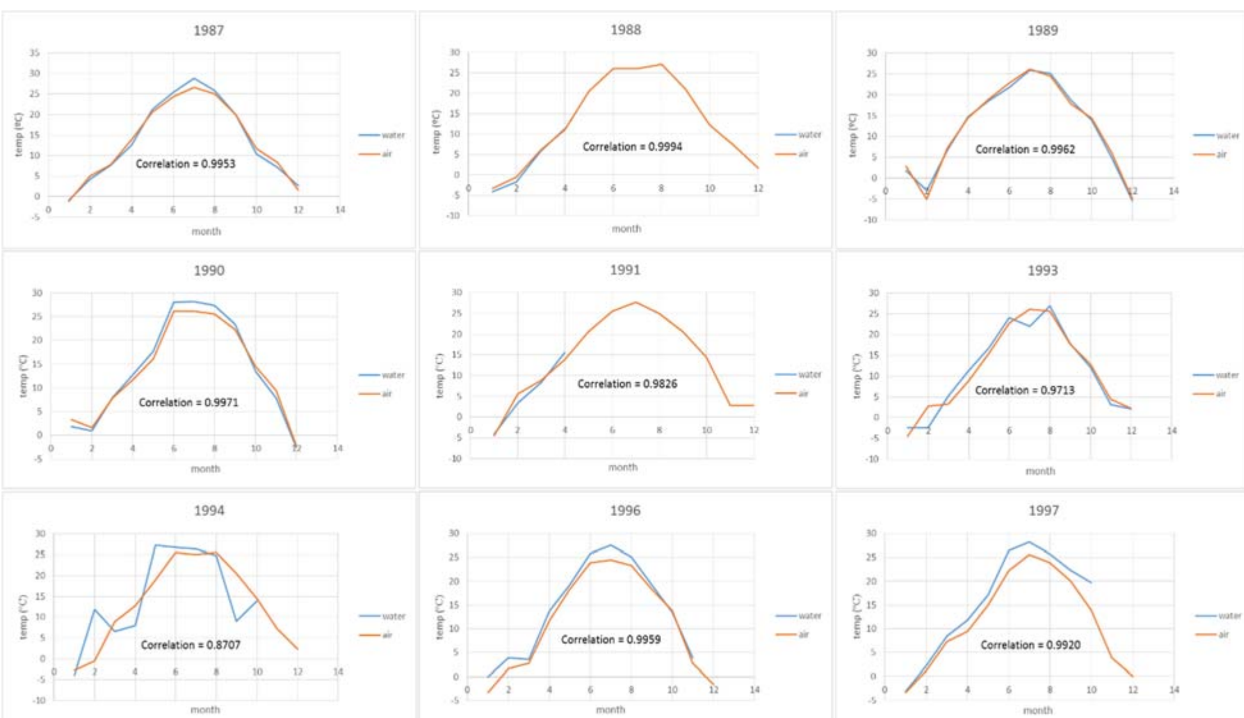

Figure 4. Graphs of air and stream temperature trends with correlation values.

Unlike many water systems, there is a minimal lag time between air temperature changes and water temperature responses. This is likely due to the fact that Kings Creek is often very shallow, so the water heats and cools rapidly. Additionally there are instances where water temperature is higher than air temperature. This may be due to the fact that, throughout the warm months, heat energy accumulates in the creek and remains elevated while the air temperature begins to decrease as the weather cools.

The year 1993 provides an interesting example of the effect that increased discharge has on stream temperature (see Figure 5). In the Midwest, the Great Flood of 1993 occurred, inundating many water systems. As previously discussed, this decreases the heat energy of water bodies (Poole and Berman, 2001). Our data show a distinct decrease in stream temperature during that time, which agrees with the literature. It is likely that other dips in stream temperature throughout our study period were caused by precipitation events as well, although none were quite as extreme as in 1993.

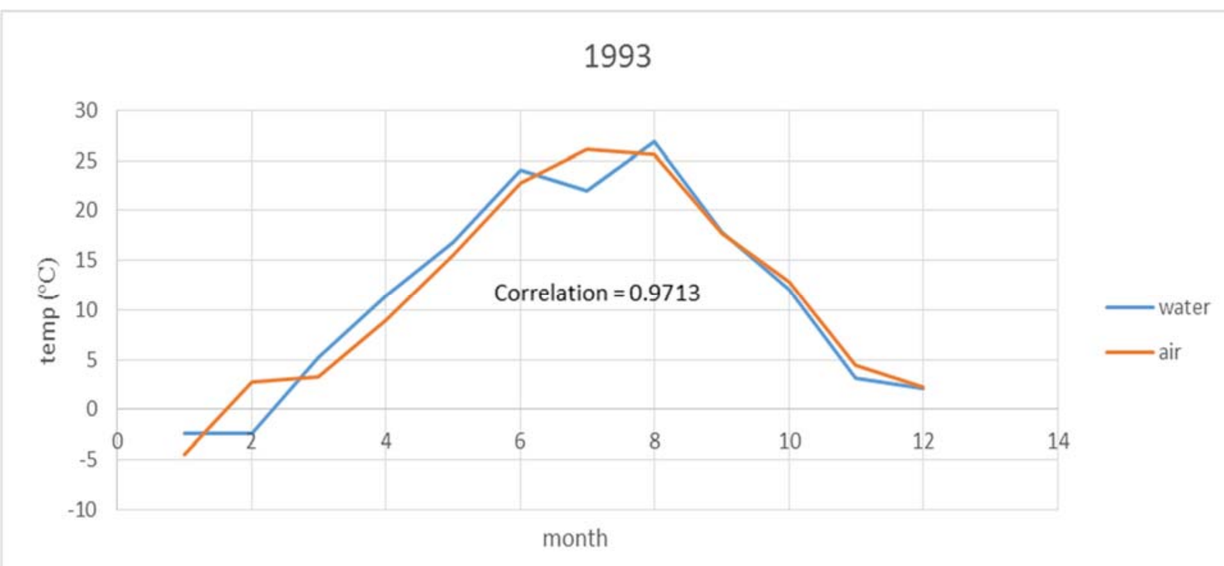

Figure 5. Graph of the year 1993, showing the influence of a mid-year flooding event.

The degree to which air temperature directly influences stream temperature is up for debate (Johnson, 2004). Although they show very similar trends, it is possible that other factors influence both sets of temperature, such as solar radiation. Since insolation warms the air as well as the water, it is difficult to estimate the exact role that air temperature plays on stream temperature. Nevertheless, these data show that air and stream temperature follow similar trends, which suggests air temperature could be a useful variable for modeling future stream temperature fluctuations.

Conclusion

Our data display a clear correlation between air temperature and stream temperature over the time period analyzed, but there are many factors besides air temperature that play a part in regulating stream temperature. Suggested future topics of study involving this stream data set should include a more detailed analysis of discharge data at Kings Creek to better understand the effect that flow has on the stream temperature. Other areas of interest include the effects of clear-cutting of the riparian woody vegetation along the creek, and an assessment of groundwater influence on the stream. Additionally, stream temperature research could be done at a finer scale, such as analyzing daily or weekly trends rather than monthly as was done here. Prairie stream temperature research such as this could go a long way in helping maintain healthy prairie stream conditions and preserving ecosystems.

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