FRESHWATER TEMPERATURE TREND IN THE INTENSIVELY MONITORED WATERSHED OF THE MIDDLE FORK JOHN DAY RIVER, OREGON

By

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Abstract

Stream restoration is a rapidly developing field, and effectiveness monitoring is critical for informing restoration design and identifying adaptive management opportunities. Stream temperature is a driver of many ecological processes in aquatic environments and has been identified as a limiting factor for juvenile salmonids in many systems in the Pacific Northwest. Therefore, my study investigated temperature trends at 86 temperature monitoring locations in the Middle Fork John Day River, Oregon – a watershed which has been the subject of intense restoration efforts over the last 15 years. I performed trend analysis for the months of July, August, and September, using response metrics of total degree hours and degree hours above the temperature threshold causing stress to juvenile salmonids. These two metrics were examined using both unadjusted values and by adjusting values for annual variation in streamflow and air temperature. Many sites did not exhibit significant trends during the period of record. Results for unadjusted temperature metrics were dominated by tributary locations, had a relatively even distribution between increasing and decreasing trends, and decreasing trends were generally not located in restoration reaches. Flow and air temperature adjusted metrics were more evenly distributed between mainstem and tributary locations, were mostly decreasing, and a greater proportion of trends were located in restoration reaches. The relatively small number of significant trends compared to the number of tests performed indicates that the system is generally temperature-stable. Tributary systems dominate temperature metrics that are not adjusted for air temperature and stream flow, and may be more sensitive to external influences and annual variation of external drivers. Lastly, the temperature-mitigating effects of restoration tend to emerge after accounting for stream flow and air temperature, suggesting that restoration efforts currently have less influence over stream temperature than fluctuations in annual climate. Some of the benefits of restoration may take additional time to be realized and continued monitoring will be necessary to capture long-term effects. Historic trends in stream flow and air temperature, as well as projections of future climate conditions, suggest that restoration effectiveness will need to increase to outpace the influence of background climate effects.

INTRODUCTION

Background

Salmonid habitat restoration in the United States' Pacific Northwest (PNW) is an expansive but relatively young field, largely fomented by the precipitous decline of anadromous salmonid populations during the mid-20th century and subsequently burgeoning into the billion-dollar industry that exists today (Rice 2019). As the body of knowledge concerning salmonid restoration has developed, so too have restoration strategies at the reach, sub-watershed, and watershed scale. The earliest restoration attempts in the PNW sought to replicate techniques developed in the eastern portion of the US, focused on creating additional fish cover, and resulted in varying levels of success (Roni and Beechie 2013). The gradual refinement of these techniques over the following 50 years produced the strategy that is most commonly observed today, which eschews the "one-size-fits-all" approach and instead seeks to identify, and remedy, the specific salmonid-limiting factors within a given focal area.

In-stream temperature is one of the most ubiquitous limiting factors of salmonids in North America (Beschta and Taylor 1988; Mohseni et al. 1999). As such, restoration design frequently includes actions intended to mitigate altered temperature regimes which have resulted from anthropogenic habitat changes. Temperature mitigation practices include floodplain reconnection, riparian protection and enhancement, irrigation efficiency, tributary connectivity, and water-rights leasing (Confederated Tribes of Warm Springs 2015). Of these, riparian protection and enhancement is the most prominent and is understood to have the greatest potential for mitigating altered temperature regimes (Johnson 2004; Rutherford et al.

1997), especially in the PNW where agriculture and timber harvest have been significant contributors to widespread deterioration of riparian condition (Beschta and Taylor 1988; Janisch et al. 2012).

Monitoring the effects of restoration activities is an essential component of the resource-management process. It is important to identify if changes in limiting factors have occurred and, when possible, determine if these changes can be attributed to restoration. The purposes of monitoring activities are manifold; they allow for evaluation of restoration techniques, inform the restoration design process, and help identify where adaptive management is required to meet ecological objectives. In this analysis, I examine in-stream temperature trend at 86 unique monitoring stations within the Middle Fork John Day River (MFJDR), a watershed which has received extensive salmonid-focused restorative treatment over the last 20 years.

Temperature

Stream temperature is an important characteristic of lotic systems that governs physiological conditions of aquatic organisms including fish (Isaak et al. 2017; Sullivan et al. 2001). In particular, temperature conditions – and especially non-ideal conditions – are reported as affecting the growth, behavior, and survival, of juvenile salmonids (Myrick and Cech 2005; Richter and Kolmes 2005) and can elicit physiological indicators of stress above certain thresholds (Feldhaus et al. 2010). Degraded habitat conditions resulting from human activities, including timber harvest, irrigation diversions, historic mining activity, and livestock grazing, are generally understood to contribute to in-stream temperature increases (Middle Fork IMW Working Group 2017).

Stream temperature is controlled by multiple environmental factors including discharge (Sinokrot et al. 2000), air temperature (Mayer 2012, Webb 2003), groundwater exchange (Constantz 1998), and physical characteristics such as substrate (Johnson 2004) and channel morphology (O'Briain et al. 2017). Atmospheric warming is expected to alter the behavior of some of these controls under projected climate scenarios, including potential departures from historic flow and air temperature dynamics (Mantua et al. 2010).

Restoration

The MFJDR has received varying levels of restoration treatment over the last 50 years. At least 84 unique restoration projects (Figure 1c) were implemented between 2008 and 2017 (Middle Fork IMW Restoration Inventory, Oregon Department of Fish and Wildlife 2018), although other actions are documented as far back as the 1970s (Stephan Charette, Oregon Department of Fish and Wildlife, personal communication).

These restoration actions span a gradient of physical extent and intensity, and include project types such as fish passage barrier removals, large wood placement, riparian and upland plant installation, cattle exclusion fencing, deer and elk exclusion fencing, reactivation of historic channels, and floodplain restoration, among others. An individual project can include one or many of these restoration treatments. In previous MFJDR studies (McDowell et al. 2021), researchers have grouped restoration actions associated with monitoring locations into broad categories to create meaningful yet simple comparison groups. These categories include: active restoration, passive restoration, active *and* passive, or neither. Active restoration implies some sort of physical manipulation of the site (e.g., large wood placement, channel alteration) while passive restoration constitutes some sort of land-use change (e.g., alteration of livestock grazing rotations, deer/elk exclosures, etc.) that will allow vegetation, channel form, hydrology, or other site conditions to recover.

Intensively Monitored Watershed

There are 15 Intensively Monitored Watershed (IMW) study locations in the Pacific Northwest, including the states of California, Oregon, Washington, and Idaho. These study locations are coordinated by the Pacific Northwest Aquatic Monitoring Partnership and seek to aggregate resources for implementing intensive monitoring in restoration focal areas. Restoration in anadromous salmonid spawning and rearing habitat is performed with the idea that increasing juvenile survival will ultimately increase adult fish returns; yet, formally linking improved juvenile habitat with increased adult returns has proven difficult (Roni, Hanson, and Beechie 2008). The IMW framework seeks to address this challenge by coordinating restoration and monitoring efforts between the multiple agencies active within a priority watershed.

The Middle Fork John Day IMW (MFIMW) was established in 2008 with the goals of evaluating the benefit of restoration efforts to summer steelhead and spring Chinook salmon, and to describe how specific restoration actions affect specific response metrics such as instream habitat quantity/quality, stream temperature, salmonid habitat use, and population uplift. The temperature monitoring locations used in this analysis were established and are currently maintained through a collective effort of multiple agencies including the North Fork

John Day Watershed Council, the Oregon Department of Fish and Wildlife, the US Forest Service, and the Confederated Tribes of the Warm Springs Reservation of Oregon and coordinated through the IMW.

Effectiveness Monitoring

Restoration effectiveness monitoring provides the information crucial for assessing the impacts of individual restoration actions and for describing trends towards desired conditions. Despite this, many salmonid habitat investments do not include monitoring as part of their overall implementation strategy (Roni et al. 2002, Bernhardt et al. 2005). The MFIMW seeks to implement coordinated monitoring efforts which quantitatively link habitat improvement actions to ecological uplift, but the resulting datasets are massive and analysis of is far from complete. Specifically, while some aspects of temperature variation have been evaluated (Middle Fork IMW Working Group 2017), a rigorous investigation of temperature trend has not been performed. Identifying temperature monitoring sites which have displayed significant trends over the period of record is a critical and informative part of the overall management framework, and may allow for identification of successful restoration actions, prioritization of areas which are increasingly contributing to stream warming, or determining when and where adaptive management is necessary to ensure project success.

MATERIALS AND METHODS

Study Area

The John Day River is the longest free-flowing river to support wild summer steelhead and spring chinook populations in the Columbia River Basin (Figure 1). It is the fourth largest drainage in the state of Oregon and encompasses nearly 21,000 km^2. The John Day Basin is conventionally delineated into five sub-watersheds for management purposes: the South Fork, Upper John Day, Lower John Day, North Fork, and Middle Fork.

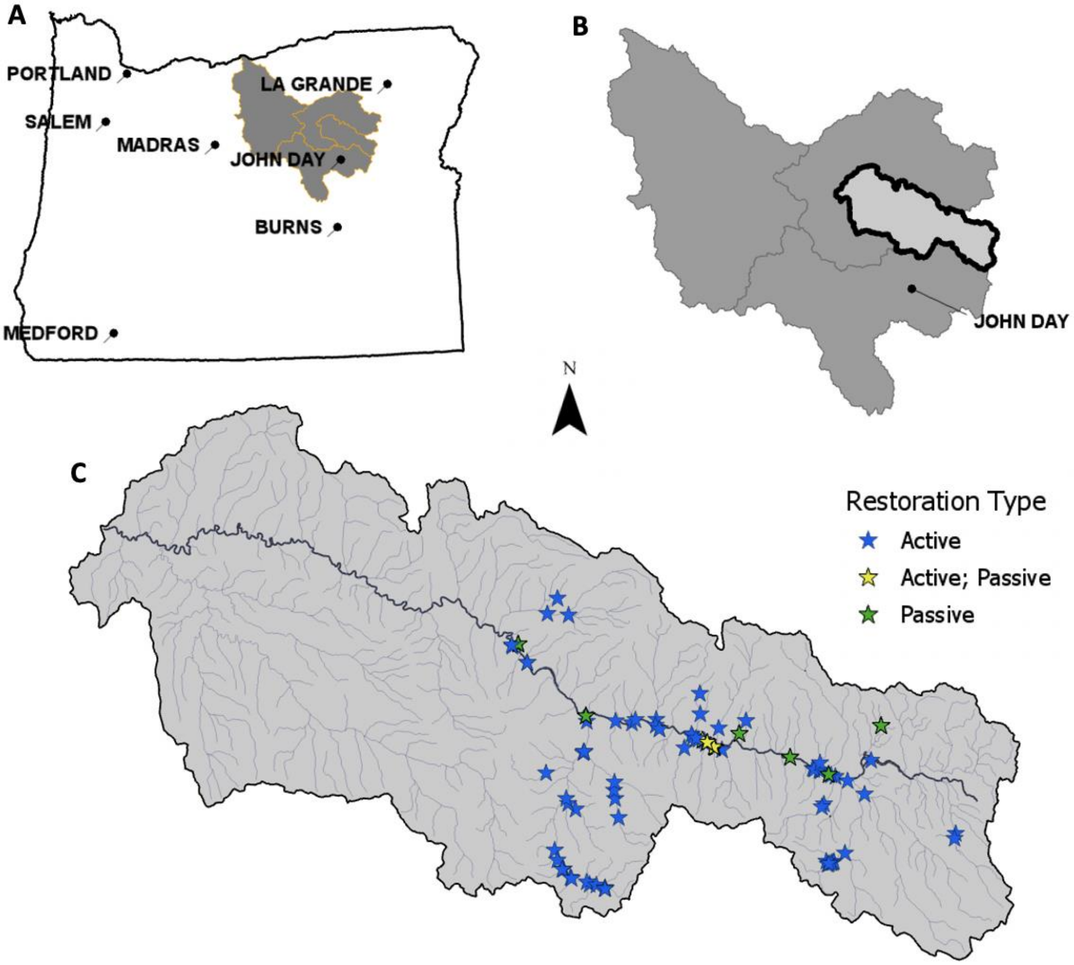

Figure 1. A) Location of the John Day Basin within the state of Oregon. B) Location of the Middle Fork John Day subbasin within the John Day Basin. C) Middle Fork hydrology and restoration locations.

The basin ranges across a diverse collective of land cover, land uses, and climate conditions, between its upstream extent in the alpine Blue Mountains and the high-desert region where it meets the Columbia River. Most of the basin experiences about 30.5 cm of precipitation annually but as much as 127 cm falls in its headwater regions. Most of the annual precipitation is accumulated between November and June. Spring snowmelt and runoff results in a hydrograph which typically peaks in April or May and reaches baseflow by late August or September (Confederated Tribes of Warm Springs 2015).

Just over half, about 54%, of the basin's area is used as agricultural land and this is the principal economic driver of the region. Much of the higher-elevation coniferous forests are located on federally owned land, while the shrub-steppe lowlands are owned both privately and by the Bureau of Land Management. A small portion of the basin is developed, including residential and agricultural infrastructure as well as road systems (Confederated Tribes of Warm Springs 2015).

This investigation is specific to the Middle Fork John Day River (MFJDR), which drains 2072 km^2, is 120 km long, and accounts for 9% of the total John Day basin by area. Elevation ranges from 670-2438 m, and receives 30.5-76.2 cm of precipitation along this elevation gradient. About 60% of the Middle Fork watershed is federally owned, with the remainder owned privately and a very small amount (~1%) owned by the state of Oregon. Similar to the basin at large, agriculture is the predominant land use with cattle being the leading commodity. Land cover is allocated evenly between mixed conifer forest (33%), western juniper woodlands (31%), and ponderosa pine forest (30%), with the remainder divided between infrastructure, alpine meadows, and emergent wetlands (Confederated Tribes of Warm Springs 2015).

Discharge records at the most downstream gauge on the MFJD (USGS 14044000 Middle Fork John Day River at Ritter, OR) indicate that discharge has averaged approximately 5.8 m^3/s (170 cfs) and annual peak discharge has averaged around 57 m^3/s (2000 cfs) since 1930 (USGS 2022).

The MFJDR has suffered deleterious land-use practices since 19th-century European settlement. Extensive agriculture and timber-harvest activities (Clair and Fields 2004) have altered landcover composition and degraded riparian condition along the mainstem MFJDR and its tributaries, which has affected local hydrology, temperature regimes, and sediment routing. During the early 20th century, the MFJDR watershed was dredge-mined for minerals including gold, which further reduced riparian vegetation and altered the existing channel structure.

Data Collection

The Middle Fork IMW temperature logger network is a collective of monitoring stations established as either restoration-specific effectiveness monitoring locations or as reference monitoring locations. Stream temperature data are collected using Hobo Pro-V2 data loggers (Onset Computer Corporation, Bourne, MA) and recorded at 1-hour intervals during logger deployment. Loggers are maintained in place using steel cable attached to a soil anchor, or in some instances by being fixed to a stationary object such as a tree or boulder (Figure 2). A PVC or metal housing is used as a solar shield to prevent measurement errors caused by solar

Figure 2. Example of a temperature logger in a PVC solar shield installed using steel cable and a duckbill anchoring system.

insolation. Loggers are either deployed year-round, or are deployed each year in the early spring and retrieved in late fall. The timing of logger deployment varies by agency, but the duration of deployment for all loggers includes the three hottest months of the year (July, August, September) which are the focus of this study. Most loggers are validated for temperature accuracy using Onset's recommended "ice-bath" QA/QC process (Onset 2022) or by corroborating in-stream measurements with a calibrated thermometer. Logger placement is not specific to habitat unit type and, while typically not documented, the habitat units captured within the logger network are expected to cover the broad habitat unit classifications of pools, riffles, fast-non-turbulent waters, and alcoves. Logger locations are also distributed between the main stem MFJDR and its tributaries, and three of the loggers included in this analysis are deployed in a unique habitat unit created through the impoundment of a steelhead-bearing tributary for historic use as a mill pond.

Site Selection for Data Analysis

Data from a total of 252 unique sites are housed in the MFJDR IMW data repository. These individual datasets are of varying annual completeness, have lengths of record ranging from one to thirteen years, are composed of legacy (inactive) and current (active) locations, and have had inconsistent quality control. The variable data quality standards of individual monitoring stations necessitated the development of selection criteria to identify individual datasets suitable for trend analysis. Initial selection criteria were: (1) at least five years of data collection through the 2021 monitoring year, (2) data were collected during the 2021 field season, and (3) the logger had an “active” designation for the 2022 field season. These criteria were developed with the objectives of: identifying monitoring locations with lengths of record sufficient for trend analysis; identifying monitoring locations with data from the most recent field season; and identifying monitoring locations where data will continue to be collected, with the intention of selecting sites which will continue to contribute to trend detection through future monitoring years.

Filtering for these criteria produced 86 candidate sites (Figure 3). These sites were reasonably balanced between tributary and mainstem locations with 47 and 39 stations, respectively. There was a higher concentration of candidate sites in the upper half of the MFJDR basin. This reflects of the greater temperature logger network there and also of the concentration of restoration activities that have occurred in upstream salmonid spawning habitat.

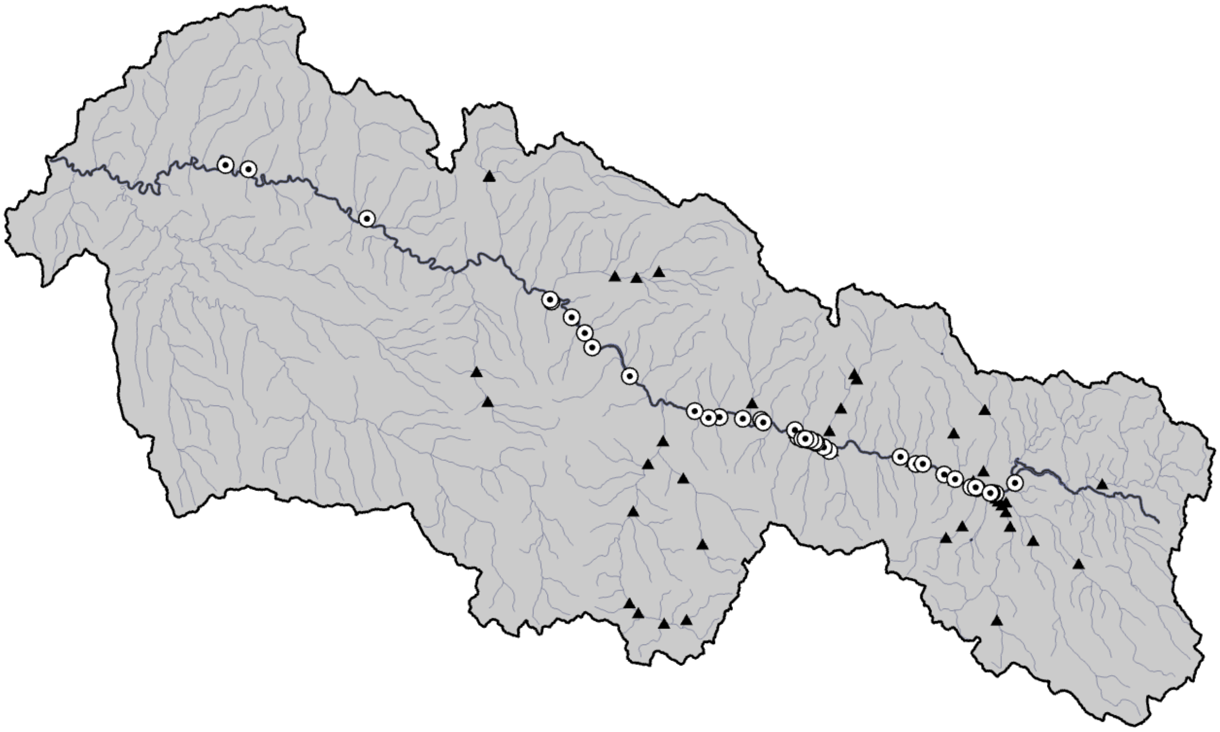

Figure 3. Locations of the 86 candidate sites. Triangles represent tributary sites and circles represent mainstem sites.

Data QA/QC

I developed a standardized quality assurance/quality control (QA/QC) protocol and applied it to all temperature data to identify erroneous data, incomplete data, or data behavior indicative of dry channel conditions. These criteria include: total daily temperature change greater than or equal to 12 °C (indicative of dry, exposed conditions, i.e. the logger is recording air temperature instead of water temperature); hourly temperature change greater than or equal to 3 °C (indicative of dry conditions); hourly temperature reading greater than or equal to 28 °C (typically observed in dry conditions, or logger is malfunctioning); hourly temperature reading less than 0 °C (logger is frozen and/or malfunctioning). Any data meeting these criteria were flagged and removed. Daily datasets were required to have a full 24 hourly datapoints to be included in the monthly dataset, and monthly datasets were required to have a full complement of daily datasets to be included in the trend analysis. A minimum of 5 full yearly datasets for a given month and site was required to be included in the trend analysis.

All QA/QC and data analysis was performed using R software (R Core Team 2018). Many candidate sites failed to meet these criteria and were subsequently excluded from the trend analysis. A total of 41 sites met QA/QC criteria for July, 49 for August, and 60 for September. A full inventory of data availability for the 86 candidate sites can be found in Appendix A.

Response Variables and Analysis Technique

Previous findings published by the MF IMW determined over-summer temperature to be the primary limiting factor for salmonids in the MFJDR (Middle Fork IMW Working Group 2017). Thus, the three hottest months of the year were selected for further examination. These months are July, August, and September – a period of about 12 weeks in which low discharge and seasonally high ambient temperatures are expected to synergistically contribute to stressful and potentially lethal conditions for juvenile salmonids.

I considered several response variables for trend detection analysis. All of these describe temperature characteristics in unique ways: daily minimums and maximums, magnitude of temperature change within or between days, number of days in which a specific temperature threshold is exceeded, or 7-day average daily maximum (7DADM). The latter metric is commonly used to describe temperature regime in a regulatory context (Sturdevant 2008). While these metrics can be useful for exploring temperature characteristics, they have distinct shortcomings when performing a trend analysis in the context of salmonid habitat. For example, a daily maximum temperature is an index of the most extreme conditions observed at a site but does not describe how long the site experienced extreme conditions, the latter of which being an important regulator of salmonid stress response. The number of days a site experiences above a certain threshold is not always useful; some sites will exceed even relatively high thresholds for the full duration of a given timeframe, while others will not exceed relatively low thresholds. Further, the “days of exceedance” metric will fail to capture subtle trends if they only occur above or below the defined threshold. Lastly, the 7DADM is calculated as a trailing moving-average of daily maximum values which, by definition, requires each 7DADM value to share five datapoints with the 7DADM from the previous day. This type of data-smoothing may obscure trends or introduce unacceptable bias. The 7DADM also arbitrarily uses a 7-day duration to evaluate stressful conditions

I ultimately selected two metrics for analysis: total degree hours (TDH), and total degree hours in exceedance (DHE). A degree hour is defined as the departure, in °C, of the hourly temperature from a given threshold. For this analysis, the TDH threshold is 0 °C and the DHE threshold is 18 °C. The DHE threshold is specific to the definition of stressful conditions for juvenile salmonids as given by the Oregon Department of Environmental Quality (Dadoly and Michie 2010). Using these metrics is justified for multiple reasons. For both degree hour (DH) metrics, the resulting summation of degree hours reflects both a temperature magnitude and the duration for which those temperatures persist. It also allows for the inclusion of all datapoints within a given day, and all days within a given month, to contribute to the overall summary statistic. This is not the case for metrics that relay on extreme values, such as maximum daily temperatures, which exclude 23 hourly datapoints from each day and must be averaged to generate a monthly temperature statistic.

Trend Analysis

Various analysis frameworks have been used to examine the effects of habitat restoration, including Before-After Control-Impact, Control-Impact, and Extensive Post Treatment study designs (Roni 2018, Stewart-Oaten et al. 1986). While these designs can be informative when appropriate, several mitigating factors contributed to my selection of a trend-analysis framework for this investigation.

Many of the sites used in this analysis have received multi-phased or sequential restoration efforts which make it difficult to parse the periods within a dataset into distinct categories for a treatment/control framework. For example, some restoration actions include an initial in-stream component followed by several years of riparian planting and/or maintenance. Other sites are restored through multiple years, and at least one restoration location included in this analysis received in-stream treatment during five consecutive years. This makes it extremely challenging and, in some instances, impossible to identify a reasonable amount of pre-implementation and post-implementation data points to compare.

There are also challenges in grouping monitoring locations in treatment/control sites due to the effect that watershed placement has on local temperature regime. Previous reports (Middle Fork IMW Working Group 2017) have demonstrated that temperature tends to decrease in a downstream to upstream fashion. Sites located in tributary systems and in the more-upstream portions of the mainstem Middle Fork tend to be cooler overall than those farther downstream. This makes it difficult, and sometimes inappropriate, to compare treatment groups

Lastly, trend can be an informative tool for restoration practitioners, and IMW partners have expressed desire to visualize data in this way (Middle Fork IMW Working Group, personal communication). An important part of the restoration and management framework is to adaptively manage restoration sites and apply additional treatment if necessary to achieve desired goals. Being able to identify if, and at what rate, site conditions are trending towards desired conditions allows restoration practitioners to prioritize adaptive management actions when the trajectory of site conditions does not align with the intended response timeline. Alternatively, knowing if a given site is responding as intended provides valuable information for informing the design of future management actions.

I summarized several descriptive temperature metrics for each site to provide context for the trend analysis, provided in full in Appendix B. Each metric is calculated as the average from each day within a given month. Across all sites and months minimum daily temperature ranged from 2.7 to 16.9 °C; maximum daily temperature ranged from 12 to 26.5 °C; average daily temperature ranged from 7.9 to 21.1 °C; and the average difference between daily maximum and minimum temperature ranged from 0.3 to 7.8 °C.

Linear Regression

I initially used linear regression to examine warm-season water temperatures through time. Each response variable – Total Degree Hours and Degree Hours of Exceedance – was summed within a given month and year. These unadjusted totals were used as response variables with observation year being the regressor. A simple linear regression of water temperature does not account for annual variation in climate characteristics, such as air temperature and discharge volume (a function of precipitation) as described below, but is important as a quantitative description of conditions experienced by fish within the period of record at these monitoring stations. Management practitioners are concerned with how temperature regimes respond in context of climate change and if restoration actions can produce detectable trends towards desired conditions regardless of climate behavior.

Residuals Regression

Annual variation in climate can have significant effects on in-stream temperature. In particular, ambient air temperature and annual flow regime can mask the influence of restoration activities on stream temperature. To address this, the methods described in "Techniques of Trend Analysis for Monthly Water Quality Data" (Hirsch 1982) were adapted to adjust stream temperatures for annual variation in streamflow and air temperature. Hirsch (1982) describes a methodology for applications in which a water quality constituent load varies strongly with discharge. In that scenario, annual variation in discharge may obscure changes in underlying processes that affect how a given constituent enters the stream system. Hirsch's approach uses linear regression to find the best-fit relationship between discharge and constituent level, calculates the difference between expected and observed levels, and then applies a Mann-Kendall trend test to the resulting set of residuals.

Building on Hirsch's methods, I performed a multiple linear regression using average monthly air temperature (NOAA 2022) and average monthly stream discharge (USGS 2022) as predictor variables and TDH and DHE as response variables. The residuals from this analysis were used as response variables for a linear regression using time (i.e., observation year) as the predictor variable. Thus, my methodology departs from Hirsch's in two ways: (1) I use multiple regression to control for multiple environmental conditions, and (2) I use linear regression instead of a Mann-Kendall test to examine trend in residuals. Controlling for annual environmental conditions in this way allows for the identification of significant changes in local stream temperature conditions that could result from some external influence other than annual variation in climate and flow conditions.

Significance Levels

I use a significance level of 0.1 to identify and organize potentially significant results from regression analyses. This significance level is more liberal than the typical convention, and may result in more Type 1 errors than would result from a conservative value such as 0.05 and 0.01. The use of alpha=0.1 is justified because the overarching objectives of this analysis are largely exploratory and the relatively small amount of annual datapoints available for trend analysis, as well as the long amount of time over which restoration effects may occur (Klein 2007), implies that trends may be weak. It is my intention to identify locations where a trend may be occurring, to investigate whether these trends tend to cluster within restoration reaches or differ between tributary and mainstem locations, and to provide insight for guiding future monitoring and analysis efforts. P-values of significant trends are provided in accompanying tables.

RESULTS

Trend Detection – Unadjusted TDH

Unadjusted total degree hours from sites were regressed against observation year within the months of July (n=41 sites), August (n=49), and September (n=60). Six sites were observed to have significant trends in July (Figure 4, Table 1) and August (Figure 5, Table 2), and four sites had significant trends in September (Figure 6, Table 3). July had four sites with decreasing trends and two with increasing trends, while August had one decreasing site and five increasing sites. All significant trends for July and August were located in tributaries and were not located within or downstream from significant restoration activity. September had two increasing sites and two decreasing sites, of which three were located on tributaries and one on the mainstem. This mainstem monitoring location (MFJD_lwrForrestCABoundary) is located at the downstream end of a heavily restored reach, while the other three sites are not located near restoration activity.

Table 1. Significant unadjusted TDH trends for July.

Site	Slope	R^2	P-Value
GraniteBoulderCr_upr1	493.330	0.628	0.006
CBW05583-477938	-164.309	0.629	0.033
CBW05583-438922	-289.027	0.910	0.003
CBW05583-250506	-144.511	0.621	0.020
BridgeCr_amouth	-161.246	0.590	0.074
BatesPond_linetop	434.222	0.603	0.040

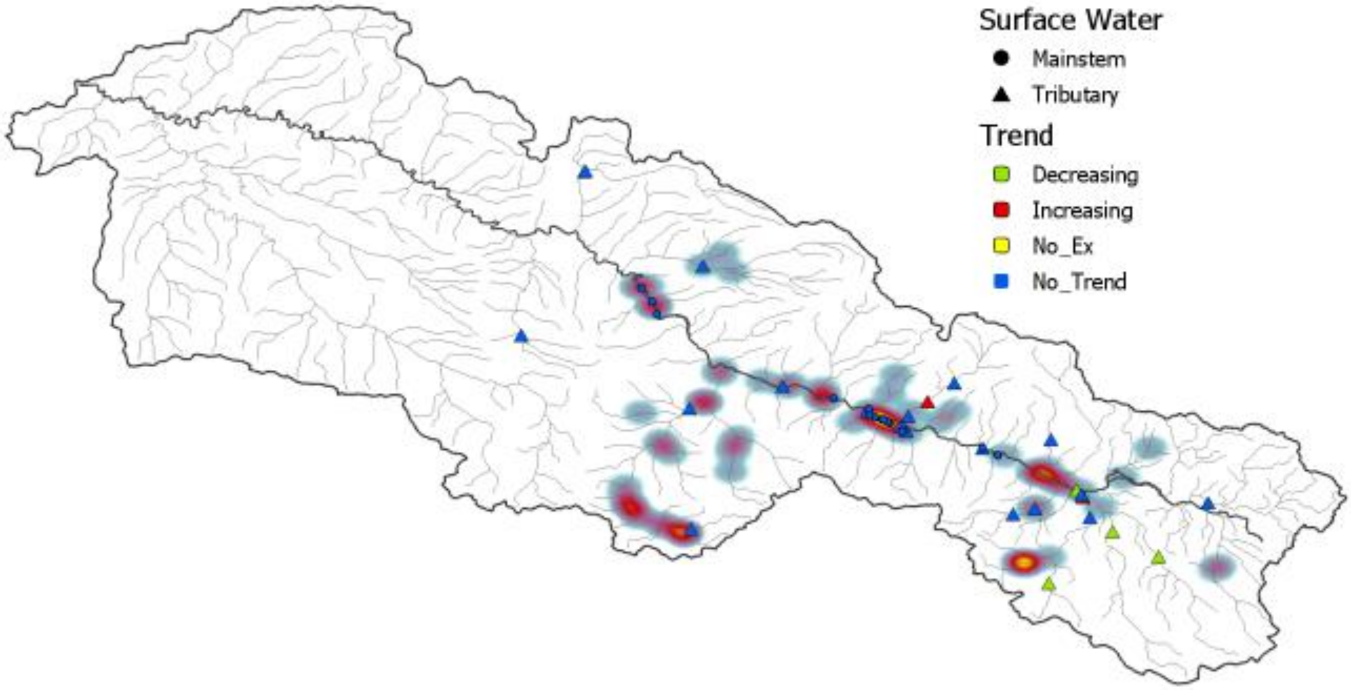

Figure 4. July trend results for unadjusted TDH.

Table 2. Significant unadjusted TDH trends for August.

Site	Slope	R^2	P-Value
LittleIndian_aMouth	123.292	0.425	0.080
IndianCr_aLittleIndian	71.957	0.397	0.028
GraniteBoulderCr_upr1	318.755	0.584	0.010
GraniteBoulderCr_up3	61.701	0.398	0.093
CBW05583-438922	-63.293	0.461	0.093
BatesPond_linetop	186.478	0.926	0.009

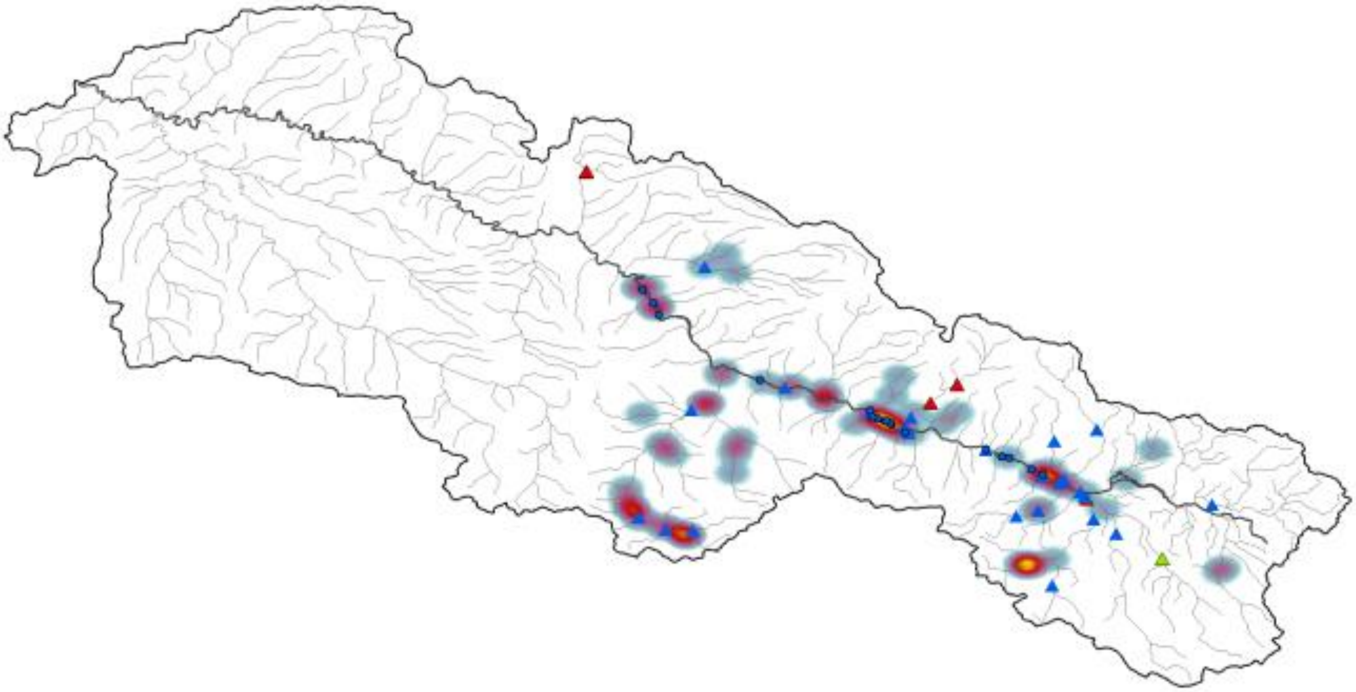

Figure 5. August trend results for unadjusted TDH.

Table 3. Significant unadjusted TDH trends for September. Bold site names are located within restoration reaches.

Site	Slope	R^2	P-Value
OJD03458-000536	-243.303	0.691	0.081
MFJD_lwrForrestCABoundary	-151.980	0.604	0.069
GraniteBoulderCr_upr1	258.021	0.495	0.016
EastFork_BigCr_Mouth	189.761	0.574	0.049

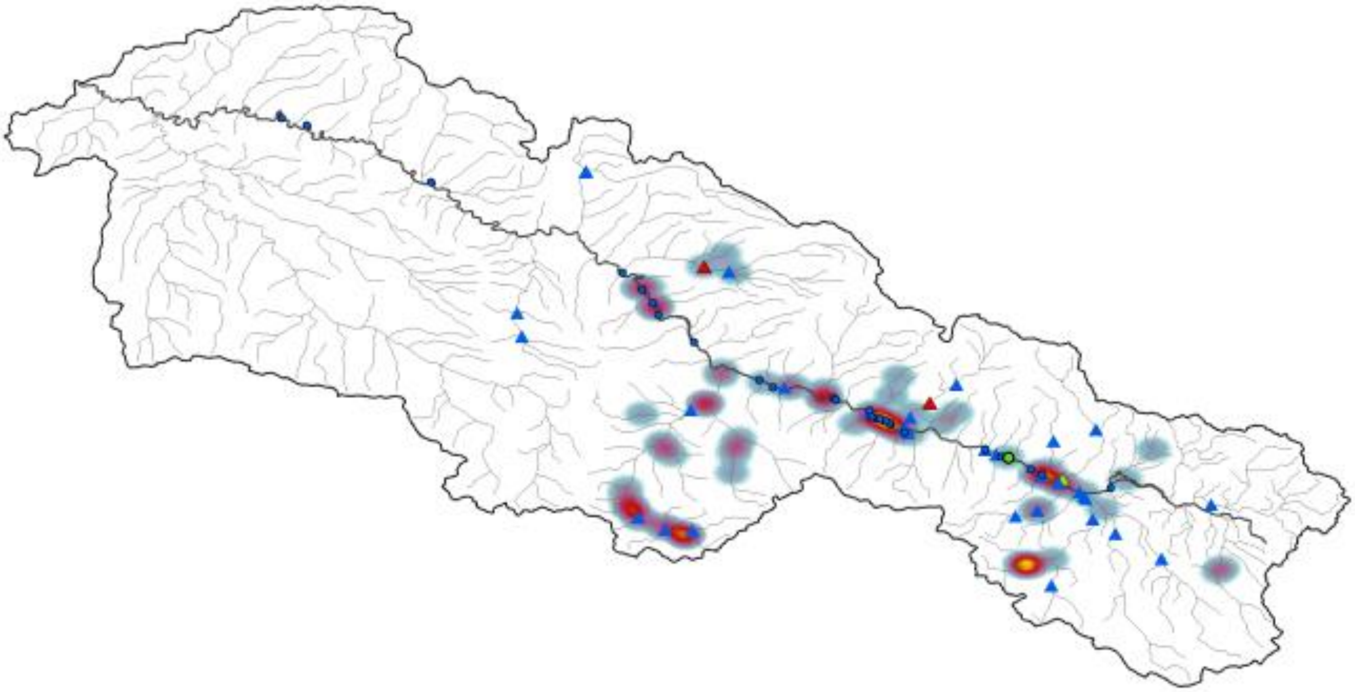

Figure 6. September trend results for unadjusted TDH.

Trend Detection – Unadjusted DHE

Significant trends in total degree hours in exceedance of 18 °C were found for four sites in July (Figure 7, Table 4), eight sites in August (Figure 8, Table 5), and one site in September (Figure 9, Table 6). July had two increasing and two decreasing sites, all of which were located in tributary stations. None of the sites observed to have significant trends in July were located near or within restoration reaches.

Of the eight sites with significant trends identified in August, three showed a decreasing trend and five showed an increasing trend. Two of these sites were located on the mainstem MFJDR (MFJD_TNC_WBoundary, MFJD_ARelocationFS) with the remainder located on tributaries. The RaggedCr_Lwr location, with a decreasing trend in DHE, was located at the mouth of Ragged Creek just above its confluence with the MFJDR and has received significant restorative treatment since 2012. The MFJD_TNC_WBoundary location, which had an increasing DHE trend, was located just downstream of less-intense restoration reach.

One location was observed to have a significant trend in September. This site is located on the mainstem MFJDR within a reach having sparse restoration activity. Many sites were observed to not accumulate any DHE in September: a total of fifteen tributary and two mainstem sites did not exceed the 18 °C exceedance threshold at any point during the period of observation within the month of September.

Table 4. Significant unadjusted DHE trends for July.

Site	Slope	R^2	P-Value
IndianCr_aLittleIndian	14.568	0.347	0.044
CBW05583-438922	-22.158	0.659	0.050
BridgeCr_amouth	-134.523	0.601	0.070
BatesPond_linetop	273.582	0.677	0.023

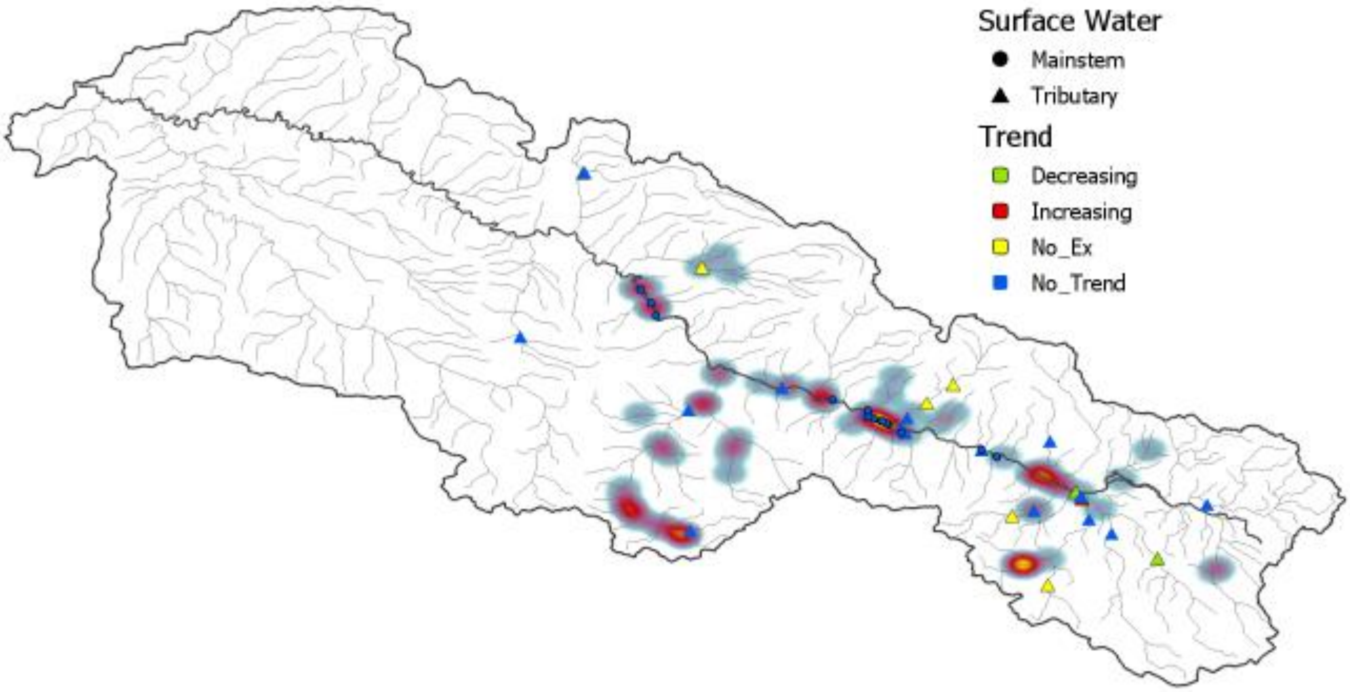

Figure 7. July trend results for unadjusted DHE.

Table 5. Significant unadjusted DHE trends for August. Bold site names are located within restoration reaches.

Site	Slope	R^2	P-Value
RaggedCr_lwr	-8.894	0.419	0.060
MFJD_TNC_WBoundary	77.602	0.658	0.050
MFJD_aRelocationFS	52.354	0.364	0.065
IndianCr_aLittleIndian	5.139	0.318	0.056
CBW05583-438922	-2.139	0.779	0.008
CampCr_upr3	-2.830	0.820	0.002
ButteCr_bculvert	1.659	0.322	0.087
BatesPond_linetop	153.625	0.929	0.008

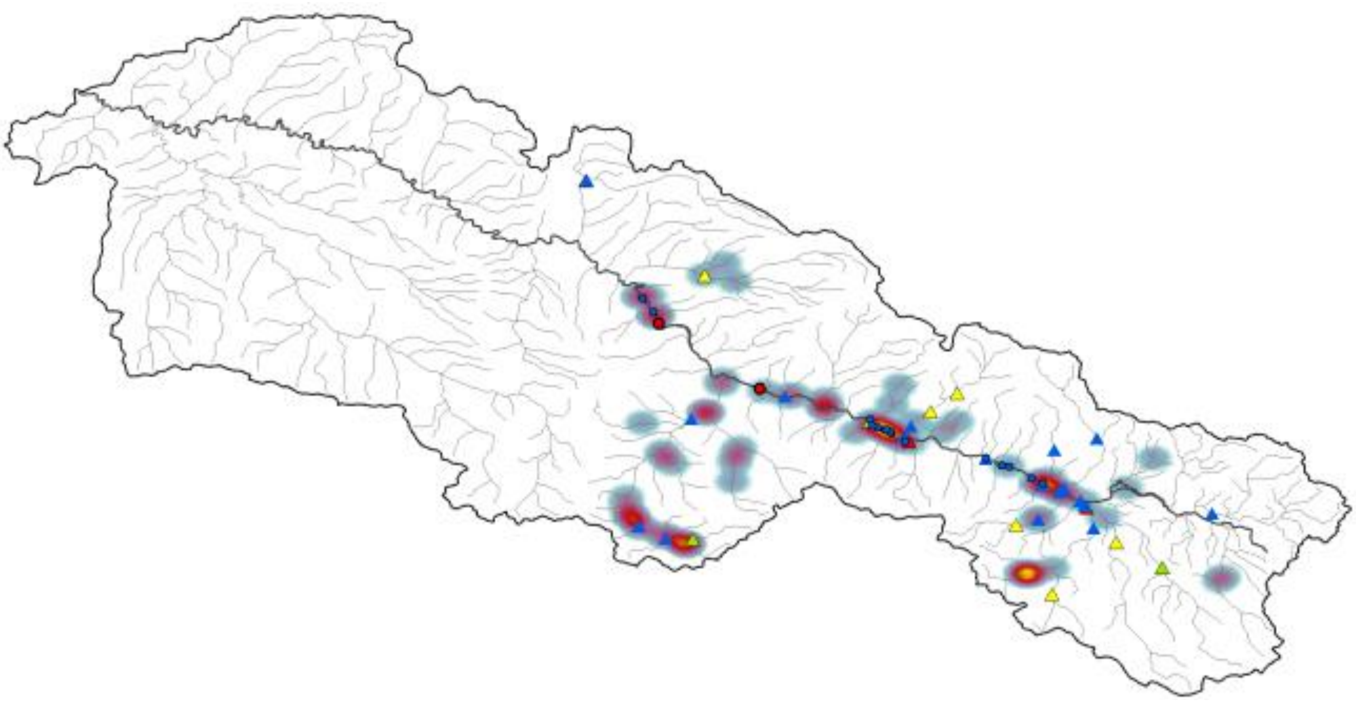

Figure 8. August trend results for unadjusted DHE.

Table 6. Significant unadjusted DHE trends for September. Bold site names are located within restoration reaches.

Site	Slope	R^2	P-Value
MFJD_aRelocationRPB	19.513	0.454	0.067

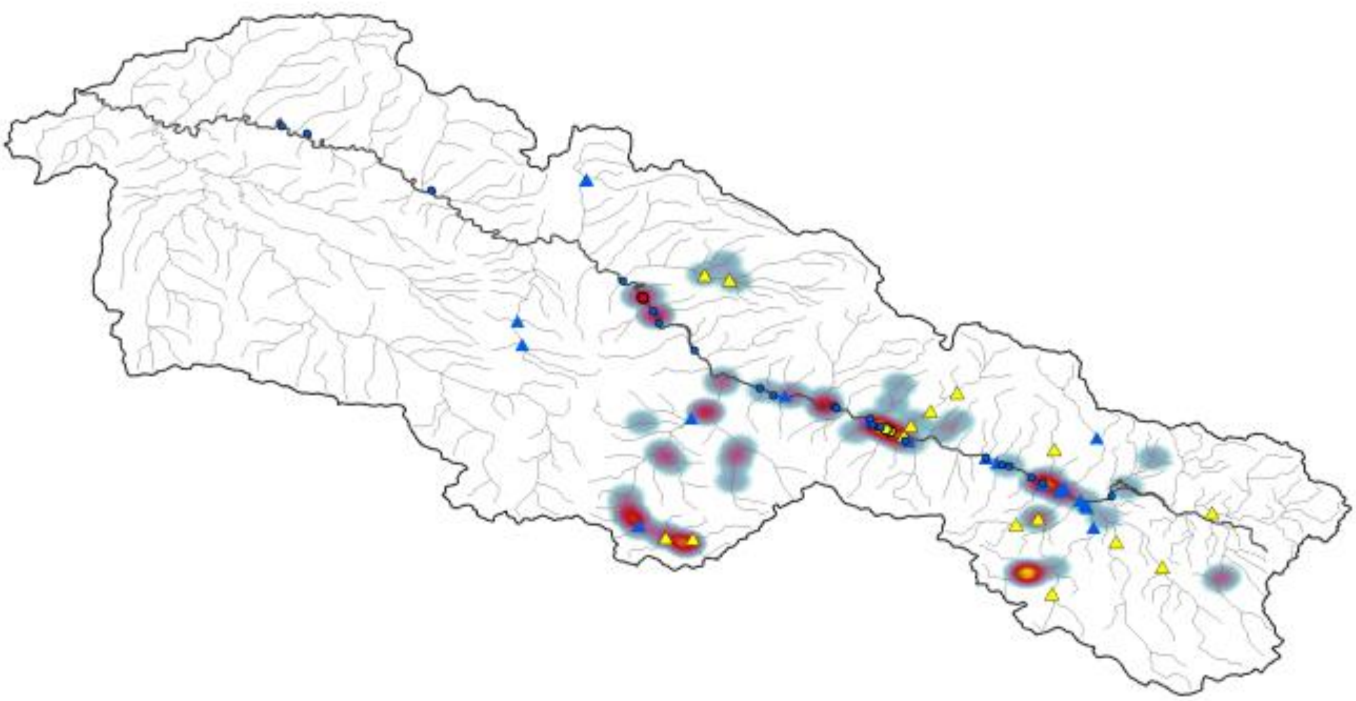

Figure 9. September trend results for unadjusted DHE.

Trend Detection – Adjusted TDH

I examined variation in total degree hours after accounting for air temperature and streamflow. The amount of TDH variability explained by flow and air temperature ranged from 22.7% to 99.6% for different sites and months, and for most sites the regression model relating TDH to air temperature and streamflow produced an R^2 value greater than 0.50. Ten locations were found to have significant trends for the month of July (Figure 10, Table 7), all of which were decreasing. That is, stream temperature was declining over time after accounting for effects of air temperature and streamflow. These sites were split evenly between tributary and mainstem monitoring stations. Six of the ten sites were located within reaches of dense restoration activity, and the remaining four locations were situated outside of any significant restoration activity.

August showed four significant trends of which three were decreasing and one was increasing (Figure 11, Table 8). All of these trends were detected at tributary monitoring sites. The three locations decreasing in adjusted TDH were not located within or adjacent to restoration reaches, and the increasing trend site was located within a reach having sparse restoration activity. September also had four sites with significant trends (Figure 12, Table 9). Three sites showed increases in adjusted TDH and one showed a decrease in adjusted TDH. Three sites were located on the mainstem MFJDR and one was located in a tributary system. Both of the MFJD_inAlcove4 and MFJD_inAlcove2 locations are within a heavily restored reach.

Table 7. Significant adjusted TDH trends for July. Bold site names are located within restoration reaches.

	Adjustment Model		Residuals Trend Model		
Site	r^2	P-Value[1]	Slope	R^2	P-Value
MFJD_inAlcove4	0.575	0.425	-485.174	0.938	0.007
MFJD_inAlcove1	0.880	0.120	-195.956	0.661	0.094
MFJD_bRaggedCr	0.983	0.000	-75.032	0.436	0.038
MFJD_bButteCr	0.996	0.004	-46.143	0.752	0.057
MFJD_aLittleBoulderCr	0.904	0.009	-49.452	0.671	0.024
LittleBoulderCr_amouth	0.822	0.032	-72.619	0.463	0.093
GraniteBoulderCr_amouth	0.408	0.455	-160.449	0.684	0.042
DavisCr_upr	0.961	0.000	-52.661	0.387	0.031
DavisCr_mid	0.962	0.000	-77.630	0.551	0.009
CampCr_upr3	0.839	0.026	-60.398	0.560	0.053

[1] P-Values of 0.000 indicate values less than 0.001

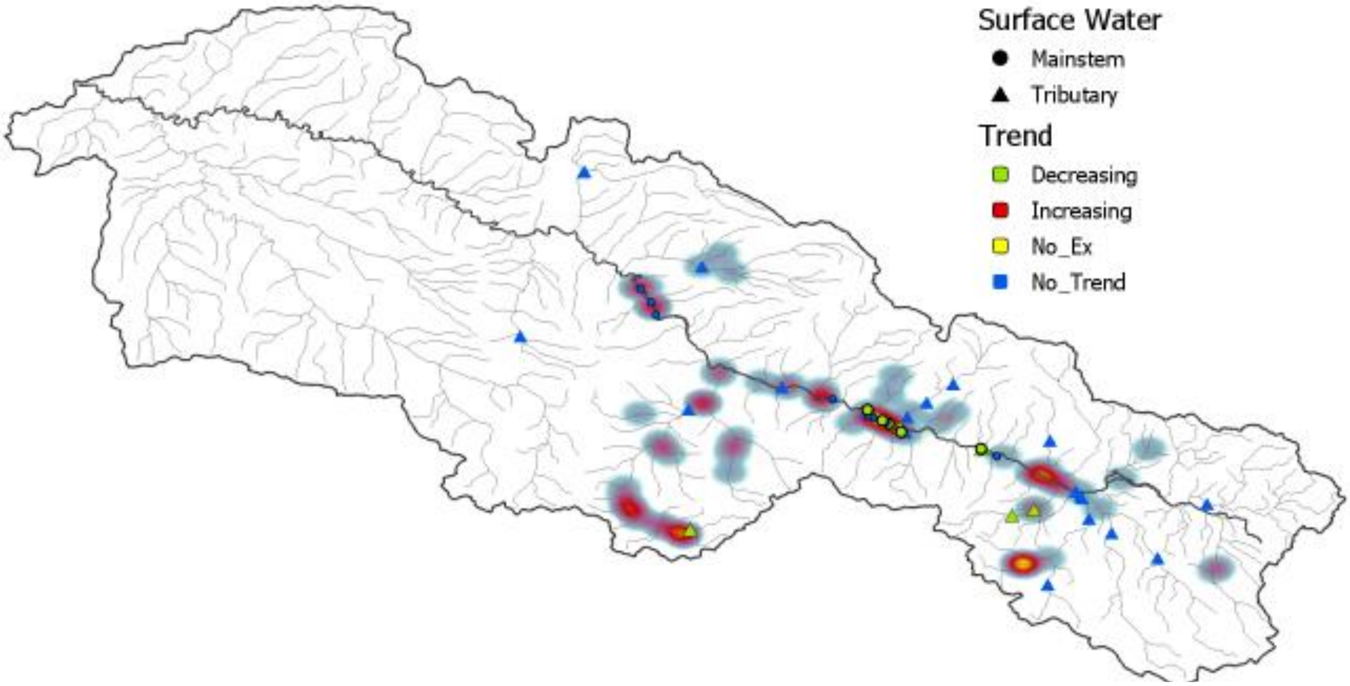

Figure 10. July trend results for adjusted TDH.

Table 8. Significant adjusted TDH trends for August. Bold site names are located within restoration reaches.

	Adjustment Model		Residuals Trend Model		
Site	r^2	P-Value	Slope	R^2	P-Value
EastFork_BigCr_Mouth	0.557	0.295	92.219	0.830	0.011
CBW05583-477938	0.227	0.526	-58.011	0.421	0.082
CBW05583-438922	0.857	0.020	-31.466	0.799	0.007
CBW05583-250506	0.400	0.279	-49.926	0.443	0.071

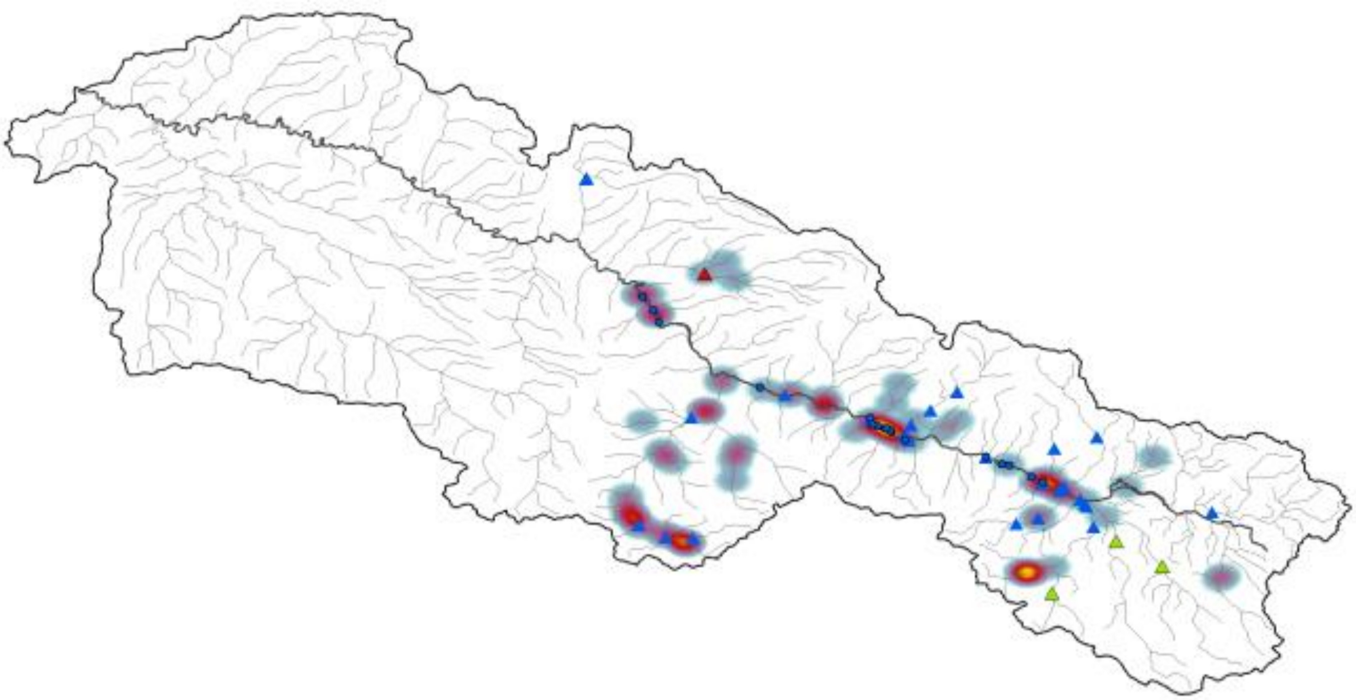

Figure 11. August trend results for adjusted TDH.

Table 9. Significant adjusted TDH trends for September. Bold site names are located within restoration reaches.

	Adjustment Model		Residuals Trend Model		
Site	r^2	P-Value	Slope	R^2	P-Value
MFJD_inAlcove4	0.745	0.255	-252.942	0.677	0.087
MFJD_inAlcove2	0.845	0.155	97.948	0.784	0.046
MFJD_aClearCr	0.956	0.002	37.509	0.591	0.044
BatesPond_linebottom	0.265	0.735	40.666	0.686	0.083

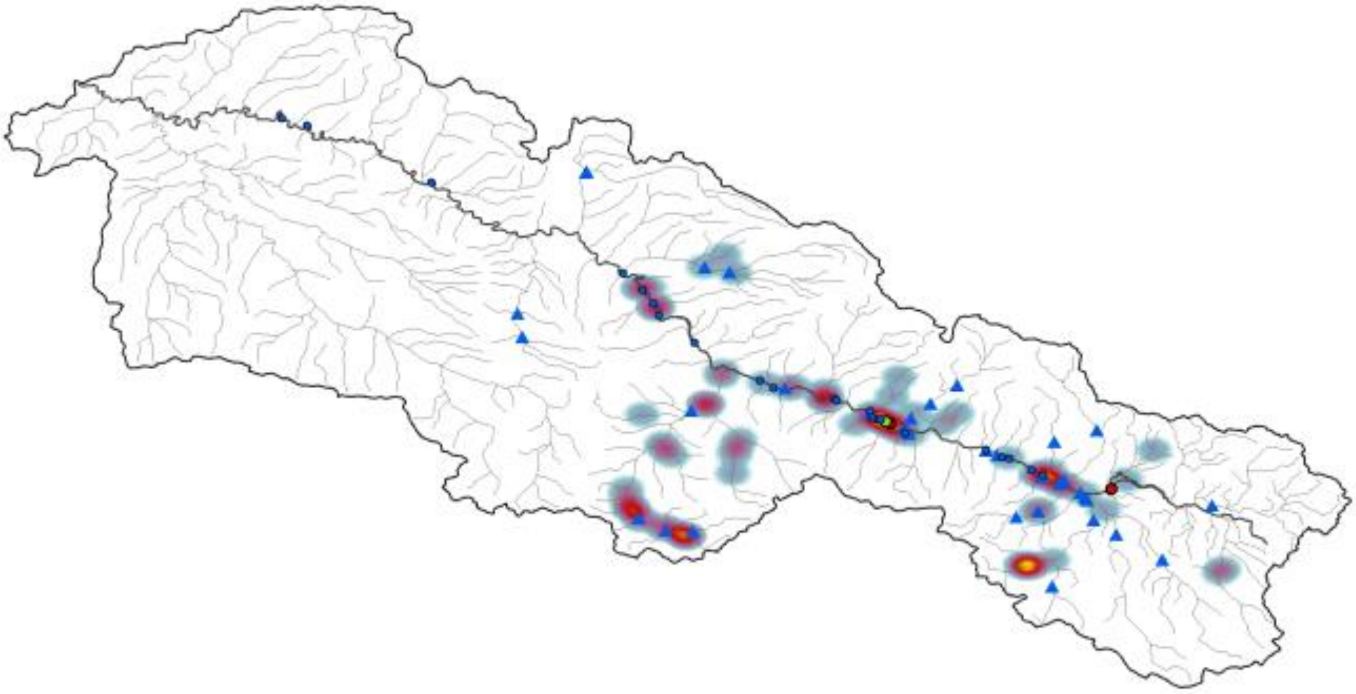

Figure 12. September trend results for adjusted TDH.

Trend Detection – Adjusted DHE

Accounting for streamflow and temperature explained less variability in DHE than for TDH, ranging from 5.4% to 85.2%. A significant trend for adjusted DHE was identified in six sites for the month of July with five decreasing sites and one increasing site (Figure 13, Table 10). Three of these sites were located in the mainstem MFJDR and three are within tributaries. The MFJD_InAlcove4, MFJD_InAlcove1, and GraniteBoulderCR_amouth locations are within a heavily restored reach and all showed decreasing trends. The remaining trends were detected at sites having sparse or no restoration efforts.

A single significant trend for adjusted DHE was observed in August (Figure 14, Table 11). This monitoring location is in a tributary system which has not received restoration treatment. Lastly, no significant trends were observed during the month of September (Figure 15), although it should be noted that the same number of sites were observed to have accumulated no DHE (i.e. no time with water temperature above 18 °C) as were identified in the unadjusted DHE trend analysis.

Table 10. Significant adjusted DHE trends for July. Bold site names are located within restoration reaches.

	Adjustment Model		Residuals Trend Model		
Site	R^2	P-Value	Slope	R^2	P-Value
MFJD_inAlcove4	0.586	0.414	-1.988	0.887	0.017
MFJD_inAlcove1	0.755	0.245	-94.314	0.707	0.075
MFJD_aLittleBoulderCr	0.852	0.022	-42.547	0.910	0.001
IndianCr_aLittleIndian	0.492	0.048	8.789	0.249	0.099
GraniteBoulderCr_amouth	0.200	0.716	-10.819	0.712	0.035
CampCr_upr3	0.614	0.149	-15.446	0.827	0.005

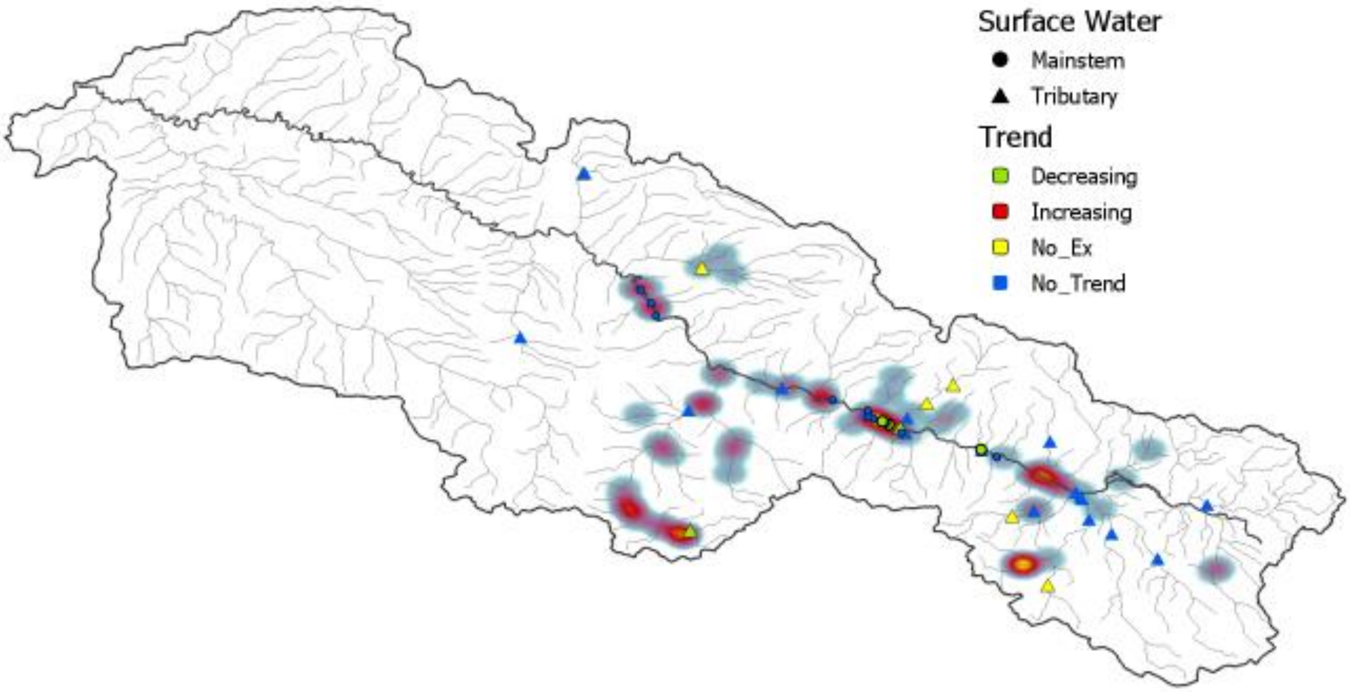

Figure 13. July trend results for adjusted DHE.

Table 11. Significant adjusted DHE trends for August. Bold site names are located within restoration reaches

	Adjustment Model		Residuals Trend Model		
Site	R^2	P-Value	Slope	R^2	P-Value
CBW05583-438922	0.054	0.894	-1.971	0.700	0.019

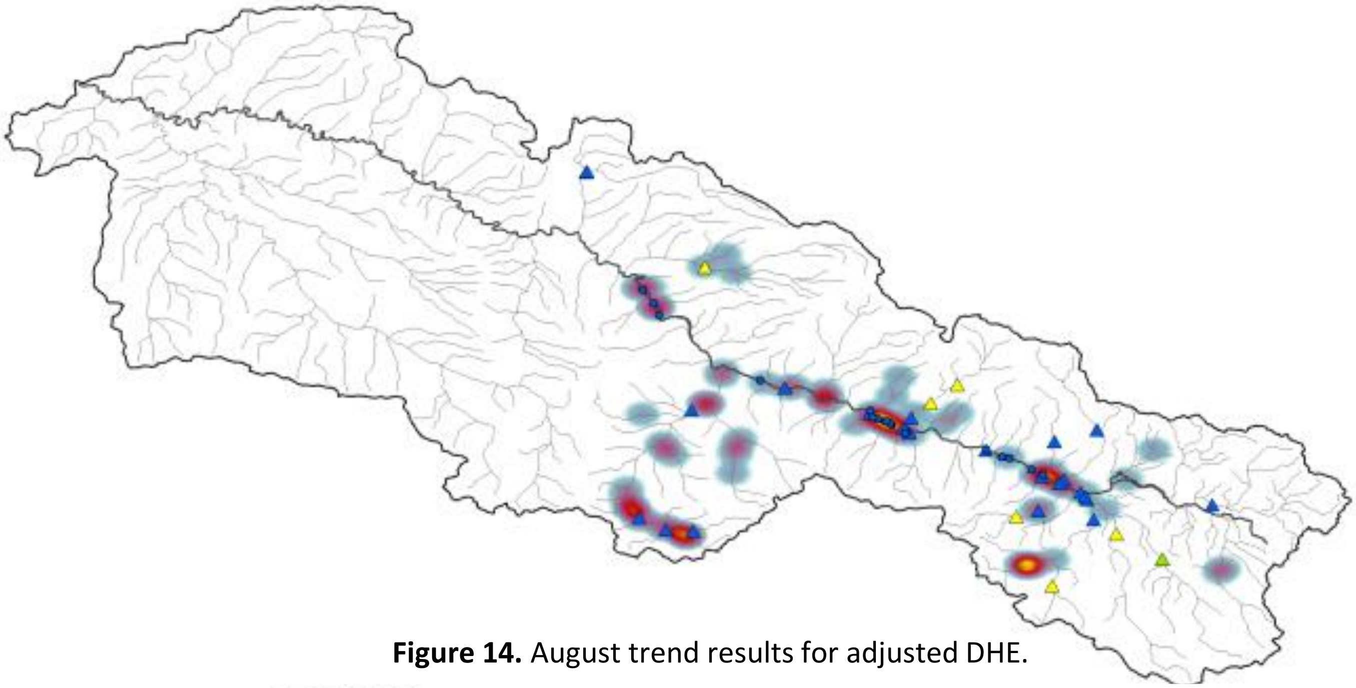

Figure 14. August trend results for adjusted DHE.

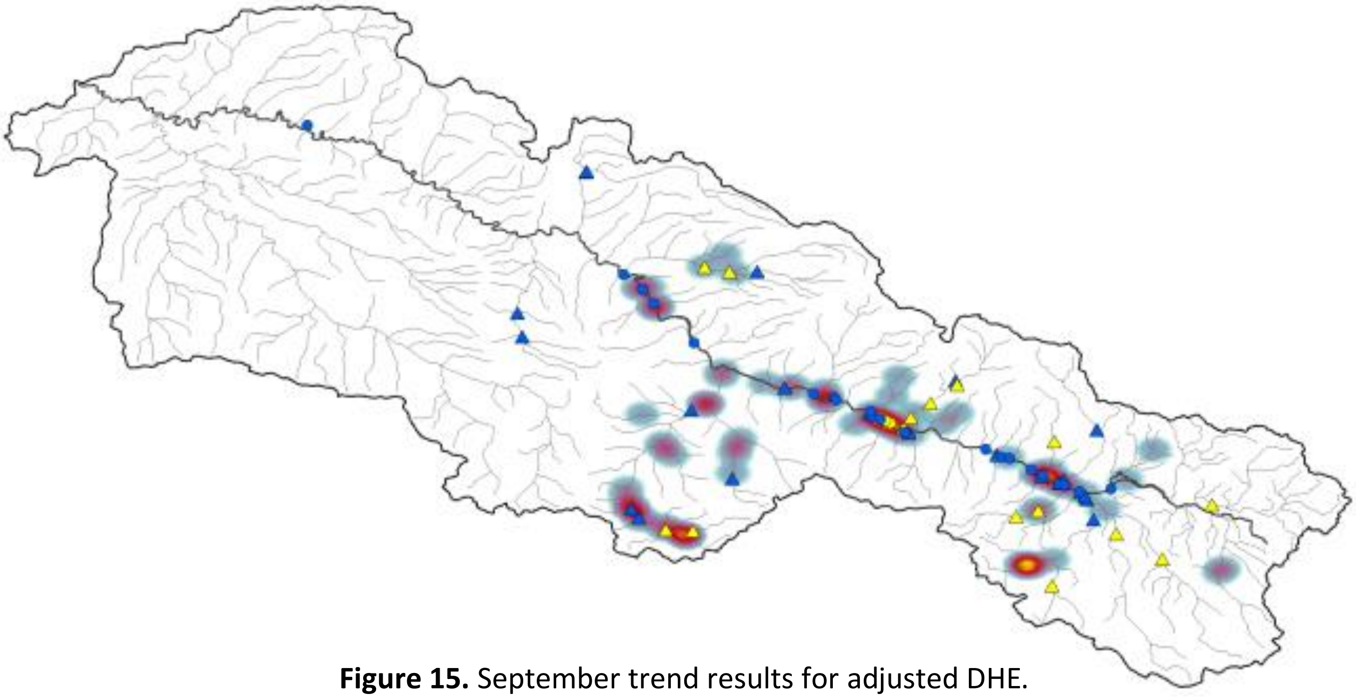

Figure 15. September trend results for adjusted DHE.

DISCUSSION

Historical Air Temperature and Flow

External environmental factors are the primary drivers of in-stream temperature, with air temperature and discharge demonstrated to account for up to 94% of annual in-stream temperature variance (Mayer 2012; Poole and Berman 2001). Therefore, it is important to place any sort of in-stream temperature trend analysis in context of recent and historical flow and air temperature trends. Annual average air temperatures for Grant County, in which the MFJDR watershed is located, has displayed a significant increasing trend of 0.11 °C per decade ($p < 0.01$) since 1930 (NOAA 2022). The period of record (2008-2021) associated with the MFIMW temperature database shows an increase of 0.78 °C per decade ($p < 0.1$). Thus, water temperature data representing the monitoring years 2008-2021 is pursuant to an air temperature regime that is generally warming, and may be increasing at a faster rate than the historical average (Figure 16).

Mean annual discharge shows a weak increasing trend during the historical period of record from 1930-2021 (USGS 2022). However, the discharge trend from 2008-2021 is decreasing – albeit with a relatively high amount of variability – at a rate of 101.8 CFS per decade. Neither of the trends observed for discharge over the historic period of record or the IMW stream temperature period of record are significant, yet the latter suggests conditions which may exacerbate high in-stream temperature conditions.

Overall, both air temperature and discharge between 2008 and 2021 display trends which would tend to contribute to warming in-stream conditions. Any trends observed in unadjusted TDH and TDE during this time should be considered in this context; increasing trends may be the expectation given these external influences, while decreasing or non-existent trends suggest additional factors which may be stabilizing or otherwise mitigating for increased air temperature and decreased flow.

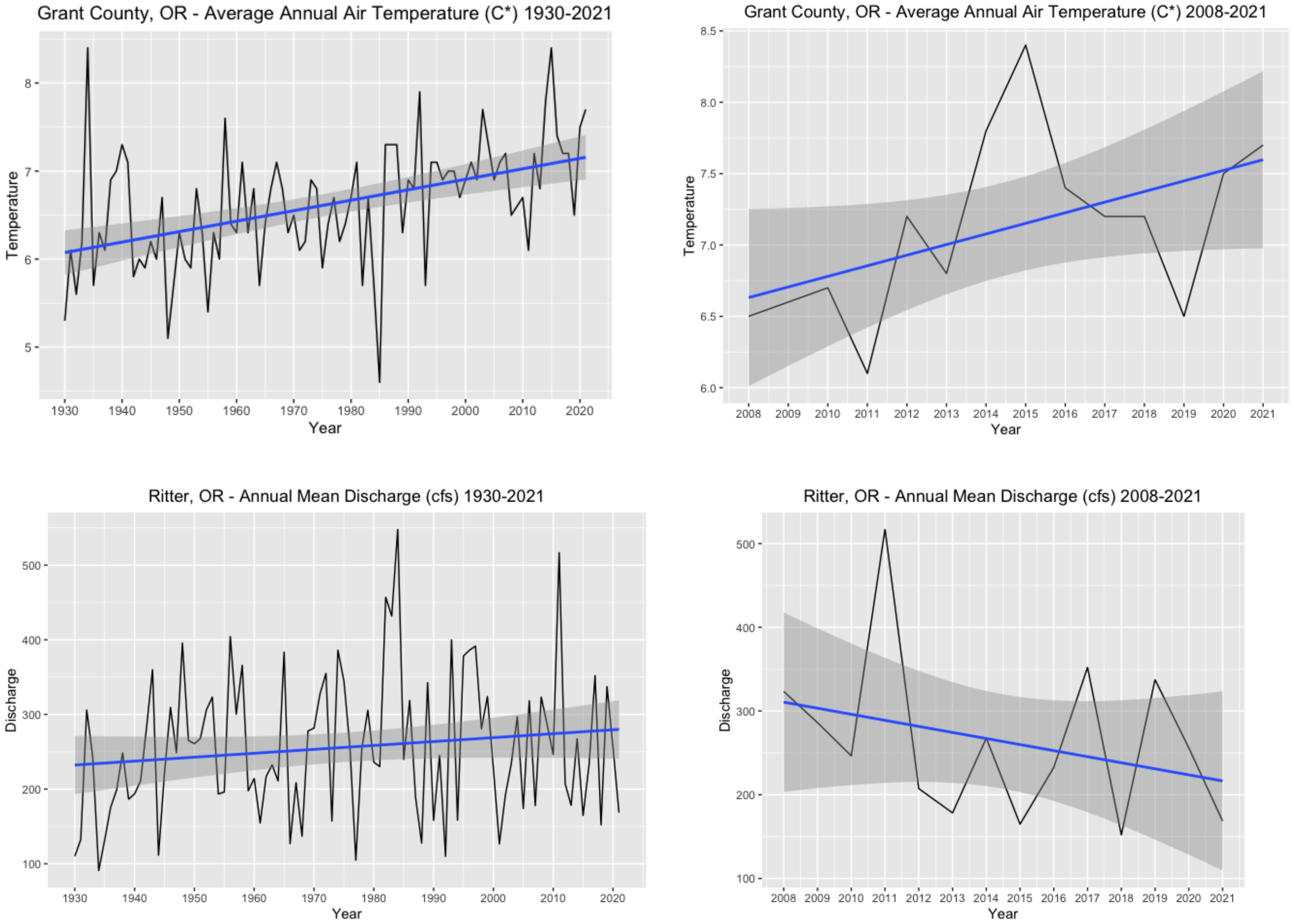

Figure 16. Clockwise from top left: average annual air temperature in Grant County since 1930; average annual air temperature during stream temperature monitoring period of record; average annual discharge at the USGS gauge station in Ritter, OR during stream temperature monitoring period of record; average annual discharge at the USGS gauge station in Ritter, OR since 1930.

Tributary vs Mainstem

Tributary sites dominated the unadjusted temperature portion of the analysis with 15 of 16 significant TDH trends and 10 of 13 significant DHE trends occurring within tributaries. For the 15 significant unadjusted TDH trends found in tributaries, 6 were found to be decreasing with the remaining 9 increasing. The 10 significant tributary trends in DHE were split evenly between increasing and decreasing. Given that all sites are subject to approximately the same external climate influences, which would promote increased temperatures from 2008-2021, it would stand to reason that some non-climate influence is driving decreasing temperature trends at certain sites. Yet, very few of the these decreasing tributary trends are within or downstream-adjacent to restoration activity. In a meta-analysis, Arismendi et al. (2012) found that many stream temperature monitoring locations with relatively short and recent periods of record exhibited cooling trends, at odds with predictions based on climate trends over the same time period. Passive, natural recruitment and maturation of riparian vegetation is one possible explanation for these observations, but additional site-specific data would be necessary to explain these observations.

Adjusted TDH trend analysis produced a more even balance of trends detected between mainstem and tributary sites, with 10 of 18 significant trends observed in tributaries. Adjusted DHE showed a similar distribution between site types and had 4 significant tributary trends and 3 significant mainstem trends for all months.

Tributaries have previously been identified as providing crucial cold-water input to the MFJDR and as being sources of thermal refugia for salmonids during the hottest portions of the year (Middle Fork IMW Working Group 2017). Examining the distribution of significant temperature trends between tributary and mainstem sites was one objective of this analysis. It seems that unadjusted TDH and DHE trends occur in tributary locations at a much higher rate than in mainstem locations, but adjusted temperature response is relatively even between the two groups. This might suggest that tributaries are more sensitive to external factors affecting temperature than their mainstem counterparts – however, the direction of unadjusted tributary trends is neither overwhelmingly increasing or decreasing. This suggests that climate variation – which has trended towards conditions which would increase stream temperature during the study period – is not wholly responsible for the observed trends in unadjusted TDH/DHE. Additional site-specific data will be necessary to determine why certain tributary sites are increasing or decreasing, especially given that very few of them are located proximate to documented restoration.

Restoration vs Control

Examining the proximity of monitoring stations having significant trends to local or upstream restoration was a primary objective of this analysis. Of the 16 locations having significant trends in unadjusted TDH, only one was near restoration activity. This site (MFJD_lwrForrestCABoundary) was at the downstream end of a Tribally-owned conservation property which has seen significant upstream restoration it the form of large wood placement, and riparian protection and enhancement. While this site was found to be decreasing in TDH, this trend was only present for September.

One site (RaggedCr_Lwr) was found to have a decreasing trend in unadjusted DHE throughout the study period and is located within the Tribally-owned Oxbow Conservation Area

(OCA). This site is located in Ragged Creek just above its confluence with the MFJDR, an area which was re-aligned, planted, and received large wood supplementation during restoration. This site only showed a significant trend during the month of August. Two other sites (MFJD_TNC_WBoundary and MFJD_aRelocationRPB) showed increasing trends in unadjusted DHE in August and September, respectively, and are located downstream of light-to-moderate restoration density – mostly comprised of passive restoration actions.

Adjusted TDH for July revealed the greatest number of decreasing trends within restoration reaches, with 5 locations within the OCA and one location in Upper Camp Creek. The OCA received an extensive, multi-phased restoration effort between 2012-2017 which included channel realignment, large wood supplementation, floodplain reconnection, and riparian protection and enhancement (Figure 17). It is noteworthy that a cluster of significant decreasing adjusted TDH trends occurred in this reach, as the OCA restoration project is by far the most intensive and extensive restoration action included in the referenced restoration inventory. Yet, these trends are only elucidated after correcting for climate variation, and with the exception of MFJD_inAlcove4, are only observed during July. While this may be encouraging for restoration practitioners, it highlights the importance of stream-temperature drivers that are outside the purview of watershed-specific management agencies. Additional actions may be necessary to strengthen the mitigation of climate-driven stream temperature influences, but it is unclear how this might be achieved.

Figure 17. Comparison of the Oxbow Conservation Area before and after restoration. Five of the 10 significant trends occurring in adjusted July TDH were observed at this location.

Relatively few significant trends in adjusted DHE were observed, but three of these were located within the OCA restoration reach. These three sites – MFJD_inAlcove4, MFJD_inAlcove1, and GraniteBoulderCr_amouth – were found to be decreasing in adjusted DHE for July and also displayed decreasing trends in adjusted TDH.

The restoration inventory used for this analysis is current through 2017. A significant amount of restoration has occurred since then and an updated inventory may provide additional context for trends that were observed to occur in non-restored areas as of 2017. Further, additional land-use changes or environmental disturbances should be taken into account when attempting to understand the causes of observed trends. For example, changes in USFS cattle grazing rotations would not be captured in the IMW restoration inventory, yet the subsequent effect on riparian condition may have important implications for understanding local temperature trend. Similarly, natural disturbance events such as forest fires may alter landscape features and result in altered stream temperature trends. While these factors may not be directly related to restoration effectiveness monitoring, they may provide important information for prioritizing future restoration reaches or evaluating other management actions affecting stream temperature.

Lastly, the specific type of restoration employed at a given location will dictate the magnitude of temperature response. For example, the placement of in-channel wood structures may elicit a smaller temperature decrease (Nichols and Ketcheson 2013) than the re-establishment of a riparian canopy (Sugimoto et al. 1997). A restoration inventory that includes metrics which quantify specific aspects of a restoration action (e.g., number of plants installed, number of wood structures installed) would provide critical insight regarding the effectiveness of specific strategies in mitigating in-stream temperature.

Conclusion

The results of this analysis are typified by a temperature monitoring network which is, for the most part, not displaying any consistent warming or cooling trend. The vast majority of sites are seemingly stable; of those that presented significant trends, most were only present for a single month. The general stability of temperature is not necessarily a bad thing, and could be indicative of mitigation that is occurring to offset external factors which are trending towards conditions which would be expected to increase temperature. Since 2008, average air temperature has increased and MFJDR discharge has decreased. While this would be expected to produce warming trends at stream monitoring stations, relatively few sites are experiencing significant increasing trends.

While stream temperature stability in the face of warming climate and decreasing flow is better than stream warming, it does not mean that the goal of managers and restoration practitioners in context of temperatures is being met. The goal is, ultimately, to reduce stream temperatures in spite of external factors, and generally this is not happening. Whether this is justification for adaptive management or modification of restoration strategy is under the purview of resource managers. The length of time for which the IMW has been active is relatively small in an ecological context, and some of the responses that would have the greatest effect on reducing stream temperature may require significant time to be realized. In particular, riparian restoration in the Middle Fork John Day is constrained by the growing season and the rate of vegetative loss due to ungulate browse (Beschta and Ripple 2005). Overall, there were relatively few significant trends detected given my use of a 0.1 significance level, and the locations and directions of trends didn't indicate strong, clear patterns. One reason for this could be the length of time over which restoration elicits a response in habitat condition, but could also be attributed to inherently noisy data, background effects, and unrestored reaches diluting the effects of local restoration.

My study attempted to identify response variables that related to two specific temperature-related metrics – the total amount of energy in the system, and the threshold at which salmonid stress is realized. Other metrics have been used for temperature analysis (Diabat 2014), and communication between researchers and managers/restoration practitioners should continue to fully define useful and relevant response metrics. The response metrics used in this analysis required fairly stringent data-availability and quality standards and ultimately precluded the use of many of the candidate sites. Alternative response metrics (e.g., average daily temperature, average daily TDH) could be adapted to datasets with small amounts of missing data and would expand analysis eligibility to a broader range of sites. The failure of many candidate sites to meet my analysis criteria was due to missing data rather than data quality issues; this highlights the need for diligent temperature logger maintenance, standardized monitoring protocols, and timely QA/QC procedures to identify corrective actions.

Altered landscapes and in-stream habitat have affected the regulation of stream temperature in the MFJDR, and the predicted effects of climate change have the potential to depress fish distribution and population health in the Pacific Northwest (Beechie et al. 2012). Stream and riparian restoration has been proposed as a method for ameliorating the deleterious effects of climate change (Justice et al. 2017) and significant resources have been allocated towards these efforts in the MFJDR. Continued coordination between data-collectors and data-users will be required to evaluate the cumulative effectiveness of both the restoration and monitoring actions employed through the Middle Fork IMW.

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Appendix A – Data Availability by Site and Month

Data Availability for Each Site by Month

	Site	July	August	September
1	BatesPond_linebottom	Yes	Yes	Yes
2	BatesPond_linemiddle	Yes	Yes	Yes
3	BatesPond_linetop	Yes	Yes	Yes
4	BigBoulderCr_upr1	* * *	* * *	* * *
5	BridgeCr_1	Yes	Yes	Yes
6	BridgeCr_amouth	Yes	Yes	Yes
7	BridgeCr_apond1	* * *	* * *	* * *
8	BridgeCr_bdam1	Yes	Yes	Yes
9	BridgeCr_pnt5mileapond	* * *	* * *	* * *
10	ButteCr_bculvert	Yes	Yes	Yes
11	CampCr_lwr2	Yes	Yes	Yes
12	CampCr_mid1	* * *	* * *	* * *
13	CampCr_upr1	*	Yes	Yes
14	CampCr_upr3	Yes	Yes	Yes
15	CBW05583-050162	* * *	* * *	* * *
16	CBW05583-076530	Yes	Yes	Yes
17	CBW05583-144394	*	*	Yes
18	CBW05583-207602	* * *	* * *	* * *
19	CBW05583-250506	Yes	Yes	Yes
20	CBW05583-275954	*	*	Yes
21	CBW05583-314610	Yes	Yes	Yes
22	CBW05583-330226	* * *	* * *	* * *
23	CBW05583-381682	*	Yes	Yes
24	CBW05583-383986	*	Yes	Yes
25	CBW05583-404210	* * *	* * *	* * *
26	CBW05583-414730	Yes	*	Yes
27	CBW05583-415218	* * *	* * *	* * *
28	CBW05583-429810	Yes	Yes	Yes
29	CBW05583-438922	Yes	Yes	Yes
30	CBW05583-449266	*	Yes	Yes
31	CBW05583-477938	Yes	Yes	Yes

Data Availability for Each Site by Month

	Site	July	August	September
32	CBW05583-515058	* * *	* * *	Yes
33	CBW05583-531698	* * *	* * *	Yes
34	ClearCr_aCORd20	* * *	* * *	* * *
35	CoyoteCr_bRoad	Yes	Yes	Yes
36	DavisCr_mid	Yes	Yes	Yes
37	DavisCr_upr	Yes	Yes	* * *
38	DeadCowGulch_amouth	*	Yes	Yes
39	DeadwoodCr_lower	*	*	* * *
40	DeadwoodCr_Upper	* * *	* * *	Yes
41	DeerhornCr_amouth	*	*	Yes
42	EastFork_BigCr_Mouth	Yes	Yes	* * *
43	GraniteBoulderCr_amouth	Yes	Yes	Yes
44	GraniteBoulderCr_lwr2	Yes	Yes	Yes
45	GraniteBoulderCr_up3	Yes	Yes	* * *
46	GraniteBoulderCr_upr1	Yes	Yes	Yes
47	IndianCr_aLittleIndian	Yes	Yes	Yes
48	LittleBoulderCr_amouth	Yes	Yes	* * *
49	LittleIndian_aMouth	Yes	Yes	Yes
50	MFJD_2.3rm	* * *	* * *	Yes
51	MFJD_a12MileCr_Plemmons	*	*	Yes
52	MFJD_a395BLM	*	*	* * *
53	MFJD_aAlcove4	Yes	Yes	Yes
54	MFJD_aAlcove5	* * *	* * *	Yes
55	MFJD_aBeaver	Yes	Yes	* * *
56	MFJD_aBigCr	* * *	* * *	Yes
57	MFJD_aBridgeCr-d	* * *	* * *	* * *
58	MFJD_aCBIV	* * *	* * *	Yes
59	MFJD_aClearCr	*	*	Yes
60	MFJD_aDavisCr	* * *	* * *	Yes
61	MFJD_aDeepCr	*	*	Yes
62	MFJD_aLittleBoulderCr	Yes	Yes	Yes
63	MFJD_aMosquitoCr	Yes	Yes	Yes
64	MFJD_aRelocationFS	Yes	Yes	* * *
65	MFJD_aRelocationRPB	Yes	Yes	Yes

Data Availability for Each Site by Month

	Site	July	August	September
66	MFJD_aVinegarCr	* * *	* * *	Yes
67	MFJD_b12MileCr_Tillay	*	*	* * *
68	MFJD_bBeaverCr	Yes	Yes	Yes
69	MFJD_bBigCr	*	*	* * *
70	MFJD_bBridgeCr	* * *	* * *	Yes
71	MFJD_bButteCr	Yes	Yes	Yes
72	MFJD_bCoyoteCr	*	*	* * *
73	MFJD_bRaggedCr	Yes	Yes	Yes
74	MFJD_bVincentCr	*	Yes	Yes
75	MFJD_inAlcove1	Yes	Yes	* * *
76	MFJD_inAlcove2	Yes	Yes	Yes
77	MFJD_inAlcove4	Yes	Yes	Yes
78	MFJD_inLowestAlcoveOCA	* * *	* * *	* * *
79	MFJD_inUpperAlcoveOCA	*	*	Yes
80	MFJD_lwrForrestCABoundary	*	Yes	Yes
81	MFJD_TNC_EBoundary	Yes	*	Yes
82	MFJD_TNC_WBoundary	*	Yes	* * *
83	OJD03458-000017	* * *	* * *	Yes
84	OJD03458-000536	*	Yes	Yes
85	RaggedCr_lwr	Yes	Yes	* * *
86	VinegarCr_amouth	*	Yes	Yes

Appendix B – 24-hour Temperature Metrics by Site and Month

Temperature Metrics by Site and Month

	Site	Month	Average (C°)	Minimum (C°)	Maximum (C°)	Delta (C°)
1	BatesPond_linebottom	July	18.4	15.1	20.4	0.4
2	BatesPond_linebottom	August	18.7	16.1	20.8	0.3
3	BatesPond_linebottom	September	14.3	11.6	16.9	0.3
4	BatesPond_linemiddle	July	19.9	16.3	22.2	1.1
5	BatesPond_linemiddle	August	20	16.8	22.9	0.9
6	BatesPond_linemiddle	September	15.1	11.7	18.6	0.8
7	BatesPond_linetop	July	20.6	16.8	24.1	2.3
8	BatesPond_linetop	August	20.7	16.9	24.5	2.1
9	BatesPond_linetop	September	15.7	11.8	21	1.8
10	BridgeCr_1	July	14.2	9.1	19.8	6.8
11	BridgeCr_1	August	14	9	19.4	6.1
12	BridgeCr_1	September	11.1	6.4	16.8	5
13	BridgeCr_amouth	July	20.7	14.8	26.3	6.5
14	BridgeCr_amouth	August	18.7	12.7	24.9	6.6
15	BridgeCr_amouth	September	14.1	8.3	21.1	5.4
16	BridgeCr_bdam1	July	21.1	16.7	25.4	3.9
17	BridgeCr_bdam1	August	19.9	15	24.8	3.9
18	BridgeCr_bdam1	September	15.2	10.9	20.2	3.2
19	ButteCr_bculvert	July	13.7	8.7	19	5.7
20	ButteCr_bculvert	August	13.3	8.3	18.4	5.3
21	ButteCr_bculvert	September	10	4.8	15.7	4.3
22	CampCr_lwr2	July	16.8	10.8	23.5	6.8
23	CampCr_lwr2	August	15.9	10.1	22.4	5.8
24	CampCr_lwr2	September	11.2	5.5	18	5
25	CampCr_upr3	July	14.3	7.8	20.4	7.1
26	CampCr_upr3	August	12.4	6.3	19.1	5.8
27	CampCr_upr3	September	8	2.7	14.1	4.3
28	CBW05583-076530	July	14.7	10.6	19.3	4.3
29	CBW05583-076530	August	14.1	10.5	17.8	2.8
30	CBW05583-076530	September	11	6.6	15.5	2.8
31	CBW05583-250506	July	10.6	7	13.8	2.9
32	CBW05583-250506	August	10.7	7	13.7	2.7

Temperature Metrics by Site and Month

	Site	Month	Average (C°)	Minimum (C°)	Maximum (C°)	Delta (C°)
33	CBW05583-250506	September	7.9	3.7	12	2.2
34	CBW05583-314610	July	17.8	12.1	22.8	6
35	CBW05583-314610	August	16.7	10.9	21.8	5.5
36	CBW05583-314610	September	12.8	6.8	18.3	4.8
37	CBW05583-414730	July	14.3	8.7	20.3	5.9
38	CBW05583-414730	September	9.9	3.9	16.3	3.7
39	CBW05583-429810	July	15.1	10.4	19.4	3.3
40	CBW05583-429810	August	13	8.8	16.7	2.9
41	CBW05583-429810	September	9.3	5.2	13.4	2
42	CBW05583-438922	July	13.5	8.1	19.4	7.2
43	CBW05583-438922	August	13.3	7.7	18.6	5.8
44	CBW05583-438922	September	9.5	4.4	15.7	4.3
45	CBW05583-477938	July	13.1	8.7	17.8	4.4
46	CBW05583-477938	August	12.3	8	16.4	3.9
47	CBW05583-477938	September	8.9	4.3	13.9	3
48	CoyoteCr_bRoad	July	15.5	10.1	20.9	5.7
49	CoyoteCr_bRoad	August	14.9	9.4	20.2	5.1
50	CoyoteCr_bRoad	September	11.8	6.5	17	4.5
51	DavisCr_mid	July	12.4	7.8	17.5	5.3
52	DavisCr_mid	August	12.4	7.7	17.1	4.7
53	DavisCr_mid	September	9.3	4.5	14.2	3.6
54	DavisCr_upr	July	11.4	7.8	14.4	2.9
55	DavisCr_upr	August	11.4	7.9	14.1	2.5
56	DavisCr_upr	September	8.8	5	12.1	1.9
57	EastFork_BigCr_Mouth	July	12.4	8	16.5	4
58	EastFork_BigCr_Mouth	August	12.2	7.7	16.4	3.8
59	EastFork_BigCr_Mouth	September	9.5	4.8	14.2	3.1
60	GraniteBoulderCr_amouth	July	14.3	9.4	19.4	5.2
61	GraniteBoulderCr_amouth	August	14.8	11.2	18.6	3.5
62	GraniteBoulderCr_amouth	September	11.8	7.8	15.6	2.1
63	GraniteBoulderCr_lwr2	July	12.8	8	17.2	4.4
64	GraniteBoulderCr_lwr2	August	13.3	8.8	17.6	4.4
65	GraniteBoulderCr_lwr2	September	10	5.2	15.2	3.5
66	GraniteBoulderCr_up3	July	11	6.6	15.1	4

Temperature Metrics by Site and Month

	Site	Month	Average (C°)	Minimum (C°)	Maximum (C°)	Delta (C°)
67	GraniteBoulderCr_up3	August	11.9	7.9	15.7	3.3
68	GraniteBoulderCr_up3	September	9.2	5.2	13.4	2.7
69	GraniteBoulderCr_upr1	July	10.6	6.4	14.5	3.7
70	GraniteBoulderCr_upr1	August	11.6	7.6	15.2	3.1
71	GraniteBoulderCr_upr1	September	8.8	4.7	13	2.5
72	IndianCr_aLittleIndian	July	14.9	9.3	20.6	5.6
73	IndianCr_aLittleIndian	August	14.2	8.8	20	5.3
74	IndianCr_aLittleIndian	September	10.3	5	16.2	4.3
75	LittleBoulderCr_amouth	July	15	8.8	21.7	7.3
76	LittleBoulderCr_amouth	August	14.5	8	20.4	6.3
77	LittleBoulderCr_amouth	September	10.6	4.4	17.5	5.1
78	LittleIndian_aMouth	July	14.8	8.8	20.5	6.3
79	LittleIndian_aMouth	August	14.2	8.6	19.9	5.4
80	LittleIndian_aMouth	September	10.7	5.3	15.8	4.4
81	MFJD_aAlcove4	July	17.9	12.1	23.3	6.2
82	MFJD_aAlcove4	August	17.5	11.8	22.8	5.2
83	MFJD_aAlcove4	September	12.9	7.1	19.3	3.9
84	MFJD_aBeaver	July	17.3	11.8	22.4	5.6
85	MFJD_aBeaver	August	16.8	11.9	21.8	4.7
86	MFJD_aBeaver	September	12.4	6.9	18.3	3.7
87	MFJD_aLittleBoulderCr	July	18.7	12.3	24.9	6.9
88	MFJD_aLittleBoulderCr	August	17.2	10.9	22.7	5.8
89	MFJD_aLittleBoulderCr	September	12.7	6.9	18.7	4.1
90	MFJD_aMosquitoCr	July	20.4	13.6	26.5	6.4
91	MFJD_aMosquitoCr	August	19.5	13.2	25.4	6
92	MFJD_aMosquitoCr	September	14.6	8.7	21	4.4
93	MFJD_aRelocationFS	July	20.2	13.3	26.1	6.5
94	MFJD_aRelocationFS	August	19.4	13.1	25.1	5.4
95	MFJD_aRelocationFS	September	14.5	8.4	20.8	4.1
96	MFJD_aRelocationRPB	July	20	12.9	25.8	6.1
97	MFJD_aRelocationRPB	August	19.4	12.9	25.7	6
98	MFJD_aRelocationRPB	September	14.9	8.9	21.7	5.3
99	MFJD_bBeaverCr	July	18.3	12.5	23.7	6
100	MFJD_bBeaverCr	August	17.4	12	22.8	5.1

Temperature Metrics by Site and Month

	Site	Month	Average (C°)	Minimum (C°)	Maximum (C°)	Delta (C°)
101	MFJD_bBeaverCr	September	13.2	7.7	18.6	4
102	MFJD_bButteCr	July	17.8	11.3	24.6	7.8
103	MFJD_bButteCr	August	17.1	10.8	24.5	7.4
104	MFJD_bButteCr	September	12.7	6.8	20.2	6.1
105	MFJD_bRaggedCr	July	17.4	11.1	23	6.4
106	MFJD_bRaggedCr	August	17.2	11.2	22.6	5.8
107	MFJD_bRaggedCr	September	13.2	7.2	18.9	4.9
108	MFJD_inAlcove1	July	15.6	12.1	19.3	4.3
109	MFJD_inAlcove1	August	15.9	12.5	19.8	3.5
110	MFJD_inAlcove1	September	13	9.7	16.6	2.1
111	MFJD_inAlcove2	July	16.1	13.6	18.2	1.5
112	MFJD_inAlcove2	August	16.8	14.9	18.4	1
113	MFJD_inAlcove2	September	13.8	10.8	16.7	0.9
114	MFJD_inAlcove4	July	14.6	13.1	15.6	0.3
115	MFJD_inAlcove4	August	15	13.7	16.2	0.3
116	MFJD_inAlcove4	September	12.6	10.1	14.6	0.5
117	MFJD_TNC_EBoundary	July	18.3	11.4	24.6	7.8
118	MFJD_TNC_EBoundary	September	13.4	6.7	21.4	6.7
119	RaggedCr_lwr	July	14.7	9.2	20.2	6.1
120	RaggedCr_lwr	August	14.3	8.8	19.5	5.1
121	RaggedCr_lwr	September	10.7	5.1	16.3	4
122	CampCr_upr1	August	15.1	7.7	22.3	7.1
123	CampCr_upr1	September	10.4	3.5	18.4	5.8
124	CBW05583-381682	August	14	8.1	20	6.9
125	CBW05583-381682	September	10.2	4	16.8	5.2
126	CBW05583-383986	August	13.9	7.6	20.7	7
127	CBW05583-383986	September	9.7	3.8	16	5
128	CBW05583-449266	August	16.9	10.5	23.1	7.3
129	CBW05583-449266	September	12.8	6.4	19.7	5.8
130	DeadCowGulch_amouth	August	12.5	8.6	18.2	6.4
131	DeadCowGulch_amouth	September	10.9	7.1	16.1	5.2
132	MFJD_bVincentCr	August	16.9	10.7	23.4	6.8
133	MFJD_bVincentCr	September	12.9	6.7	19.5	6.1
134	MFJD_lwrForrestCABoundary	August	16.8	10.1	22.8	6.9

Temperature Metrics by Site and Month

	Site	Month	Average (C°)	Minimum (C°)	Maximum (C°)	Delta (C°)
135	MFJD_lwrForrestCABoundary	September	12.9	6.8	18.5	5.6
136	MFJD_TNC_WBoundary	August	18.4	11.9	25.4	7.2
137	MFJD_TNC_WBoundary	September	14	6.9	21.4	5.7
138	OJD03458-000536	August	15.5	9.3	21.5	7.3
139	OJD03458-000536	September	11.3	5.2	17.4	5.3
140	VinegarCr_amouth	August	15.6	8.8	22.3	7.3
141	VinegarCr_amouth	September	11.2	4.7	18.3	6
142	CBW05583-144394	September	11.4	4.1	19.8	5.9
143	CBW05583-275954	September	14.5	8.7	20.9	4.8
144	DeadwoodCr_lower	September	9.3	3.7	15.6	4.2
145	DeerhornCr_amouth	September	10.3	3.5	18.4	6.4
146	MFJD_a12MileCr_Plemmons	September	16.3	9.5	23.4	6.2
147	MFJD_a395BLM	September	15.6	8.6	24.1	6.4
148	MFJD_aClearCr	September	13.2	6.5	20.5	6.7
149	MFJD_aDeepCr	September	14.2	8.6	21.5	5.7
150	MFJD_b12MileCr_Tillay	September	16.3	9.5	23.9	5.8
151	MFJD_bBigCr	September	13.9	7.3	22.8	6.3
152	MFJD_bCoyoteCr	September	13.4	6.8	20.6	6.3
153	MFJD_inUpperAlcoveOCA	September	12.6	7.6	17	3.6