Variables Related to Temperature in Walla Walla Streams

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Abstract

Waterways provide vital habitats and resources to many ecologically and culturally significant organisms. However, preserving these areas has become more difficult as global climate change negatively impacts the viability of water resources. In response, local non-profit organizations, such as Kooskooskie Commons in Walla Walla, Washington work to mitigate these effects. Kooskooskie Commons focuses on connecting local community members to their natural resources through education. Their recent riparian restoration projects, that replaced overgrown exotic plants with native plants, aimed to provide streambed shading to decrease water temperatures for habitats for aquatic organisms, such as Chinook salmon (*Oncorhynchus tshawytscha)*. While these plants grow, the effects of shading cannot yet be evaluated. Instead, stream quality data could be used to better understand the entire system. Due to the availability of data, we could not run statistical analyses, but instead we used graphs to compare Kooskooskie Commons' temperature data to variables that could relate to stream temperatures. These variables consisted of air temperature, precipitation levels, dissolved oxygen (DO) levels, and temperature and discharge of Mill Creek, a stream that flows into distributaries in this study. From these comparisons we generated the following hypotheses. Air temperature, Mill Creek temperature, and Mill Creek discharge drive local Walla Walla stream temperatures. Conversely, precipitation levels do not strongly influence stream temperature while stream temperatures largely do not affect DO levels.

Introduction

Rivers and streams are ecologically important in creating habitat, particularly for aquatic organisms, and vital for preserving culturally significant practices. Maintaining sufficient in-stream flows and stream temperatures allow larger populations and a wider variety of species to create habitats in them (Bond et al. 2015). Conversely, large-scale changes to aquatic habitats can endanger these organisms. For example, habitat alterations and excessive water extraction led to the extinction of Chinook salmon (*Oncorhynchus tshawytscha)* for more than 80 years in the Walla Walla River (Columbia River Inter-Tribal Fish Commission 2019). Their reintroduction in 2001 resulted from an agreement that allowed the Walla Walla River to flow year-round again. The reappearance of salmonids in this area proved significant ecologically (Schindler et al. 2003), and culturally due to the importance of salmon in the first foods of the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) (Washington Water Trust 2019b). In addition to sufficient amounts of water, aquatic organisms also require a specific range of temperatures to survive (Webb et al. 2008). Ensuring sufficient water levels and water quality can determine the degree to which culturally and ecologically significant organisms can create habitats in these streams.

Aquatic species, including salmon, encounter additional challenges as the effects of global climate change impact rivers and streams. As air temperatures rise, water temperatures also increase (Morrill et al. 2001). From this relationship, researchers can even predict stream temperatures from air temperatures (Caissie et al. 2001). Therefore, as the effects of the rapid increase in global air temperature become progressively harmful, preserving the viability of waterways becomes more difficult (Oreskes 2004). Aquatic species quickly feel these changes as the waters they live in become increasingly uninhabitable. Salmon populations rely on a stable and specific range of water temperatures to regulate their body temperatures and reproductive cycles (Pankhurst and Munday 2011). Stream temperatures substantially above these ranges threaten aquatic individuals and populations. In this way, global climate change impedes efforts to sustain stable populations of these organisms.

Other impacts of climate change also decrease the viability of waterways as habitat for organisms. As air temperatures increase, the fraction of precipitation as rainfall increases with simultaneous decreases in snow accumulations and earlier snowmelt (Isaak et al. 2012). The combination of these effects causes streams to discharge more water earlier in the year, leaving less in-stream during the warmer summer months. Stream temperatures also impact dissolved oxygen (DO) levels in creeks because cool waters hold gases more easily than warm waters (Harvey et al. 2011, Marzadri et al. 2013). The amount of available oxygen determines a stream's capacity to support life because almost all organisms require oxygen for cellular respiration. For Chinook salmon, reduced levels of DO, potentially related to elevated stream temperatures, can negatively impact growth and development at different life stages as well as juvenile and adult swimming, feeding, and reproductive abilities (Carter 2005). These consequences demonstrate ways in which increased air temperatures impact the livability of rivers and streams for aquatic organisms.

In addition to climate change, water extraction policies also influence local streams. Particularly in arid areas, water users and managers heavily influence the availability of water resources (Kjelgren et al. 2000). In Walla Walla, Washington, the prior appropriation doctrine allows landowners to extract water from rivers based on the seniority of their water rights (Washington River Conservancy 2009). Historically, this doctrine also caused waterways, such as the Walla Walla River, to dry out, particularly in the summer months (Preusch 2002) while water supplies often ran out before all rights holders receive their share. Overallocation of water rights in Walla Walla County, where water rights, or paper rights, outnumbered physical water, also compounded the effects of the prior appropriation doctrine (Pierson 2018). Additionally, institutional policies promoted the inefficient use of water. For example, the state's water code of 1917 promoted the practice of "use it or lose it" (Washington State Department of Ecology 2019), where water rights holders had to use all of their allocated water to receive the same amount in subsequent years. This policy incentivized using as much water as possible, even if unsustainable and unnecessary, to have access to their entire water right later. Further, those who initially allocated water rights did not consider the importance of maintaining in-stream flow for organisms dependent on these streams (Sinokrot and Gulliver 2000). For 80 years prior to 2001, the Walla Walla River ran dry every summer as farms extracted water from it along its path from the Blue Mountains to the Columbia River, eventually causing Chinook salmon to become extinct in this drainage (Preusch 2002). In 2001, due to the efforts of local organizations, a portion of water rights were reallocated to endangered fish species, including Chinook salmon, which helped maintain in-stream flows. This example demonstrated that as the importance of aquatic habitats became increasingly pronounced, more stakeholders advocated for in-stream flows to promote the viability of aquatic and riparian habitats.

Projects to increase the quality of fish habitats and migratory pathways have included riparian restoration projects that shaded streams and improved channel morphologies. Shading from riparian vegetation caused significant changes in stream temperatures (Webb 1996). In Mendocino County, California, Opperman and Merenlender (2004) demonstrated that restored and shaded areas had water temperatures within an acceptable range for fish while unrestored areas had warmer water that could have been detrimental to prevalent steelhead populations. The restored portions also had qualitatively different channel morphologies and significantly greater heterogeneity than controls, which fish populations benefitted from. However, an analysis of riparian revegetation projects from 1984 to 2007 in the interior Pacific Northwest did not determine the overall success of these efforts (Wall 2011). A variety of methods and sample sizes made comparisons between projects difficult. Increased communication between project managers and standardization of methodology could elevate the future success of riparian restoration projects in this region. The results of previous studies guided our project implementation and management, and Kooskooskie Commons hoped to provide additional context for the effects of shading from riparian restoration work.

As climate change and water policies affected local streams, non-profit organizations utilized riparian restoration to mitigate these impacts. Revegetating riparian areas to improve water quality for aquatic populations has become an increasingly utilized method (Johnson 2004). Using plant roots to stabilize the soil and plants and trees to shade the stream could improve aspects of water quality, particularly temperature and flow (Sheedy and Paris 2014). Due to previous successes of riparian restoration projects in improving water quality (Rood et al. 2003), local organizations hoped to promote similar effects in this drainage. Kooskooskie Commons, in Walla Walla, Washington, worked on riparian restoration projects to mitigate elevated water temperatures in local creeks. We expected these projects to foster decreased stream temperatures that could provide spawning pathways and habitats for migratory fish populations once plants grew large enough. Previously mentioned policy changes also supported these goals by working to maintain in-stream flows for aquatic organisms. Kooskooskie Commons focused on shading streambeds to decrease the amount of direct solar radiation on the water and thereby alleviate the effects of a main contributor of stream temperature fluctuations (Thomas 2005).

We aimed to better understand the variables in this system that potentially related to stream temperature using Kooskooskie Commons' data. Following restoration projects, Kooskooskie Commons placed water temperature monitors in 22 sites along 11 local Walla Walla creeks. Researchers then collected water quality data including, but not limited to, temperature, from 2014 to 2018. While these data can eventually provide more useful information about the efficacy of riparian restoration projects, this cannot be assessed until plants grow large enough to provide sufficient shading. In the meantime, we used the available data, particularly stream temperature and DO levels, to generate hypotheses about the system. We examined five variables of interest, namely air temperature, precipitation, DO levels, Mill Creek discharge, and Mill Creek stream temperature, and used graphs to explore their relationships to local stream temperatures. Mill Creek, a major tributary of the Walla Walla River, flows into the distributaries in this study and could thereby have impacted their temperatures. Gaining a better understanding of the relationships between these factors and stream temperatures could contribute to future research and assist stakeholders in conserving aquatic species in the face of global anthropogenic climate change.

Methods

Kooskooskie Commons, a non-profit in the city of Walla Walla, Washington, focuses on connecting community members to their natural resources. Starting in 2013, this organization worked with willing landowners with properties by local creeks to implement riparian restoration projects. Kooskooskie Commons targeted areas by the presence of invasive species, such as reed canary grass (*Phalaris arundinacea*), in the streambeds. We observed that the growth of these weeds crowded the channels and competed with native species to contribute to elevated stream temperatures (Johnson 2016). Kooskooskie Commons attempted to remove these invasive species and replace them with native plants. This organization believed native plants would be less likely to invade streambeds and could provide the necessary shading to decrease direct solar radiation on streams. We aimed to promote lower stream temperatures by producing open stream beds and riparian shading once the native plants grew large enough.

Beginning in 2014, Kooskooskie Commons collected water quality data to monitor completed riparian restoration projects. We placed Hobo® TidbiT v2 Water temperature Data Loggers, hereafter called TidbiTs, in both restored and non-restored sites along a total of 11 spring-fed and distributary creeks in Walla Walla (Table 1). Stream monitoring extended from upper Yellowhawk Creek below its division from Mill Creek to its confluence with the Walla Walla River (Figure 1). In three locations along Yellowhawk Creek, Kooskooskie Commons used a different TidbiT, a Hobo® Dissolved Oxygen Data Logger, that included a dissolved oxygen (DO) monitoring tool in addition to a temperature sensor. TidbiTs recorded the temperature, in ˚F but later converted to ˚C, and DO, in mg/L, every 30 minutes. These monitors, which remained in the streams, as well as a portable monitor, an HI9829 from Hanna Instruments, Inc., that measured DO, pH, and turbidity, collected data from the same locations. Kooskooskie Commons researchers aimed to visit monitoring sites monthly to offload measurements from TidbiTs with a Hobo® Waterproof Shuttle by Onset. During these visits, interns also placed the portable monitor in the stream for 10 minutes and collected continuous data for the variables stated above. After returning from the field, researchers offloaded data from the Shuttle and the portable monitor to their respective computer software programs where data could be graphed.

Our study utilized data from 22 monitoring sites along 11 creeks, however the amount available data for each site varied. We studied Yellowhawk Creek, Stone Creek, Lassiter Creek, Butcher Creek, Russell Creek, Lincoln Creek, Titus Creek, Caldwell Creek, Whitney Spring Creek, and Cottonwood Creek. Most streams had both a 'Source' site and a 'Mouth' site, while others had only one or had more than two monitoring sites (Table 1). 'Source' sites referred to a stream's furthest point from confluence with a larger waterway and 'Mouth' sites indicated the point of confluence. All sites contained a TidbiT that remained in-stream and continuously collected temperature data even when researchers could not visit sites. Alternatively, we only had DO, pH, and turbidity data from the portable monitor for the months that researchers visited the sites. Consequently, stream temperatures from TidbiTs make up the majority of available data. Nevertheless, many consecutive months did not have stream temperature data partly because researchers moved TidbiTs between sites throughout the project. Because months with available and reliable data often did not overlap between sites, statistical analyses could not evaluate the success of riparian restoration projects. A comparative study between restored and unrestored areas also would have been inconclusive due to the small sample size and insufficient time since revegetation to provide shading. The limited sample size also prevented us from using predictive models to compare potential influences of stream temperature. Instead, we created graphs to examine the relationships between various factors and water temperatures in Walla Walla streams.

Missing data resulted not only from gaps created through collection methodology, but also from the elimination of clearly anomalous data. We decided to systematically remove data that seemed to exceed probable water temperatures. For example, we noted measurements over 37.8˚C that suggested that the TidbiT measured the air rather than water, potentially due to dry streambeds particularly in the summer months. However, temperature measurements below 37.8˚C also had to be eliminated. To systematically exclude anomalous data, we created a decision rule to distinguish between the daily fluctuations of water and air temperatures because air temperatures had distinctively greater ranges. We discarded days with ranges of 3.3˚C or greater because TidbiTs likely measured the air rather than the water at least once. If we discarded more than 15 days in a month, the entire month's data would be excluded due to insufficient representation of that month's temperatures. Rationale for this decision rule also came from the observation that months with days with ranges of 3.3˚C tended to have days with even greater ranges, i.e. 5+˚C. These days often also included measurements near 37.8˚C and higher. Conversely, daily ranges below 3.2˚C tended to fall closer to 0.5-1˚C, which we believed represented normal water fluctuations. For this reason, we used these larger ranges to identify days with air temperature measurements.

We chose variables by considering potential relevance to stream temperature and then collected much of those data from publicly accessible websites. Kooskooskie Commons interns collected stream temperature, excluding Mill Creek, and DO data. We gathered air temperature and precipitation data from Weather Underground that used measurements collected from the Walla Walla Regional Airport for The Automated Surface Observing Systems (ASOS) program. The United States Geological Survey (USGS) and Walla Walla Basin Watershed Council collected Mill Creek discharge and Mill Creek temperature data, respectively, and made them publicly available online. We assessed Mill Creek Mill Creek because it flowed into local distributary streams (Washington Water Trust 2019a). For this reason, we wanted to examine if its qualities, namely discharge and temperature, influenced distributary creek temperatures. We graphed and compared data for these factors to stream temperature data from Kooskooskie Commons. By analyzing graphical patterns and relationships, we hypothesized the effects of potential variables related to temperature in Walla Walla streams.

Results

Kooskooskie Commons used graphs to compare Walla Walla monthly maximum stream temperatures to related variables and visualize potential relationships and patterns between them. Of the variables of interest, air temperature, Mill Creek discharge, and Mill Creek water temperatures seemed to be most correlated with local Walla Walla stream temperatures. Conversely, precipitation and dissolved oxygen levels (DO) did not seem closely related to stream temperature.

Air Temperature

Although Walla Walla monthly maximum air temperatures varied more than monthly maximum stream temperatures, these variables followed similar seasonal patterns. Spring creeks source sites displayed seasonal fluctuations similar to those of air temperature (Figure 2). However, between source sites, ranges also varied.

Distributary monitoring sites portrayed a similar seasonal pattern to spring creeks and air temperature (Figure 3). However, compared to the spring creeks, distributary monitoring sites, such as those on Yellowhawk Creek, had a greater range in temperature (Figure 4). Yellowhawk Creek had more monitoring sites than other creeks in the system and therefore allowed us to more deeply analyze patterns in a single stream. Generally, months with high air temperatures, also had high stream temperatures while we also observed the reverse.

Precipitation

Precipitation data suggested an inversely proportional relationship to stream temperatures in Walla Walla. Comparing the total monthly amount of precipitation to monthly maximum stream temperatures of local creeks showed that high levels of precipitation corresponded to low creek temperatures. Similarly, months with low precipitation levels generally also had high water temperatures. However, months with precipitation measurements outside of the seasonal pattern did not have corresponding temperature measurements.

Spring creek source data from December 2014 through December 2016 demonstrated that months with low precipitation levels, had high stream temperatures (Figure 5). Including all spring creek monitoring sites also showed this pattern (Figure 6).

Graphing all distributary monitoring sites with precipitation demonstrated a pattern similar to that of spring creeks and precipitation (Figure 7). Particularly the first two years of data collection showed an inversely proportional relationship between precipitation and stream temperature. Specifically, the Garrison Creek Mouth monitoring site demonstrated that as total precipitation decreased, stream temperatures also decreased.

However, graphs of only distributary source sites with precipitation displayed conflicting results (Figure 8). While some places, such as the summer of 2015, indicated an inverse relationship, others, such as the summer of 2017, showed a direct relationship. Looking more closely at Yellowhawk Creek as an example of distributary creeks also did not clarify the relationship between total precipitation and distributary stream temperature (Figure 9). Overall, these graphs did not convey a clear connection between precipitation and local Walla Walla stream temperatures.

Dissolved Oxygen

This study compared DO and temperature from three sites along Yellowhawk Creek. Dissolved oxygen (DO) levels and stream temperature graphs did not show an easily identifiable relationship between these variables. In assessing the patterns, we also noted the small range of temperatures at each site.

Minimum DO levels demonstrated conflicting results in both 2017 and 2018. In June 2017, while YH (Yellowhawk Creek) Mouth DO levels and stream temperature seemed to be inversely proportional, these variables at YH at Rupars showed direct proportionality (Figure 10). This graph did not provide useful information for evaluating the relationship between these variables. Measurements from 2018 also did not portray a clear relationship between stream temperature and minimum DO (Figure 11).

Maximum DO levels at these three Yellowhawk Creek sites also displayed contradictory results when compared to stream temperatures at the same sites. In 2017, while DO levels demonstrated a linear pattern, stream temperatures fluctuated from high to low, to high again

(Figure 12). From May to June in 2018, maximum DO and maximum stream temperature both increased at YH at Plaza Way (Figure 13). However, at YH at the Mouth, maximum DO levels decreased slightly while stream temperatures increased.

In each of these graphs, the ranges of temperatures in these sites did not vary substantially. Maximum and minimum measurements for both years only differed by less than 5˚ during these summer months while DO levels fluctuated more between years.

Mill Creek Discharge

We observed an inverse relationship between monthly average Mill Creek discharge and stream temperature. The graph of spring creek source sites showed that seasonal variations similarly impacted Mill Creek flow and local stream temperatures (Figure 14). For example, as discharge decreased in the summer months, the stream temperatures at Kooskooskie Commons monitoring sites tended to increase. However, water flowed from Mill Creek into distributary creeks, but not spring-fed creeks. Therefore, comparing the distributary graph (Figure 15) to the spring creek graph (Figure 14) allowed Kooskooskie Commons to more easily observe the relationship between Mill Creek and distributary temperatures.

Mill Creek discharge and distributary stream temperature data often showed inverse patterns. Distributary monitoring sites and Mill Creek discharge demonstrated opposite patterns of seasonal fluctuations particularly in the first two years of data collection at Garrison Creek and Yellowhawk Creek sites (Figure 15). Considering Yellowhawk Creek on its own suggested a relationship between Mill Creek discharge and Yellowhawk Creek temperature (Figure 16). Specifically, May 2017 showed an abnormally high discharge from Mill Creek and a low stream temperature at Yellowhawk Creek at Plaza Way. This observation could be indicative of Mill Creek discharge's relationship with distributary stream temperatures.

Mill Creek Temperature

The distributary source stream temperatures demonstrated a similar pattern to that of Mill Creek temperature. As discussed in reference to discharge, Mill Creek water did not flow into spring creeks although these creeks did seem to follow similar seasonal fluctuations (Figure 17). Compared to spring creeks, distributary source temperatures showed patterns more similar to that of Mill Creek temperature (Figure 18). This graph indicated a potential relationship between water temperatures in Mill Creek and distributary streams.

Discussion

These graphs suggested that air temperature and two aspects of Mill Creek, a water source for many of these streams, discharge and temperature, impacted Walla Walla stream temperatures. Stream temperature, air temperature, precipitation, Mill Creek discharge, and Mill Creek stream temperatures graphs generally followed seasonal patterns while dissolved oxygen (DO) graphs did not. With the limited data, we could not make definitive conclusions about the relatedness of these variables to stream temperatures in Walla Walla, but we hypothesized that air temperature, Mill Creek discharge, and Mill Creek temperature influenced stream temperatures. Conversely, we did not hypothesize causality between precipitation and stream temperatures or DO and stream temperatures. Additional data, over more years with increased consistency, would promote a deeper understanding of this system, however these hypotheses can guide future research and project implementation.

Air temperatures likely impacted to stream temperatures because both variables displayed similar patterns; however, the exact connection between these factors could not be interpreted from these graphs. In the summer, both temperatures increased, while they decreased again in the winter and fluctuated between extremes throughout the spring and fall. Air temperature significantly impacts water temperature (Mohseni and Stefan 1999; Ficklin et al. 2013) and we aimed to demonstrate this relationship in Walla Walla creeks. However, we were unable to distinguish between the multiple ways in which air temperature could have impacted water temperature from these graphs. For example, direct solar radiation could influence water temperature. This pathway would not necessitate a direct effect of the air on the water. Another possibility would be the conduction of heat from the air to the water, linking air temperature to water temperature. Alternatively, solar radiation could heat riparian areas and thereby influence stream temperatures through conduction from the heated ground. It is also likely that a combination of these pathways impacted streams. Future experimental studies could work to distinguish between the effects of these pathways and lead to a better understanding of this relationship. Nevertheless, the similarity between the patterns in these graphs led us to hypothesize that air temperatures affect stream temperatures.

These graphs did not clearly indicate a direct causal pathway between precipitation and stream temperatures. In-stream water can come from precipitation, which can impact temperature, however streams also receive water from a variety of other sources (Poole and Berman 2001). In Walla Walla, hot and dry summers had low levels of precipitation while cold winters received high levels. In this way, seasonal variations affected precipitation and temperature patterns similarly. Our graphs did not distinguish this pathway from another possibility where the amount of water added through precipitation affected temperature. The former relationship seemed more likely because of air temperature's potential influence on both total monthly precipitation and monthly maximum stream temperatures. Additionally, while stream temperatures largely followed regular seasonal fluctuations, multiple months, such as July 2016, fell outside of this pattern (Figure 5). When these unexpected peaks and valleys occurred, stream temperatures did not have corresponding measurements. From these observations, we hypothesized that precipitation did not heavily drive creek temperatures.

In an air temperature graph and a precipitation graph, one site followed a different pattern likely because it monitored a pond rather than a stream. The Rutzer Property site did not show seasonal fluctuations, rather it had a more consistent pattern throughout the year and a smaller range than other sites. The observed abnormalities at this site could be because it was not a continuously flowing stream. Rather, this waterway was a spring-fed pond, where the addition of cool spring water seemed to keep temperatures consistently low. The data demonstrated that the Rutzer Spring Pond had more consistent water temperatures compared to local spring fed streams which we could attribute to the difference in category of waterway.

The graphs demonstrated that stream temperature likely did not influence dissolved oxygen (DO) levels in these creeks. However, the limited sample size of DO data also made extrapolating relationships difficult. While we considered both maximum and minimum DO levels, minimum DO levels would have been more informative in relation to elevated stream temperatures because of their inverse relationship (Truesdale and Downing 1954). The minimum would also have been more relevant to the improvement of fish habitat (Carter 2005). Although we expected DO levels to decrease as water temperatures increased, we found conflicting results. Within these datasets, a few months demonstrated this inverse relationship between temperature and DO but others suggested a direct relationship between the variables. However, other factors such as pressure, salinity, and level of chemical and biological processes also impact DO levels but because Kooskooskie Commons did not measure these other qualities, we did not know their effects. Additionally, detecting significant changes in DO levels potentially required larger temperature ranges (Wetzel 2001). For example, in Wetzel's study, the difference from 0˚C to 30˚C yielded a change of only 8mg/L to 15mg/L, a 7mg/L shift. In comparison, stream temperatures at our DO sites along Yellowhawk Creek only differed by 5˚. This relatively small difference in water temperature did not show the expected corresponding changes in DO levels. Given that these stream temperatures varied minimally, potentially because data only existed from summer months, this variable may have had little influence on DO compared to other, unstudied factors during these months. Thus, within the larger context of promoting migratory fish habitat, DO may not need to be closely monitored in this creek because these graphs do not show its tight association with stream temperature.

Similar to the effects of precipitation, the causality between Mill Creek discharge and other stream temperatures could not be determined, but the graphs did show a correlation between them. We included spring creeks, which received water from springs, even though Mill Creek discharge did not directly influence them. Instead, we graphed these variables to compare distributary creeks to. Multiple pathways could have linked Mill Creek discharge to distributary stream temperatures. For example, if the volume of water flowing from Mill Creek directly influenced distributary creek temperatures, then these variables would be causally linked. Another possibility would be that both factors displayed similar patterns because seasonal variations affected them in similar ways, because in the winter, temperatures tended to be cooler when Mill Creek also had more water and elevated discharge levels. In this pathway, Mill Creek discharge did not influence stream temperatures. However, abnormally high Mill Creek discharge levels and correspondingly low stream temperatures in two sites along distributary creeks in March 2017 provided evidence for a direct connection between these variables (Figures 15 and 16). The addition of water into streams, whether from another waterway or from groundwater, affect distributions of fish (Chu et al. 2008), potentially indicating discharge's influence on water qualities, such as temperature. From these observations, we hypothesized that Mill Creek discharge influenced local stream temperatures and should be a continued area of study. However, the increased discharge would only have correlated to decreased temperatures if Mill Creek temperatures remained low as it flowed into distributaries. Therefore, we discuss this variable next.

Another aspect of Mill Creek, temperature, also potentially influenced distributary stream temperatures; however other stream characteristics that we not study could be considered. While spring creeks and distributaries both followed similar seasonal temperature patterns, two distributary streams, Yellowhawk Creek and Garrison Creek temperatures lined up more closely with Mill Creek temperatures than spring creek temperatures did. Because Mill Creek flowed into distributaries but not spring creeks, this observation potentially demonstrated Mill Creek stream temperature's differential relationship to distributary temperatures versus spring creek temperatures. However, similar to the discussion of Mill Creek discharge, these graphs made it difficult to extrapolate the overall impact of Mill Creek, including water temperature, on these creeks. For instance, other qualities of Mill Creek, such as depth and flow rate, could have been more similar to distributaries than spring creeks and could have contributed to the similarity of these temperature patterns. Nevertheless, patterns in these graphs led to the hypothesis that Mill Creek temperatures influenced distributary stream temperatures.

Limited by inconsistent data, we used these graphs to make tentative connections between these variables and stream temperatures. One drawback arose from the establishment of monitoring sites. Kooskooskie Commons defined stream sources as the furthest points from the point of discharge and the mouths as the points of discharge into a larger body of water. Although we often labelled monitoring sites as sources or mouths in this study, they varied in their exact placement, with some monitoring sites at the stream sources or mouths and others varying in distances of up to half a kilometer away. These disparities resulted from limited access to streams and the necessity of landowner approval to place the TidbiT and access their land for subsequent data collection visits. This imprecision resulted in inaccurate comparisons between similar locations along streams. For example, a graph of spring creek sources may not have truly compared temperatures at these locations. Furthermore, while we established some sites at the onset of the project, we only retained a subset of these while we added others throughout the project. Additional data gaps resulted from inconsistent data collection practices caused by frequent staff changes, occasional datalogger failures, and occurrences of dry streams. For these reasons, our conclusions consist of hypotheses about stream temperature in this drainage to inform future research directions.

To increase the reliability of results, Kooskooskie Commons could benefit from increased standardization of data collection methodology and organization in future monitoring projects. At times, Kooskooskie Commons had limited staffing, and therefore could not collect data. Little overlap between researchers also resulted in incomplete transitions of methodology. Moving forward, Kooskooskie Commons could standardize data entry methods with a detailed metadata to increase the consistency of collection. Alternatively, if Kooskooskie Commons cannot guarantee regular site visits, the variables under study may need to be reevaluated or the tools used to measure them could be upgraded. This study may have shown that DO, for example, may not have to be closely monitored in Yellowhawk Creek due to low stream temperature variability. Implementing durable monitors that can persist in the streams and reliably collect the desired data throughout the year would also be optimal. However, if monitors cannot persist in-stream for extended periods of time, perhaps Kooskooskie Commons may then benefit from prioritizing certain months for data collection. For instance, if summer months provided the most valuable information on rising water temperatures, then focusing on those months could be both more attainable and informative in the long term. Thus, Kooskooskie Commons could analyze the success of riparian restoration projects using multiple summers of consistent data. Maintaining these priorities may assist the organization in increasing data quality as well as in conducting deeper analyses to make more definitive conclusions about variables related to Walla Walla stream temperatures in the future.

The ecological and cultural importance of these stream temperatures emphasize the necessity of continued research. In the face of global climate change, aquatic organisms, such as Chinook salmon in the Pacific Northwest, live in increasingly threatening habitats. Understanding the variables affecting water quality, particularly temperature, will assist in the creation of effective conservation programs. The riparian restoration projects that Kooskooskie Commons and other organizations have focused on contribute to efforts to increase the viability of local streams and create habitat for ecologically and culturally significant organisms.

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Table 1. Kooskooskie Commons Monitoring Site Locations. Shortened labels of monitoring sites are provided alongside their longer title. “Source” locations refer to the furthest place along that stream from its estuary or confluence with another creek while “Mouth” locations indicate where the creek discharges. Spring-fed and distributary creeks are distinguished under the Stream Type column. Latitude and longitude coordinates indicate exact locations of monitoring sites.

Label	Full Name	Stream Type	Latitude	Longitude
BUTMO	Butcher Creek at the Mouth	Spring	46.0658	-118.3533
BUTSO	Butcher Creek at the Source	Spring	46.0764	-118.3269
CALDM	Caldwell Creek at the Mouth	Spring	46.0343	-118.3328
CALDS	Caldwell Creek at the Source	Spring	46.0485	-118.3041
COTPR	Cottonwood Creek at Plaza Way	Distributary	46.0259	-118.3462
GARMO	Garrison Creek at the Mouth	Distributary	46.0278	-118.4295
GARRS	Garrison Creek at the Source	Distributary	46.0723	-118.2844
LASCB	Lassiter Creek at Burns Property (Source)	Spring	46.0193	-118.3488
LASOM	Lassiter Creek at the Mouth	Spring	46.0258	-118.3724
LINMO	Lincoln Creek at the Mouth	Spring	46.0668	-118.3587
LINSO	Lincoln Creek at the Source	Spring	46.0654	-118.3211
RUSPR	Russell Creek at Plaza Way	Distributary	46.0294	-118.3447
RUTZP	Rutzer Spring Pond	Spring	46.0303	-118.3543
STOMO	Stone Creek at the Mouth	Spring	46.0339	-118.3818
STONS	Stone Creek at the Source	Spring	46.0586	-118.3105
TITMO	Titus Creek at the Mouth	Distributary	46.0785	-118.2750
WHIRU	Whitney Creek at Rupar Property	Spring	46.0303	-118.3566
WHISP	Whitney Creek at the Source	Spring	46.0328	-118.3530
YELAC	Yellowhawk Creek at Alder (Source)	Distributary	46.0675	-118.2882
YELMO	Yellowhawk Creek at the Mouth	Distributary	46.0169	-118.4006
YELPR	Yellowhawk Creek at Plaza Way	Distributary	46.0327	-118.3447
YELRU	Yellowhawk Creek at Rupar Property	Distributary	46.0285	-118.3597

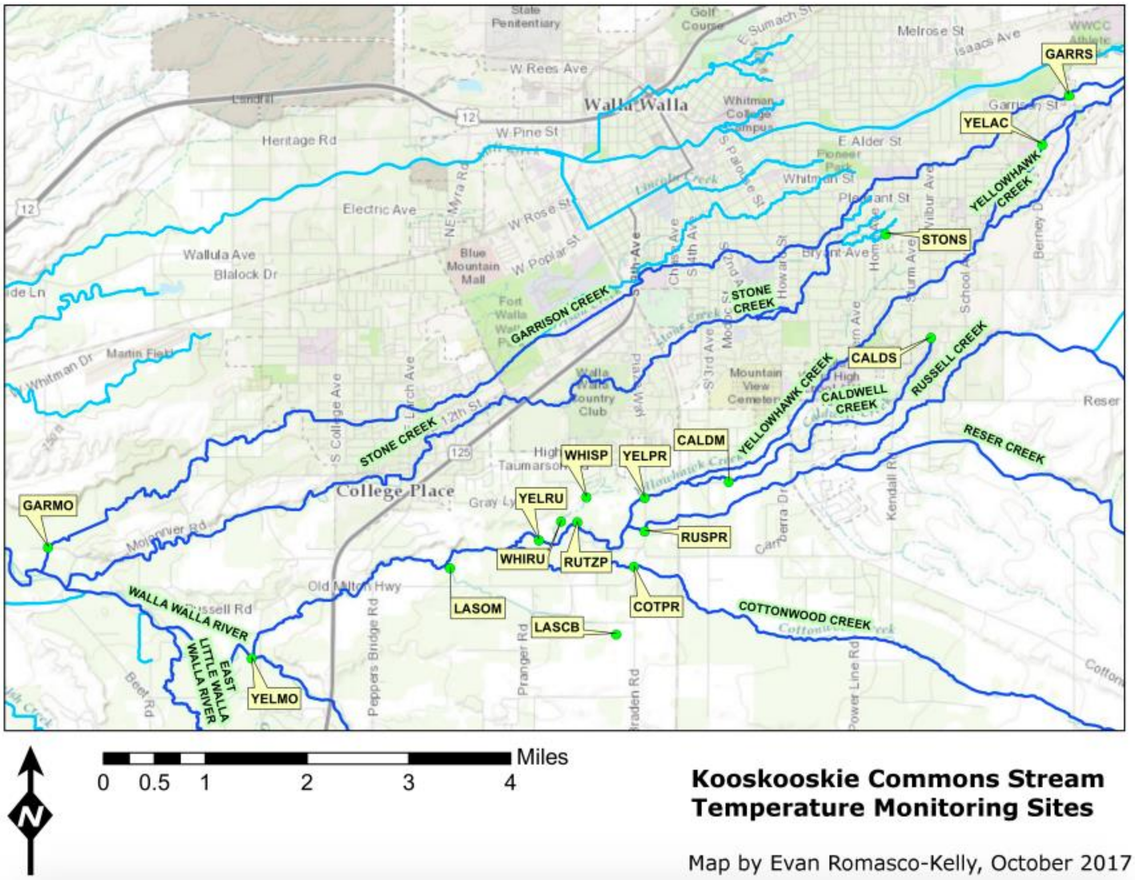

Figure 1. Map of Current Kooskooskie Commons Monitoring Sites. Streams are highlighted with the specific locations of data collection at the bright green dots and labeled.

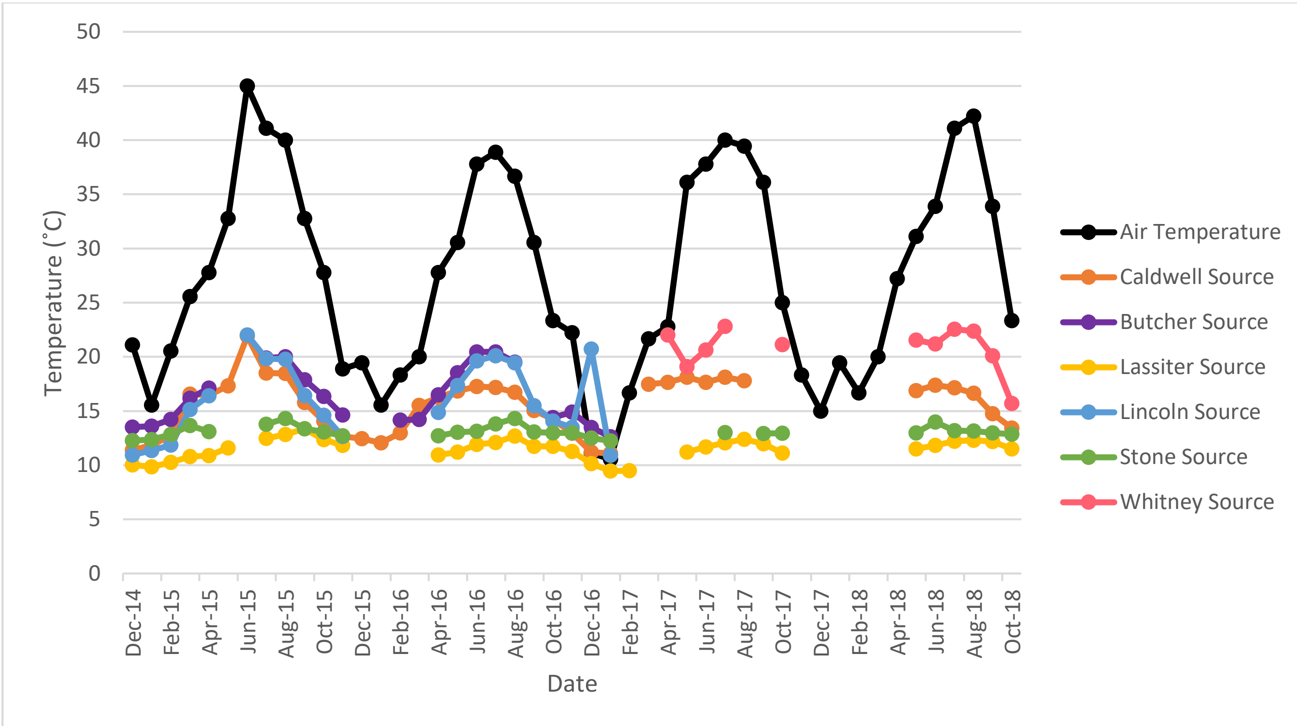

Figure 2. Maximum air temperature compared to maximum stream temperature at spring creek source sites. Monthly maximum stream temperatures at the monitoring sites located at spring creek sources were graphed in relation to monthly average Walla Walla air temperature displayed in black over the same time.

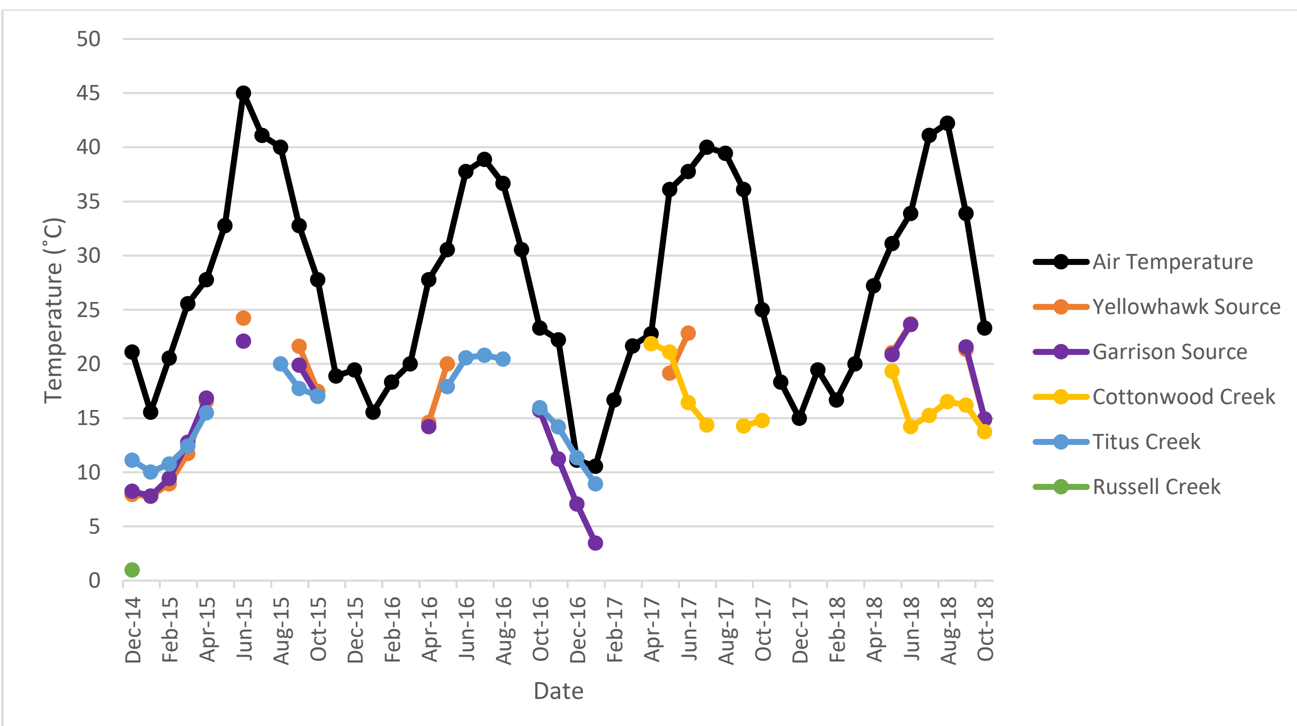

Figure 3. Maximum air temperature compared to maximum stream temperature at distributary source sites. Monthly maximum stream temperatures at monitoring sites for distributary sources were graphed against monthly average Walla Walla air temperature displayed in black over the same time.

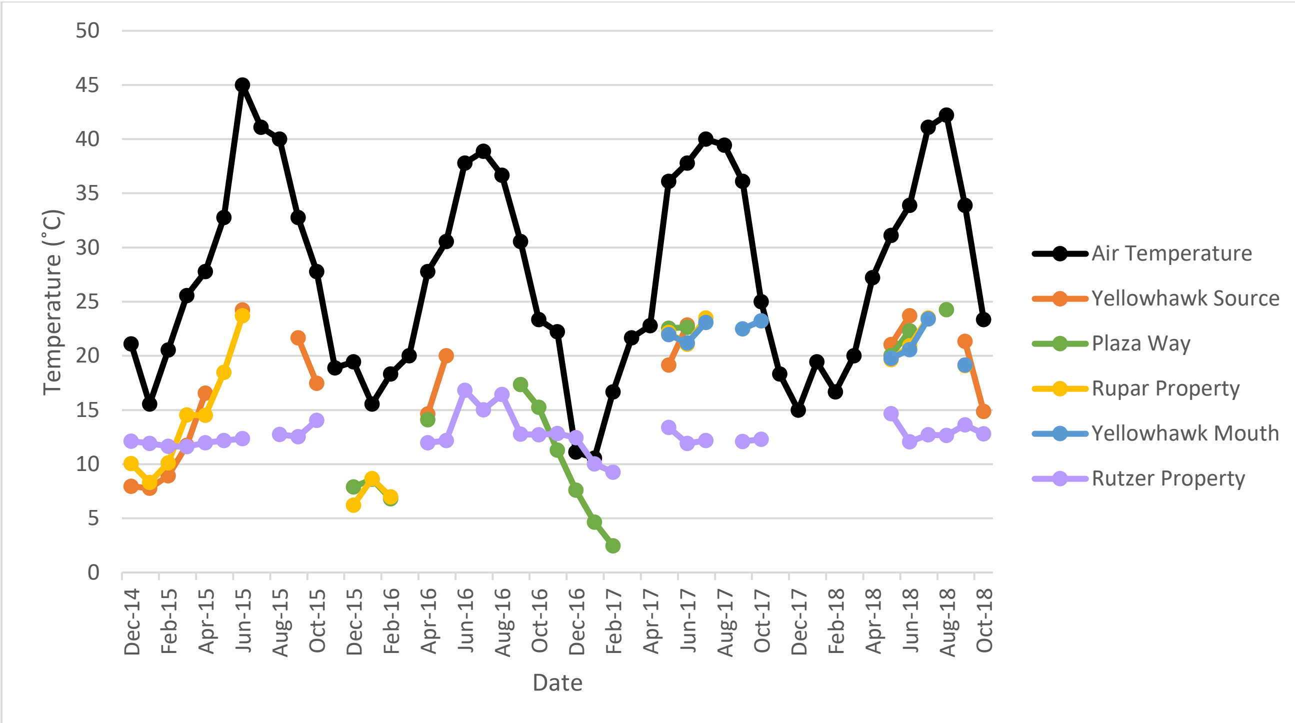

Figure 4. Maximum air temperature compared to maximum stream temperature for Yellowhawk Creek sites. Monthly maximum stream temperatures at Yellowhawk Creek monitoring sites were graphed against monthly average Walla Walla air temperature displayed in black over the same time.

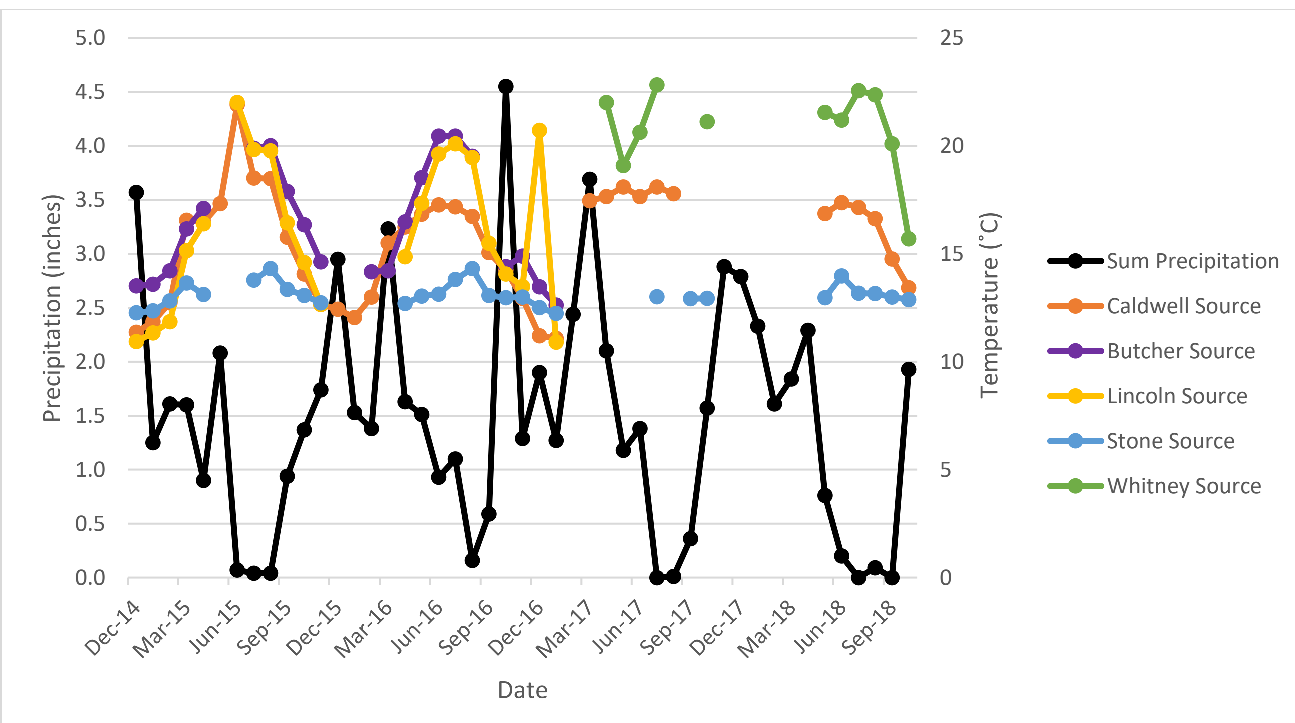

Figure 5. Total monthly precipitation compared to maximum stream temperature at spring creek source sites. Monthly maximum stream temperatures at spring creek source monitoring sites were graphed against the monthly sum of precipitation in Walla Walla displayed in black across the same time.

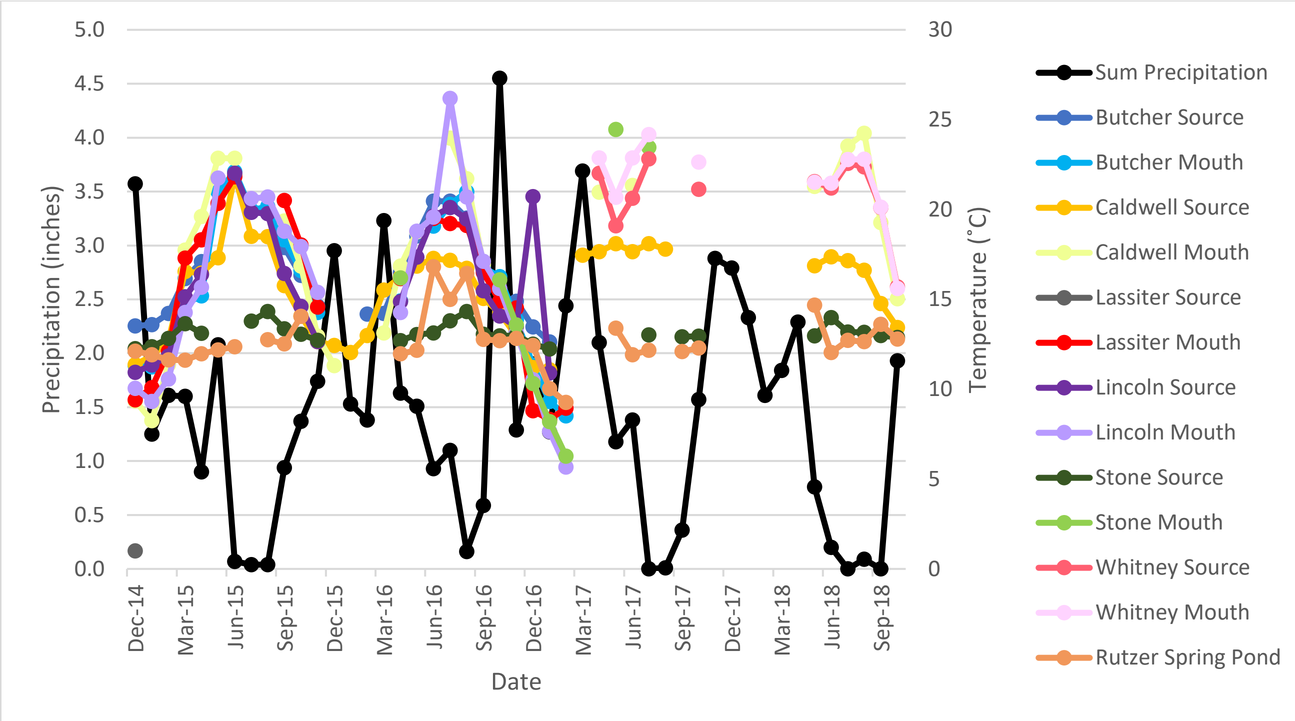

Figure 6. Total monthly precipitation compared to maximum stream temperature at all spring creek sites. Monthly maximum stream temperatures from all spring creek monitoring sites were graphed against the monthly sum amount of precipitation in Walla Walla displayed in black across the same time.

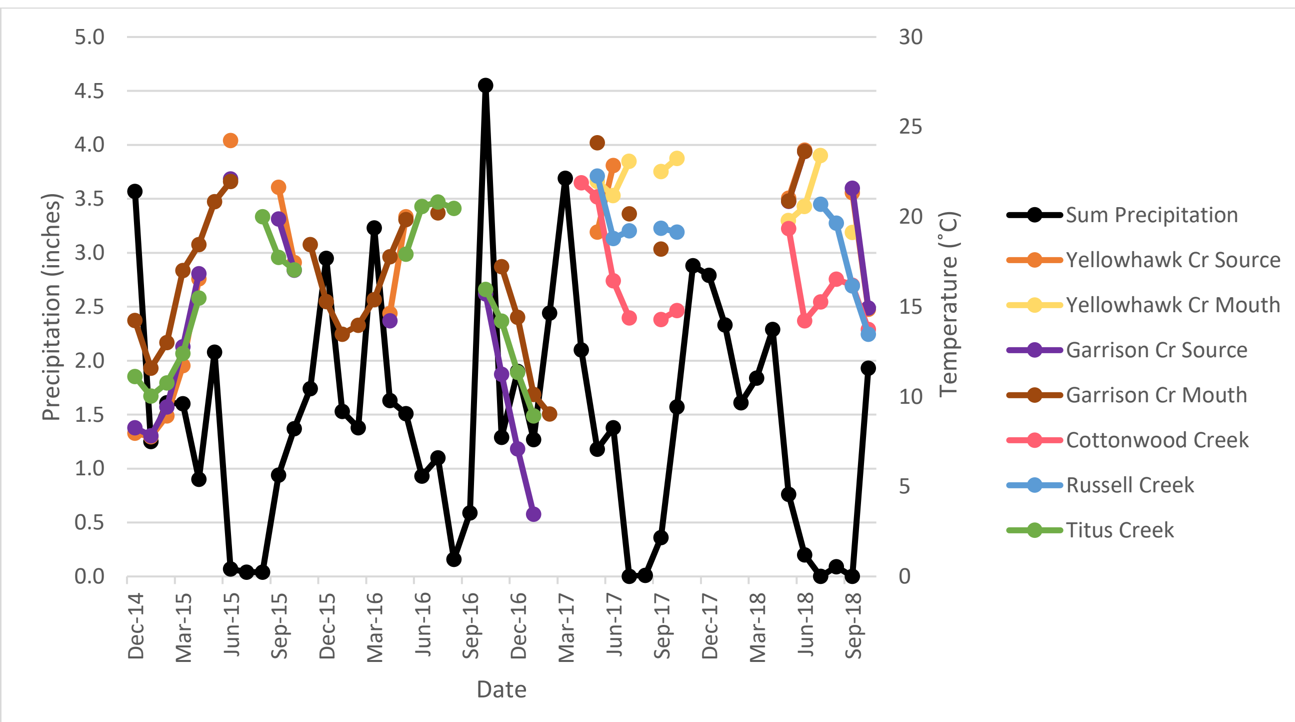

Figure 7. Total monthly precipitation compared to maximum stream temperature at all distributary sites. Monthly maximum stream temperatures from all distributary monitoring sites were graphed against the monthly sum precipitation in Walla Walla displayed in black across the same time.

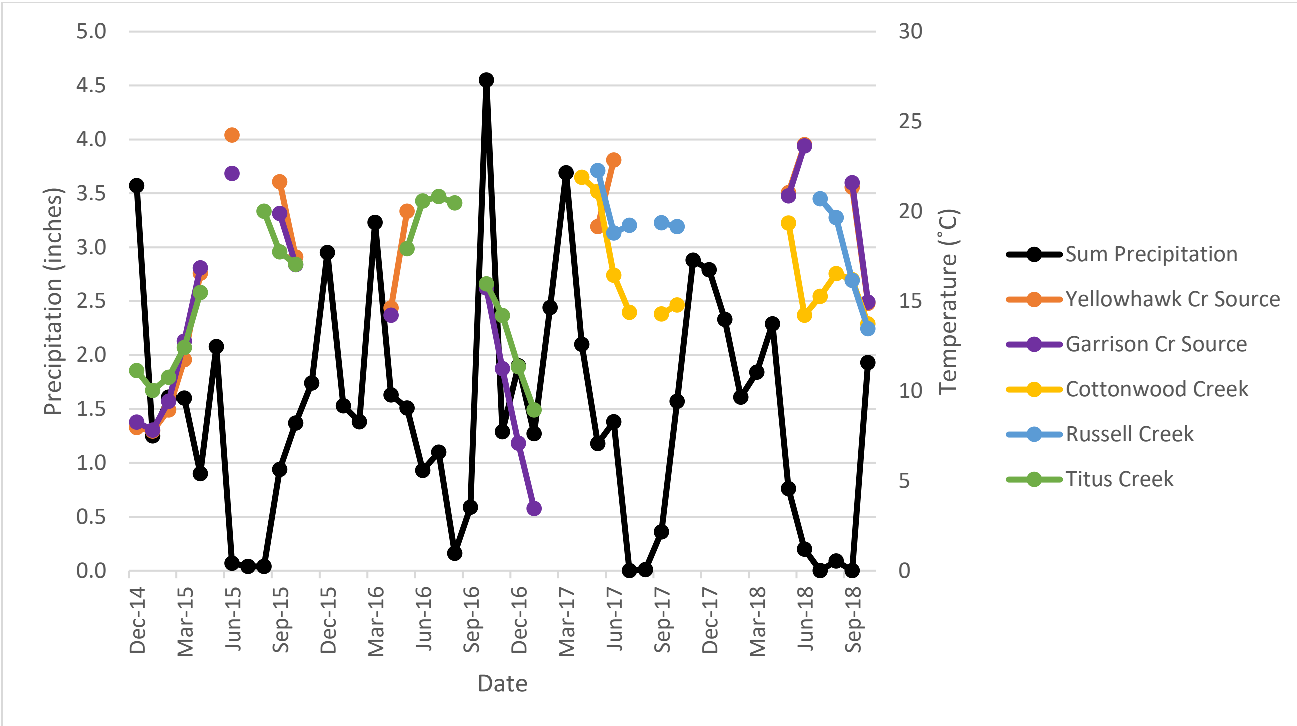

Figure 8. Total monthly precipitation compared to maximum stream temperature at distributary source sites. Monthly maximum stream temperatures from distributary source monitoring sites were graphed against the monthly total precipitation in Walla Walla displayed in black across the same time.

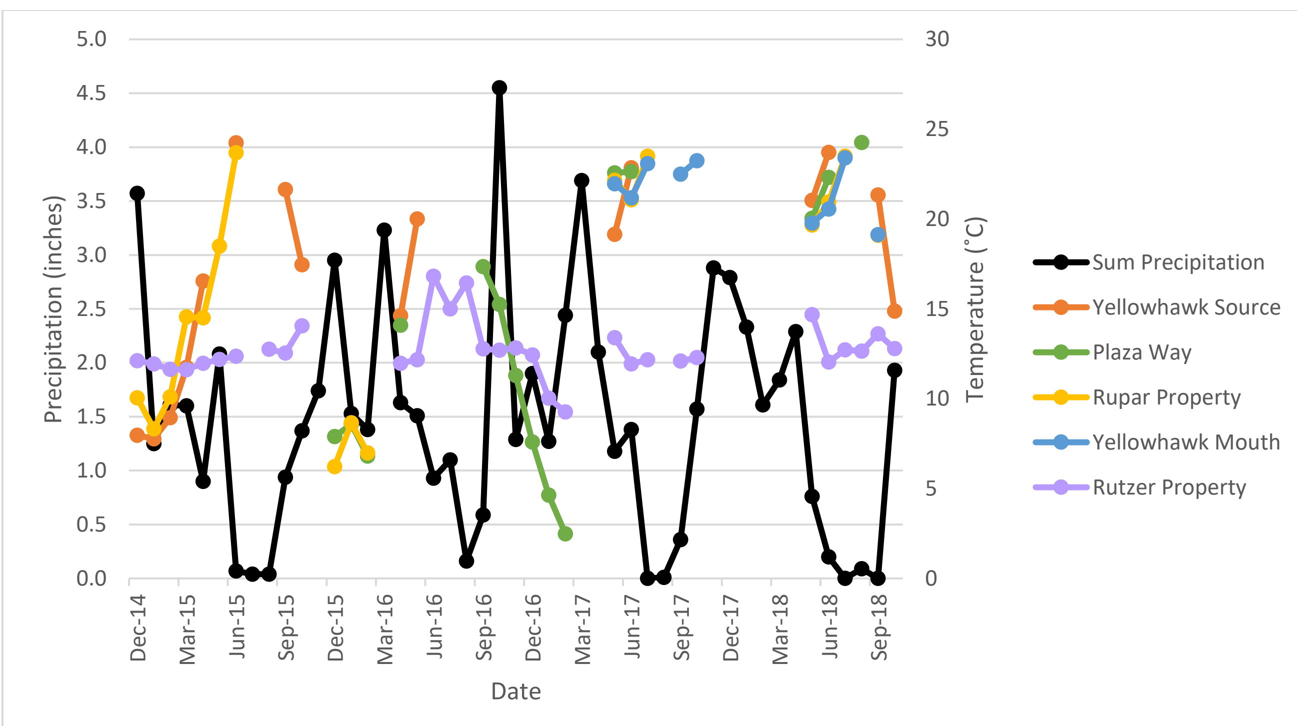

Figure 9. Total monthly precipitation compared to maximum stream temperature at Yellowhawk Creek sites. Monthly maximum stream temperatures from all Yellowhawk Creek monitoring sites were graphed against the monthly total amounts of precipitation in Walla Walla displayed in black over the same time.

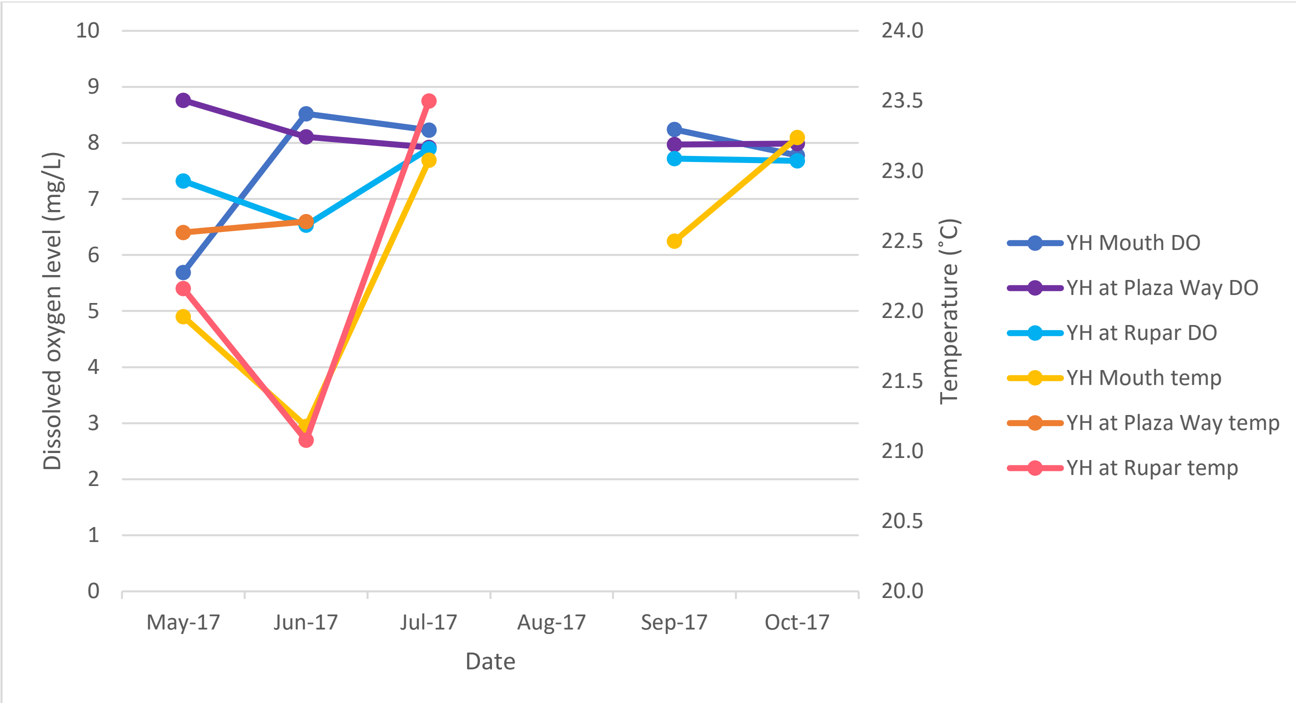

Figure 10. Minimum dissolved oxygen levels compared to maximum stream temperature at three Yellowhawk Creek sites in 2017. Monthly minimum dissolved oxygen levels are displayed in cooler colors (blues and purple) while the maximum stream temperatures are displayed in warmer colors (yellow, orange, and pink). These three sites represent Yellowhawk at the Mouth, Yellowhawk at Plaza Way, and Yellowhawk on Rupar Property.

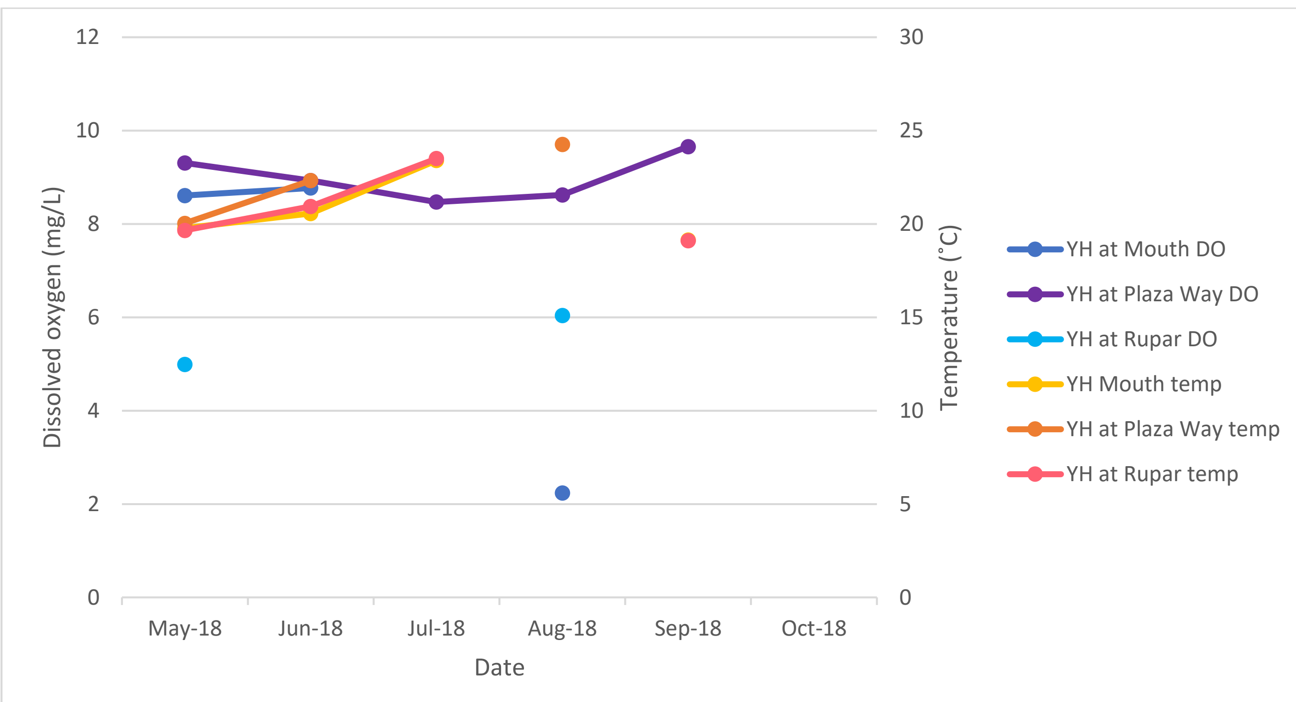

Figure 11. Minimum dissolved oxygen levels compared to maximum stream temperature at three Yellowhawk Creek sites in 2018. Monthly minimum dissolved oxygen levels are displayed in cooler colors (blues and purple) while the maximum stream temperatures are displayed in warmer colors (yellow, orange, and pink). These three sites represent Yellowhawk at the Mouth, Yellowhawk at Plaza Way, and Yellowhawk on Rupar Property.

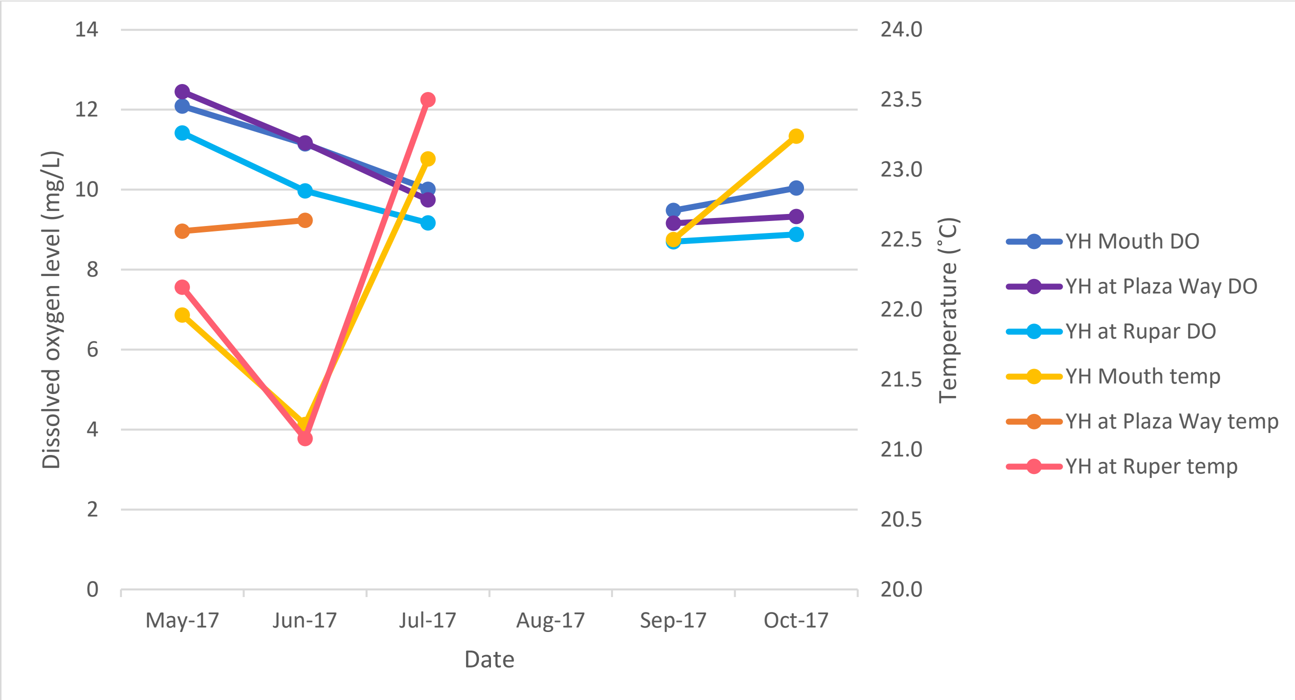

Figure 12. Maximum dissolved oxygen levels compared to maximum stream temperature at three Yellowhawk Creek sites in 2017. Monthly maximum dissolved oxygen levels are displayed in cooler colors (blues and purple) while the maximum stream temperatures are displayed in warmer colors (yellow, orange, and pink). These three sites represent Yellowhawk at the Mouth, Yellowhawk at Plaza Way, and Yellowhawk on Rupar Property.

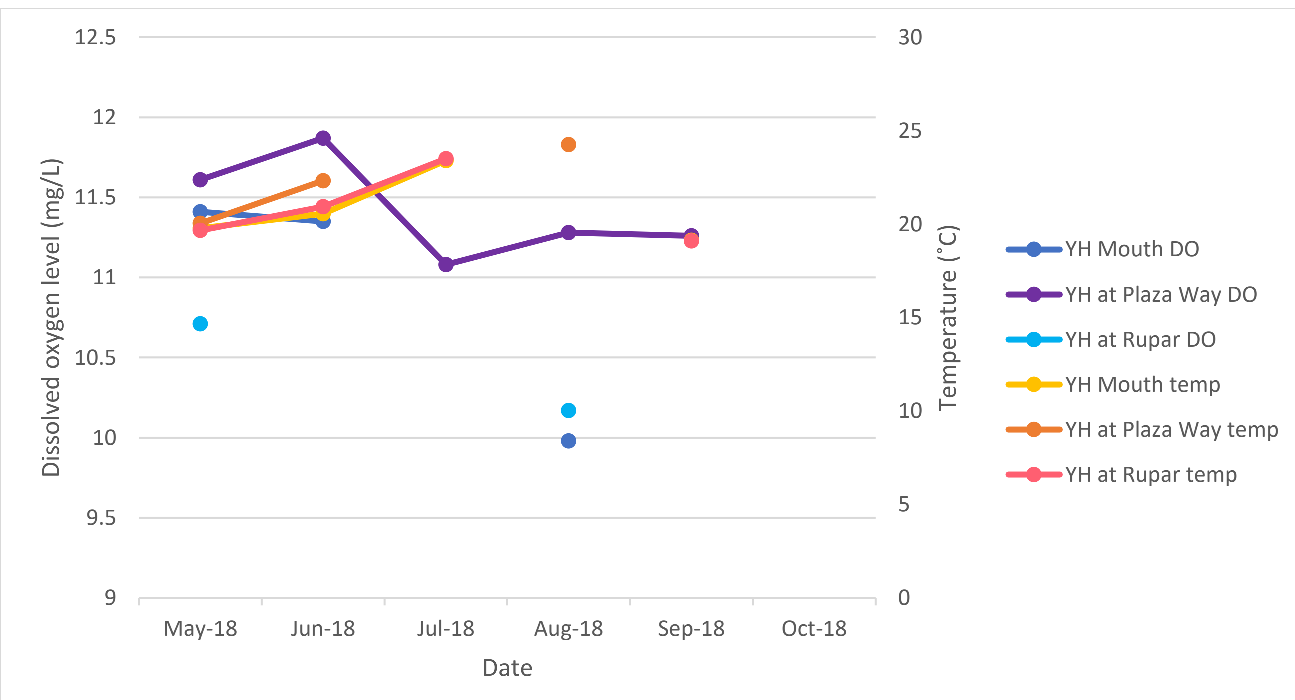

Figure 13. Maximum dissolved oxygen levels compared to maximum stream temperature at three Yellowhawk Creek sites in 2018. Monthly maximum dissolved oxygen levels are displayed in cooler colors (blues and purple) while the maximum stream temperatures are displayed in warmer colors (yellow, orange, and pink). These three sites represent Yellowhawk at the Mouth, Yellowhawk at Plaza Way, and Yellowhawk on Rupar Property.

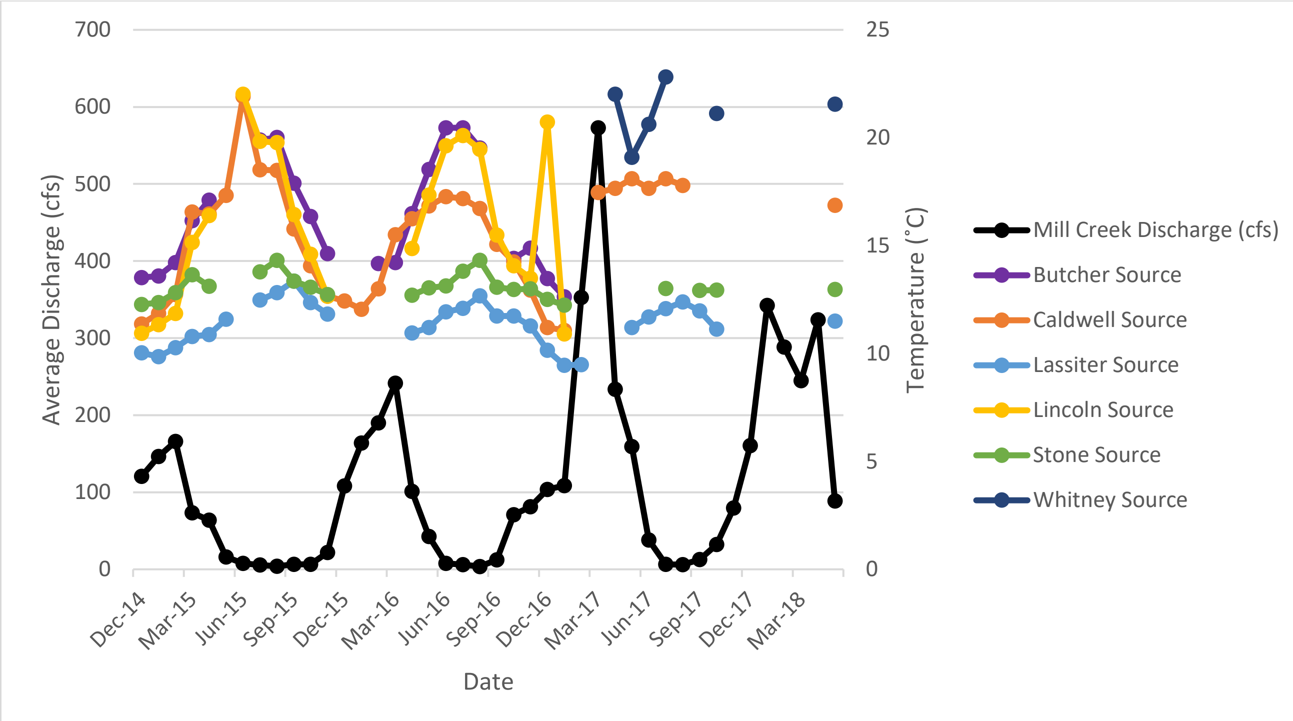

Figure 14. Monthly average Mill Creek discharge compared to maximum stream temperature at spring creek source sites. Monthly maximum stream temperatures from spring creek source monitoring sites were graphed against monthly average Mill Creek discharge displayed in black across the same time.

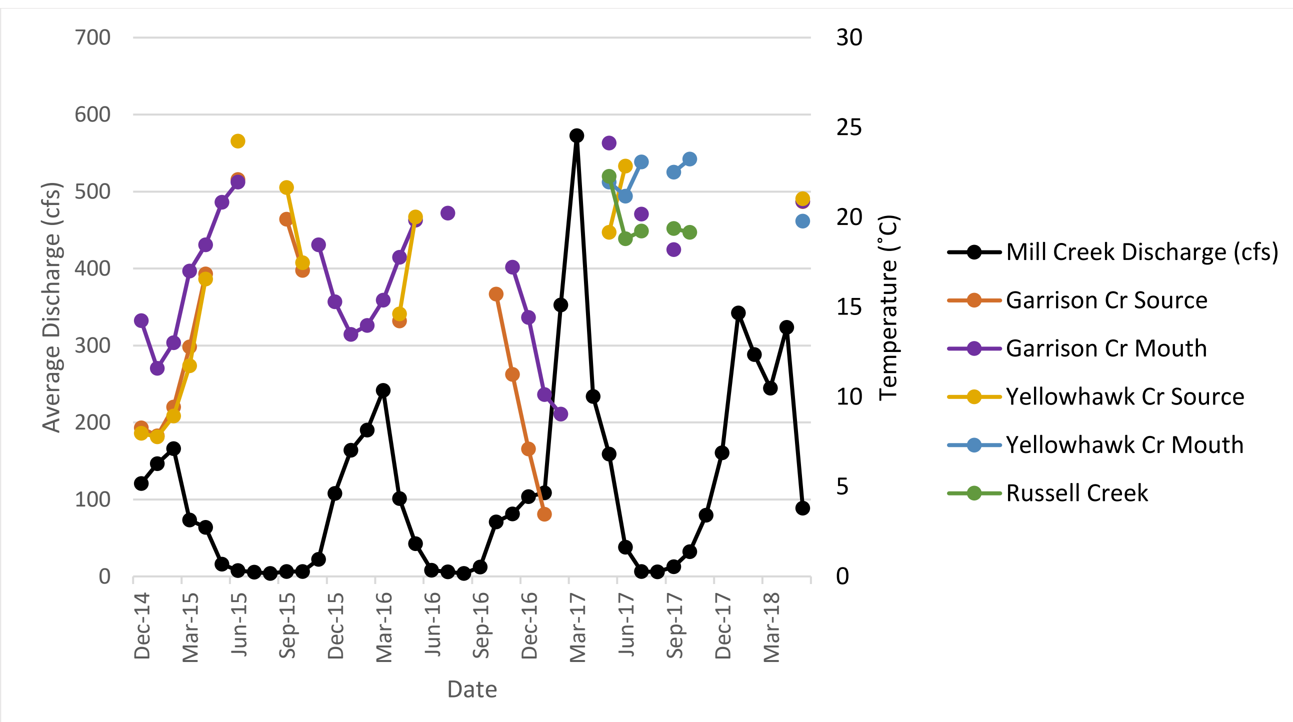

Figure 15. Monthly average Mill Creek discharge compared to maximum stream temperature at all distributary sites. Monthly maximum stream temperatures for all distributary monitoring sites were graphed against monthly average Mill Creek discharge displayed in black across the same time.

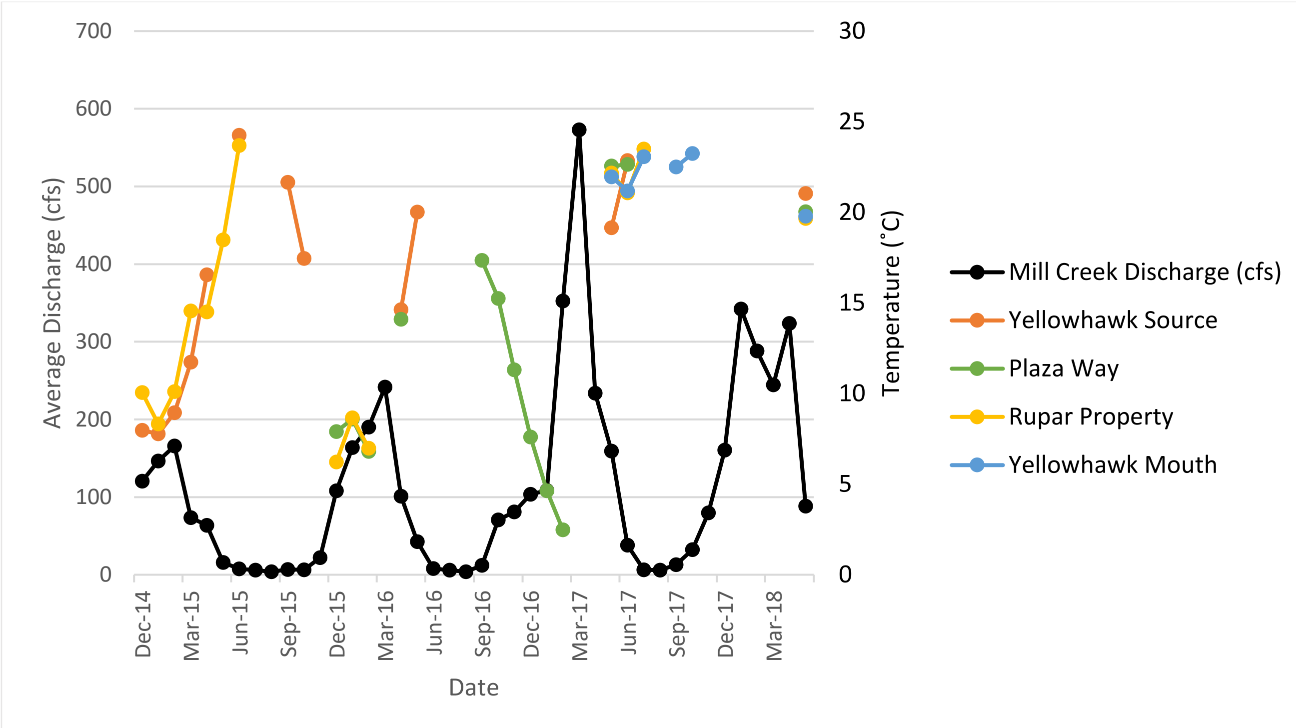

Figure 16. Monthly average Mill Creek Discharge compared to maximum stream temperature at Yellowhawk Creek sites. Monthly maximum stream temperatures at all Yellowhawk Creek monitoring sites were graphed against monthly average Mill Creek discharge displayed in black across the same time.

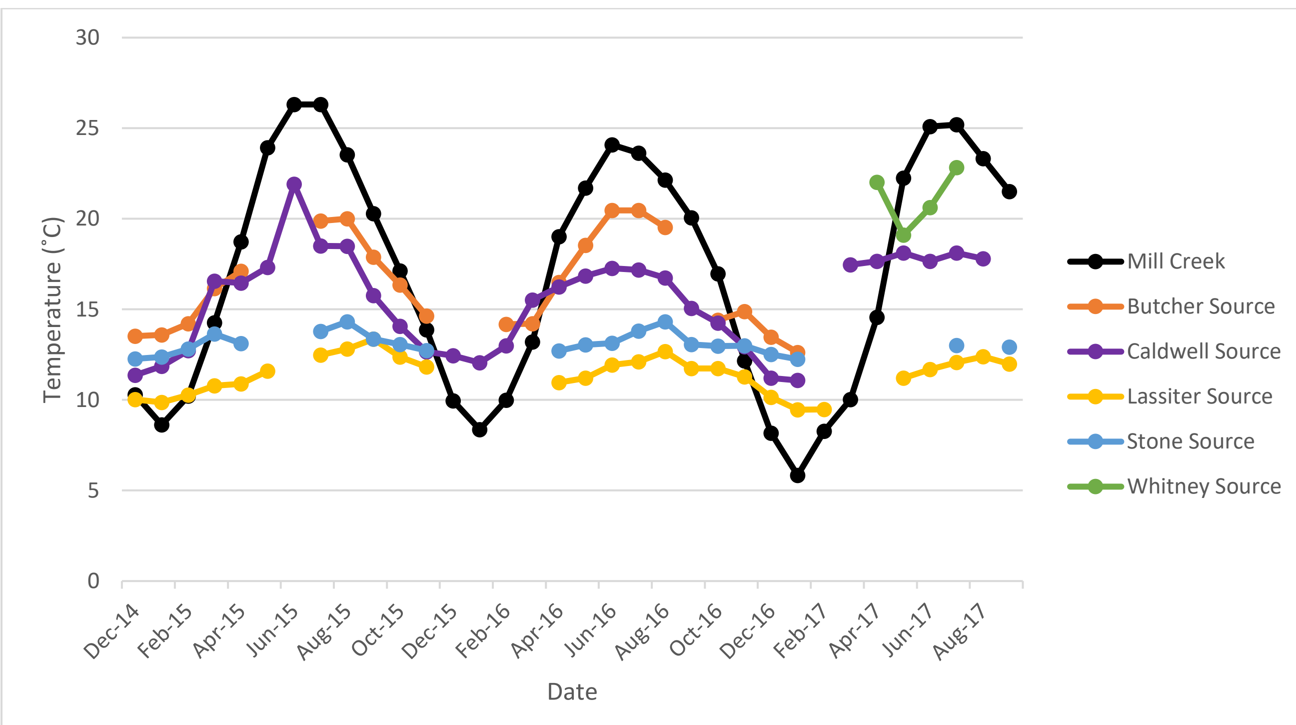

Figure 17. Monthly average Mill Creek stream temperature compared to maximum stream temperature at spring creek source sites. Monthly maximum stream temperatures at spring creek source monitoring sites were graphed against monthly average Mill Creek stream temperatures displayed in black across the same time.

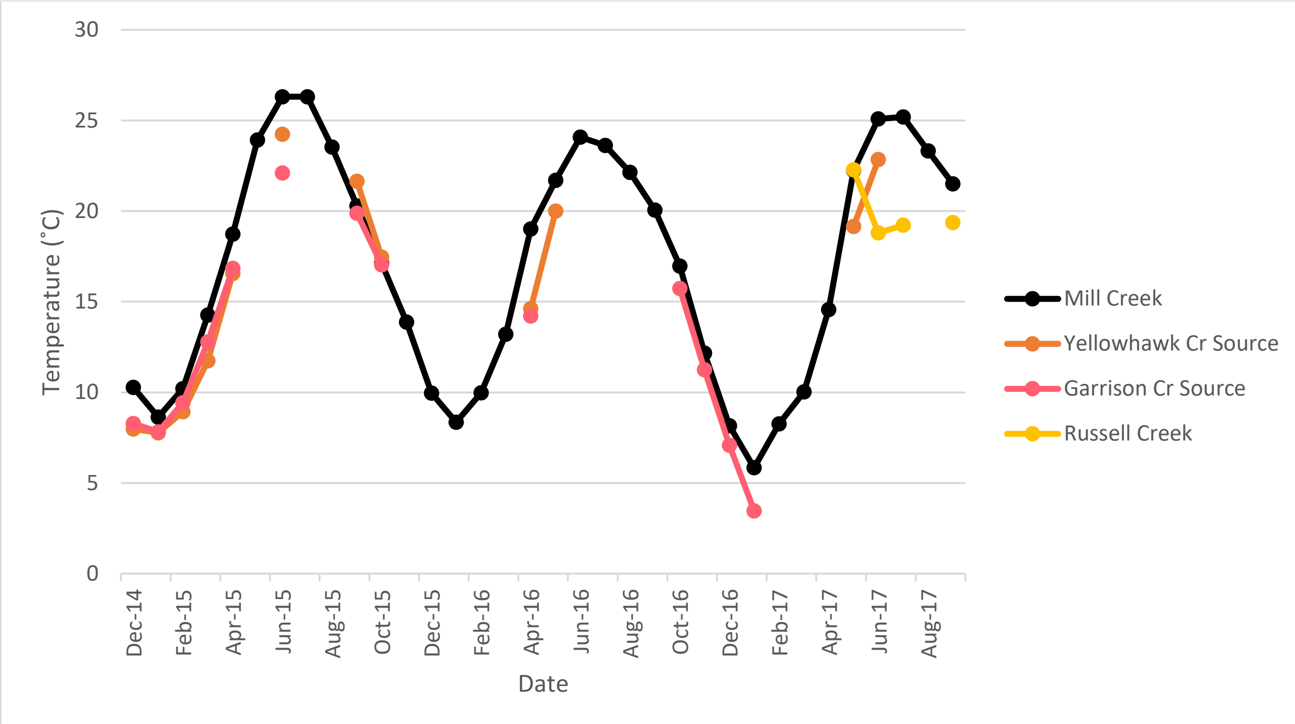

Figure 18. Monthly average Mill Creek stream temperature compared to maximum stream temperature at distributary source sites. Monthly maximum stream temperatures from distributary monitoring sites were graphed against monthly average Mill Creek stream temperatures displayed in black across the same time.