Umpqua Basin Stream Temperature Characterization – Reference Site 2022 Update and North Umpqua Comparison Site Analysis

(Covering Project Duration 1998-2022)

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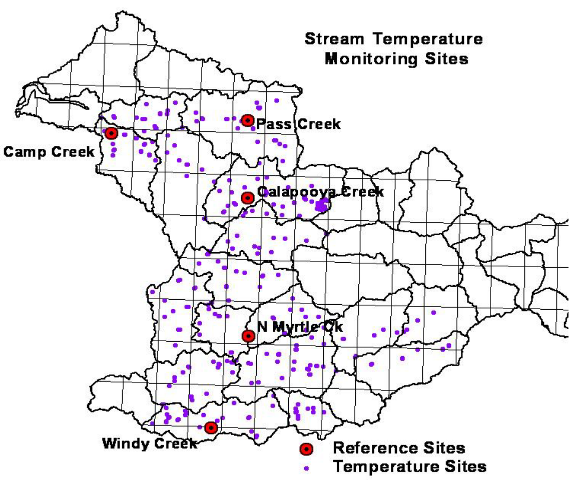
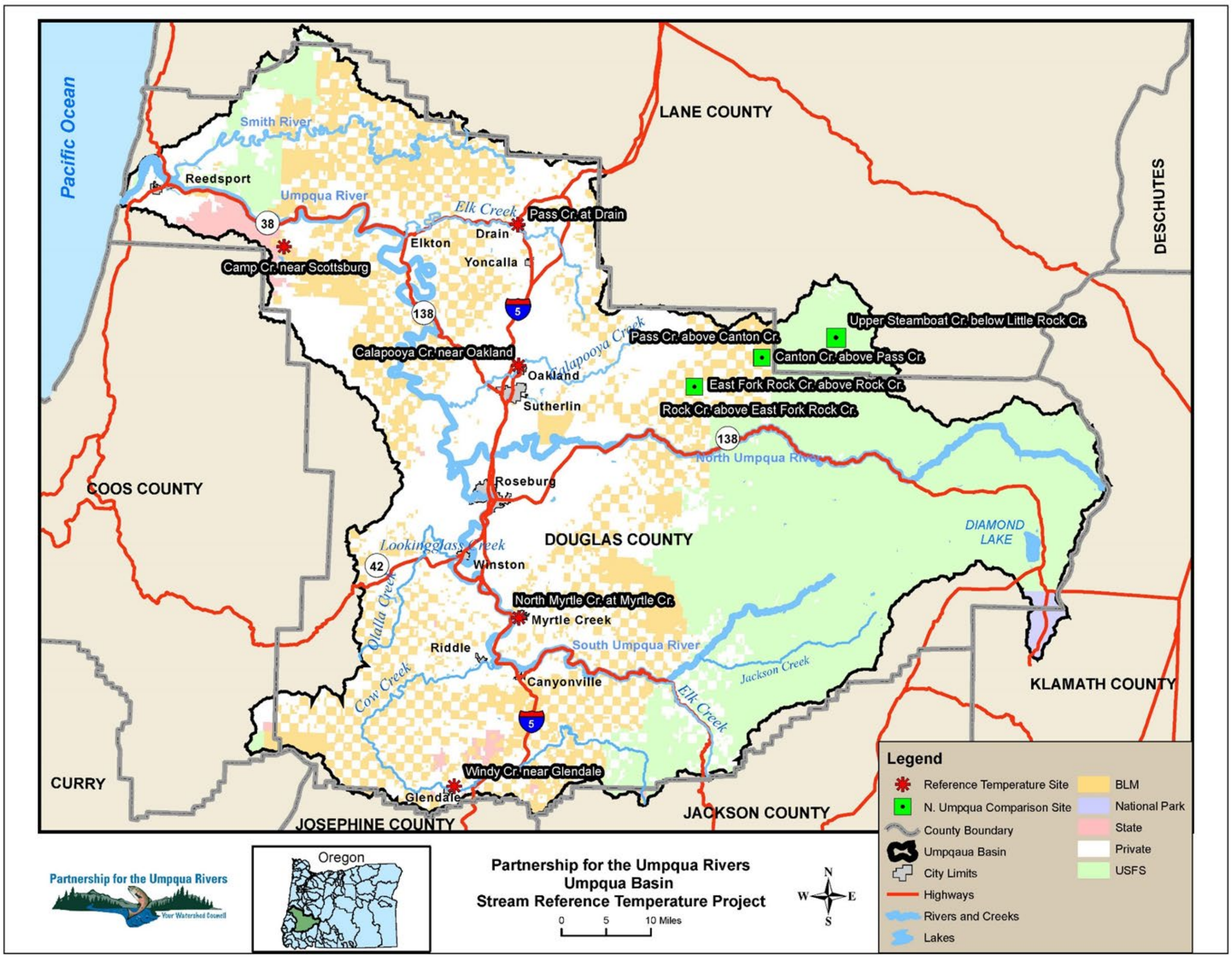
This is the continuation of a long-term summer stream reference temperature monitoring project in the Umpqua Basin of Southwestern Oregon. This report is an update of that project focusing on 2022 stream temperature conditions and comparing that to the air and stream temperature data collected since 1998. In 2020, the project was expanded into the North Umpqua Subbasin and this report will include analysis of stream temperature monitoring of historic sites in that subbasin during a similar timeframe.



The original study, the Umpqua Basin Stream Temperature Characterization Project, was conducted from 1998 – 2001 sampling approximately every ten square miles, to establish the range of variability of stream temperature in the Umpqua Basin temporally and spatially (Smith, 2001a). Air and stream temperature monitoring of five reference sites, chosen based on varying climatic conditions and distance to divide (a surrogate for drainage area), has continued annually to document the patterns of stream temperatures in the Umpqua Basin with an annual report being produced (Smith, 2003, 2004, and 2005; Dammann and Smith, 2006; Dammann, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020a, and 2021). This long-term data set, with 24 years of data, provides a rare opportunity to study stream temperature patterns at these five reference sites (Calapooya, Camp, North Myrtle, Pass, and Windy Creeks). The data and analysis from these sites has been widely used by natural resource professionals working in the basin aiding in science-based management including: supporting effectiveness monitoring of salmon and steelhead habitat restoration projects, corroborating stream temperature baselines and trends in the basin, normalizing for annual variability in other project areas and burn scars lacking long-term data; investigating stream resiliency; and developing strategic plans for water quality and native fisheries preservation.

Photo 1. Downstream from Pass Creek site.

Since the reference temperature sites are in the Umpqua River and South Umpqua Subbasins, partners working in the North Umpqua Subbasin (BLM, The North Umpqua Foundation, PacifiCorp – the North Umpqua Hydroelectric Project, and USFS) expressed interest in the applicability of the reference temperature project analysis to streams in the North Umpqua Subbasin as well, and if the same models and relationships could be used for comparison. For this reason, five historic long-term stream temperature monitoring sites (called comparison sites), were selected based on fisheries, drainage area, disturbance history, proximity to restoration projects in Rock, Canton, and Pass Creeks, and applicability to sites within the newly designated Frank and Jeanne Moore Wild Steelhead Special Management Area. This historic data from four BLM and one USFS monitoring sites (Map 2) were analyzed in the same manner as the reference temperature sites and has been included in the annual reports since 2020 (BLM sites) and 2021 (USFS site). The addition of these sites allows for a better characterization of the entire Umpqua Basin



Map 2. Umpqua Basin Stream Reference Temperature Project and North Umpqua Comparison Sites (Map courtesy of Joe Carnes, PUR)

This report will (1) discuss the effects of air temperature, flow, and day length on stream temperature at these sites focusing mainly on air temperature (2) analyze stream temperature patterns at the Umpqua basin reference temperature sites for 2022 as well as the period of record (3) discuss several methods of using the reference temperature data in conjunction with project data throughout the basin to reduce annual variability and to expand on project data lacking multiyear data and (4) analyze the historic BLM and USFS data from the North Umpqua "comparison" sites to determine trends and demonstrate the feasibility of using similar analysis tools for data in this subbasin. For specific analysis on previous years including climatological conditions, air temperatures, stream temperature analysis, see previous annual reports (Smith, 2003, 2004, and 2005; Dammann and Smith, 2006; Dammann, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020a, and 2021).

Site characteristics are shown in Table 1. The original five reference temperature sites are in the left columns and the added North Umpqua sites are in the right columns. Some of the North Umpqua sites have been monitored since before 1998, but that data is not analyzed in this report.

Table 1. Site information.

	Calapooya Ck	Camp Ck	N Myrtle Ck	Pass Ck	Windy Ck	Canton Ck above Pass	East Fork Rock Ck above Rock Ck	Pass Ck - NU (Pass above Canton)	Rock Creek above East Fork Rock Ck	Upper Steamboat Ck below Little Rock Ck
Period of record for this report	1999-present	2000-present	1999-present	1998-present (no 2005)	2000-present	1998-present (no 2001 & 2003)	1998-2000, 2004-present (no 2013, 2015 or 2018)	1998-present (no 2001, 2003 & 2013)	1998, 2004-present (no 2013, 2016, 2018)	1998-present (no 2001-2003)
Additional Historic Data (not included)	-	-	-	-	-	1991-1997 (no 1993)	1994, 1996, 1997	-	1996-1997	1969-1997
Type of site	Reference Temperature	Reference Temperature	Reference Temperature	Reference Temperature	Reference Temperature	North Umpqua Comparison (BLM data)	North Umpqua Comparison (BLM data)	North Umpqua Comparison (BLM data)	North Umpqua Comparison (BLM data)	North Umpqua Comparison (USFS data)
Drainage area (acres)	103,500	22,550	37,190	40,090	15,660	12,480	14,270	10,230	23,800	33,540
Maximum elevation in drainage (ft)	4400	2560	3300	1960	3700	4800	4600	4200	4700	5980
Tributary to	Umpqua R	Mill Ck	Myrtle Ck	Elk Ck	Cow Ck	Steamboat Ck	Rock Ck	Canton Ck	N. Umpqua R	N. Umpqua R
Subbasin	Umpqua	Umpqua	S. Umpqua	Umpqua	S. Umpqua	N. Umpqua	N. Umpqua	N. Umpqua	N. Umpqua	N. Umpqua

Factors Affecting Stream Temperature:

In the Pacific Northwest, stream temperatures affect the aquatic life with higher summer stream temperatures increasing stress in native cold-water salmonids resulting in decreased vigor and possibly death (Brett, 1952; Hokanson, *et al.*, 1977; and Bell, 1986). Stream temperatures are influenced by a combination of factors including day length, canopy cover, discharge, topography, stream bed and morphological characteristics, and solar radiation (Beschta, *et al.*, 1987). Radiant energy, specifically, solar radiation, is a very important factor in heating streams (Brown, 1969 and Beschta, *et al.*, 1987), and the sun has been called the principal energy source for warming of streams (Brown and Kryiger, 1970). Isaak *et al.* (2012) also found that air temperature was a much stronger predictor of stream temperature than discharge. Solar radiation reaching streams is reduced by canopy cover, but can vary daily due to changes in day length, changes in cloud cover, and changes in solar output (which is often expressed by air temperature changes).

2022 Regional Weather Summary:

The reference temperature sites are surrounded by the cities of Roseburg, Eugene, and Medford in Western and Southwestern Oregon; therefore, the air temperature patterns and extremes at these sites follow those of these three cities (Tables 2, 3, and 4; NWS, 2022a and 2022b; and Iowa State University of Science and Technology (ISU), 2022). While the reference temperature study sites do not have headwaters in the snow zone, their headwaters are in the transient snow zone; therefore, flows are not typically impacted by the snowpack. The North Umpqua sites to the east are slightly higher in the watershed with a small portion of the watershed above them in the snow zone (>4000 ft.) and a larger portion in the transient snow zone (Table 1). Significant past summer weather patterns or events during the period of record of this study are included in this update, but for a complete description, see previous annual reports.

May, 2022 was cooler and wetter than normal during the first half of the month and cooler in the second half. Medford did not have a day above 90ºF degree day in May. The average first day above 90ºF is May 20th. (NWS, 2022c) The first three weeks of June were wetter and cooler and the final week was dryer and hotter, but cooled down the last few days of the month. Notably, Medford air temperature didn't exceed 90ºF until June 21st (NWS, 2022d). July, 2022 began cool with significant rain around the 4th of July. A more typical summer weather pattern began July 10th with hot, dry temperatures. The last week of July, temperatures were very hot throughout the region, on track to stay in the high 90's or over 100 degrees, until the McKinney Fire in Siskiyou County, California ignited on July 30th cooling the region with the blanket of smoke. (NWS, 2022e) August was characterized by persistent hot and dry conditions and the end of August brought smoke from Rum Creek Fire near Galice, Oregon. (NWS, 2022f). Hot, dry conditions continued until September 11th, and then there was cool and wet conditions until the last week of September, when there were a few days of hot temperatures followed by cooler, more typical weather (NWS, 2022g). In October, a persistent high-pressure system, brought unusual warmth to the region and blocked the storm track preventing any rainfall until October 21 (NWS, 2022h).

In Roseburg in 2022, May through September had higher daily minimum and maximum temperatures compared to normal with the exception of May (Table 2). The most significant departures were for average maximum temperature in August (+4.5°F) and average minimum temperature in September (+3.9°F). Precipitation was greater than normal in May (+0.59") and June (+1.92") and slightly less than normal in August. July and September were within 0.03 inches of the normal precipitation (Table 2). This is contrasted with 2021 where the late June heat dome resulted in the average maximum temperatures were 7.5°F above normal and the 2nd warmest July on record with 4.7°F above normal (Dammann, 2021).

Photo 2. Elk Creek just below Pass Creek site during high June flows.

Table 2. Monthly Average Maximum Temperatures and Monthly Precipitation for Roseburg, Oregon from May to September, 2022 and 2021. All National Weather Service (NWS) data are preliminary and have not undergone final quality control. (NWS, 2022c, 2022d, 2022e, 2022f, 2022g, NWS, 2021c, 2021d, 2021e, 2021f, and 2021g)

Month	Average Maximum Temperature	Departure from Normal	Average Minimum Temperature	Departure from Normal	Monthly Precipitation	Departure from Normal
May, 2022	66.9°F	-4.1°F	46.4°F	-1.5°F	2.68”	+0.59”
June, 2022	77.0°F	+0.3°F	53.2°F	+0.7°F	2.85”	+1.92”
July, 2022	87.2°F	+1.4°F	59.2°F	+1.8°F	0.25	-0.01”
August, 2022	90.4°F	+4.5°F	59.7°F	+2.6°F	Trace	-0.23”
Sept., 2022	82.1°F	+2.0°F	56.1°F	+3.9°F	0.88”	+0.03”

Month	Average Maximum Temperature	Departure from Normal	Average Minimum Temperature	Departure from Normal	Monthly Precipitation	Departure from Normal
May, 2021	73.8°F	+2.8°F	47.2°F	-0.7°F	0.75”	-1.34”
June, 2021	84.2°F	+7.5°F	56.2°F	+3.7°F	1.45”	+0.52”
July, 2021	90.5°F	+4.7°F	59.8°F	+2.4°F	Trace	-0.26”
August, 2021	87.8°F	+1.9°F	58.9°F	+1.8°F	0.04”	-0.19”
Sept., 2021	81.6°F	+1.5°F	52.4°F	+0.2°F	2.26”	+1.41”

There were several “heat waves” (defined here as three or more consecutive days greater than 85°F) throughout Summer, 2022 (Table 3). From July 24 through September 10 there were only five days with maximum temperatures <85°F – August 10, 12, 19, 27 & 28. This means there was essentially a seven-week heat wave. In addition, in the 9 weeks between July 10 – Sept. 10, there were only 9 days with temperatures <85°F. (Table 3) For comparison in 2021, there was also a nine-week heat wave from June 17 to August 19 (shifted a month earlier than in 2022) with only seven days lower than the threshold amount (Dammann, 2021).

Table 3. Heat waves with at least three consecutive high maximum daily air temperatures above 85°F in Roseburg, Oregon from May to September, 2022. All National Weather Service (NWS) data are preliminary and have not undergone final quality control. (NWS, 2022a)

Date Range	Location	Daily Maximum Air Temperatures
June 25-27	Roseburg	97-100°F
July 10-15	Roseburg	86-96°F
July 17-21	Roseburg	85-94°F
July 24 – August 9	Roseburg	85-103°F (exceeding 100°F - 103, 101, & 102 on 7/25, 7/26, and 7/29 respectively)
August 13-18	Roseburg	87-101°F (exceeding 100°F – 101 on 8/17 & 8/18)
August 20-26	Roseburg	89-98°F
August 29 – Sept. 10	Roseburg	86-99°F

Summer, 2022, there were weather records broken for the three cities in the region (Table 4). In June, there were three rainfall records broken and in July through September there were several maximum temperature records broken and one high minimum temperature on July 30th (Table 4). The last week of July, temperatures were very hot throughout the region, on track to stay in the high 90’s or over 100 degrees, until the McKinney Fire in Siskiyou County ignited on July 30th which blanketed and cooled the region. The week before the fire began the maximum temperatures ranged from 92-103ºF in

Roseburg and 99-114ºF in Medford. Under the blanket of smoke, they cooled to the high 80's to mid 90's (NWS, 2022a). If the fire hadn't occurred, the heat wave would have challenged Medford's all time record for consecutive number of days at or above 100ºF (NWS, 2022e). The daily record of 114ºF in Medford on July 29 was one degree short of the all time high of 115ºF set on 7/20/1946 and 6/28/2021. Even with the cooler temperatures from the smoke, August was the hottest August on record for Medford (Table 4), breaking the record from 2017. During the time of the record-breaking July temperatures, there was also high nighttime air temperatures as well. The significance of high minimum temperatures is discussed in the

"The Effects of Minimum (Nighttime) Temperatures on Summer Stream Temperatures" section.

Table 4. Record weather events for Roseburg, Medford, and Eugene, Oregon from May to September, 2021. All National Weather Service (NWS) data are preliminary and have not undergone final quality control. (Iowa State University of Science and Technology, 2022- and NWS, 2022a, and 2022b)

Date	**Location**	**Record Broken**
June 4, 2022	Roseburg	Highest maximum rainfall for this date (0.66")
June 12, 2022	Roseburg	Highest maximum rainfall for this date (0.74")
June 17, 2022	Medford	Highest maximum rainfall for this date (0.79") and lowest maximum temperature for this date (60°F)
July 25, 2022	Roseburg	Highest maximum temperature for this date (103°F)
July 25, 2022	Medford	Highest maximum temperature for this date (107°F) – ties old record from 1988
July 26, 2022	Eugene	Highest maximum temperature for this date (102°F) – ties old record from 1988
July 28, 2022	Medford	Highest maximum temperature for this date (111°F) – breaks old record of 108°F set in 2009
July 29, 2022	Medford	Highest maximum temperature for this date (114°F) – breaks old record of 109°F set in 2009 (Note: Medford's all-time record high is 115°F set 7/20/46 & 6/28/21)
July 30, 2022	Eugene	Highest minimum temperature for this date (64°F)
August 17, 2022	Roseburg	Highest maximum temperature for this date (101°F)
August 18, 2022	Eugene	Highest minimum temperature for this date (65°F) – ties old record from 1941
August 30, 2022	Roseburg	Highest maximum temperature for this date (99°F)
September 10, 2022	Roseburg	Highest maximum temperature for this date (99°F) – ties old record from 1973
August, 2022	Medford	Hottest August on record – average temperature of 79.0°F breaks the old record of 78.1°F from 2017.

Note: The NWS office in Medford covers Medford and Roseburg. The NWS office in Portland covers Eugene. Sometimes they report different statistics.

Note: Period of records: Roseburg (1930-1965 & 1997-present), Medford (1911-present), Eugene (1892-present)

Temperature Monitoring Methodology:

Beginning between 1998 and 2000, summer air and stream temperature data were collected with continuous temperature recorders set for 30-minute intervals at the five reference sites. From 1998-2008, temperatures were collected from at least July 1 to mid-September; beginning in 2009, the period of record has been from at least June 21 to September 21. However, in 2022, due to extremely high flows, temperature recorders weren't placed until June 22 or June 26. (Figures 1 and 2)

In 2022, as in other years, continuous temperature recorders (Onset Tidbit v.2 model recorders using Onset HOBOware Pro Software) were deployed and placed in the stream and in a nearby tree (for riparian air temperature). Temperature recorders were set to record at 30-minute intervals and deployed after water levels decreased from the high June flows. They were retrieved after September 21. Pre and post season ice/warm water bath accuracy checks on all temperature recorders as well as field audits of the equipment were performed with a National Institute of Science and Technology (NIST) certified digital thermometer (that is checked annually by DEQ Water Quality Monitoring Section staff for accuracy). Temperature monitoring and accuracy checks were conducted according to protocols outlined in the Water Monitoring and Assessment Mode of Operations Manual, Version 3.2 (ODEQ, 2009). The project follows PUR's Quality Assurance Project Plan (QAPP) (PUR, 2014a) and the September, 2016 amendment (PUR, 2016a).

BLM and USFS stream temperature monitoring data has historically been placed during the summer season with the objective of capturing the 7DAM stream temperature and the maximum amount of summer temperature data possible dependent on other workloads and fire and weather conditions. BLM and USFS data also undergo field and pre and post season accuracy checks. However, some of the BLM sites that have been converted to year-round sites in 2013 and did not have pre and post season ice/warm bath accuracy checks for several years. Onset tidbits have very little drift and it is doubtful there is any associated drift error with this equipment, so all data were included in this analysis. However, the lack of some of the data audits did lower the data quality level with the DEQ trend analysis from A to B or to E (unknown quality). It should be noted that in 2020 & 2021 the BLM partnered with PUR, and PUR monitored the East Fork Rock Creek BLM site.

2022 Results - Air and Stream Temperatures:

Figure 1 shows the air temperature taken at the five reference sites and Figure 2 shows the stream temperature at the five reference temperature sites and five North Umpqua comparison sites. At the reference temperature sites, streamside vegetation at the site and upstream has been consistent throughout the course of this study. Also, some of these streams, particularly Calapooya Creek, are quite large, and the riparian vegetation is not as strong of an influence on stream temperature as it is in smaller streams. Metadata on the riparian vegetation and shading has been collected, riparian site characteristics are very stable and unlikely to change under the current ownerships and management objectives, barring wildfire.

The characteristics of the North Umpqua sites have been stable until 2020. The Archie Creek Fire began the morning of September 8th, 2020 and burned through portions of the Rock Creek drainage (Dammann, 2020a). Both the East Fork and Rock Creek water temperature recorders were in place at that time. As a result of the fire, 33% of the drainage burned above Rock Creek at the East Fork confluence (9% high burn severity, 13% moderate, 7% low, and 4% unburned (rock/stream) and 96% of the drainage burned above East Fork Rock Creek at the confluence (38% high burn severity, 35% moderate, 14% low, and 9% unburned (rock/stream) (BLM GIS data, Archie Creek Fire, 2020 and Dammann, 2020a). The Archie Creek Fire did not burn into the Canton and Pass Creek drainages, nor into the Steamboat Creek watershed (Dammann, 2020a). For more information about the effects of the fire on stream temperatures in 2020 at the time the fire burnt over and while there was a blanket of smoke over the region see Dammann (2020a).

At the Rock Creek site on August 3rd between 12:30 and 13:00 the temperature drops and then stays low the rest of the summer with diminished diurnal fluctuation (Figure 2). There was excavation work in the stream at that time to create pools to try to encourage cooling from hyporheic flow. The work got in close proximity upstream from the site at that time. While the excavation met the desired goal of encouraging hyporheic flow and decreasing stream temperature, it also affected the temperature at this site after the excavation occurred. While the 7DAM stream temperature for this site was on July 30 and that would be consistent with other sites, the August data would be thrown out from other analysis (including the trend analysis, see subsequent section).

High air temperatures over several days appear to have a stronger effect on increased stream temperature compared with shorter periods of high temperatures since the streams don't have much opportunity for nighttime cooling with the former. This is evident in the stream temperature patterns seen at the reference sites (Figure 1 and 2). As we would expect, when the highest air temperatures are occurring in the surrounding cities, they are for the reference temperature sites as well (Figure 1), and the heat waves at the reference sites corresponded with those in the surrounding cities (Table 3 and Figure 1). The 7-day average maximum (7DAM) stream temperature is a statistic used to describe the average of the maximum stream temperatures over a seven day period (described here as occurring on the center date of that rolling seven day period).

The heat wave of late July to early August had the strongest effect on the 7DAM stream temperature during this summer season. All ten of the sites had the 7DAM stream temperature during that time frame from July 30 to August 1. Windy Creek was the only site with a 7DAM stream temperature on August 1. In previous years (Dammann, 2021, etc.) it has also had delayed timing of the date of this statistic, possibly due to flow conditions or the location in the watershed (as it is the furthest south). Also, the diminished diurnal fluctuation of Windy Creek's stream temperature seems to indicate possible hyporheic flow later in the summer (Figure 2) when flows are lower.

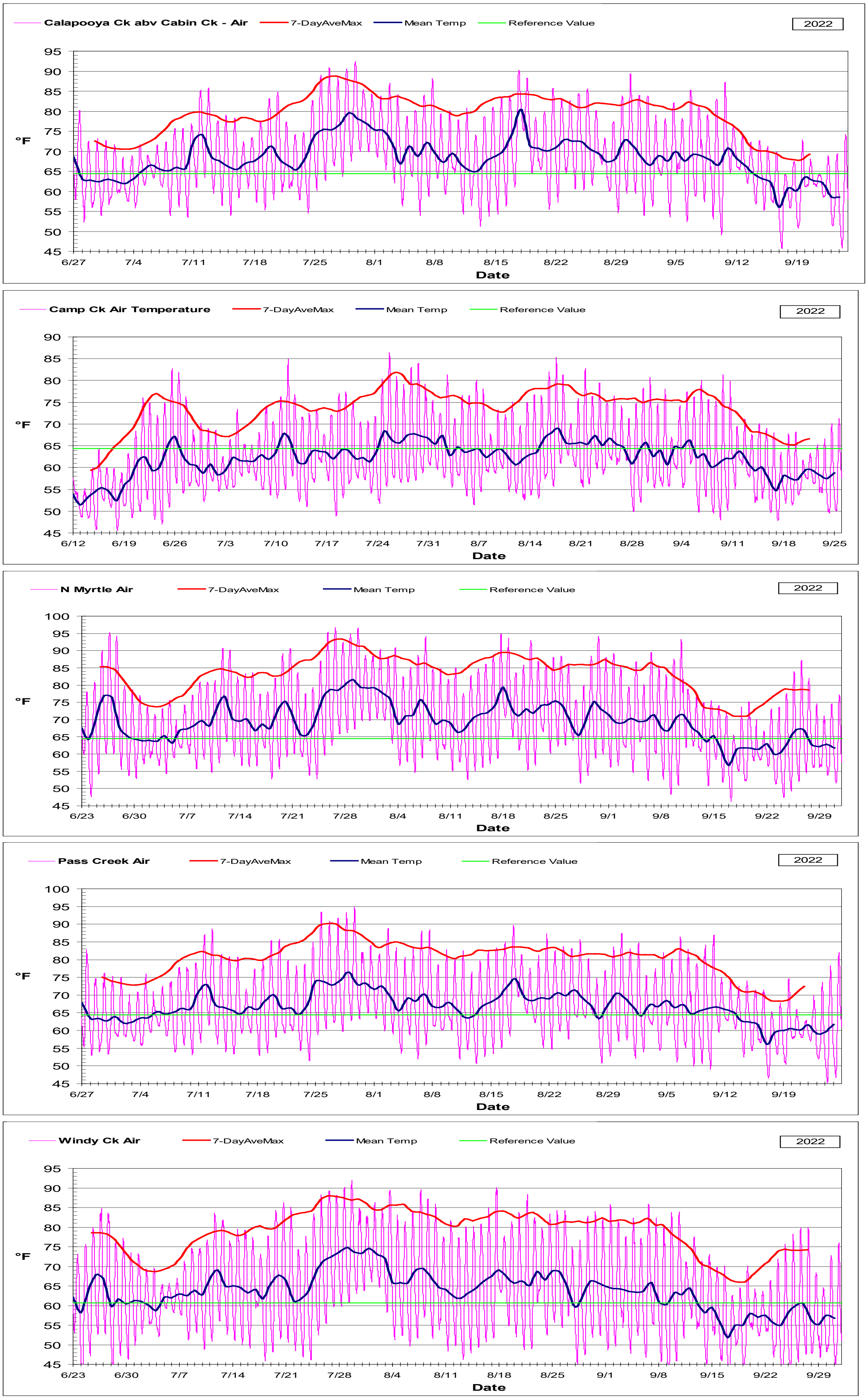


Figure 1. 2022 Umpqua Basin reference site air temperature data measured at 30-minute intervals. The reference value is set at the Oregon Department of Environmental Quality (ODEQ) temperature standard for stream temperature (64.4°F for all except Windy Creek which is 60.8°F (ODEQ 2003 & 2018)). The 7-day average maximum (7DAM) air temperature is centered on the date of the rolling 7-day period.

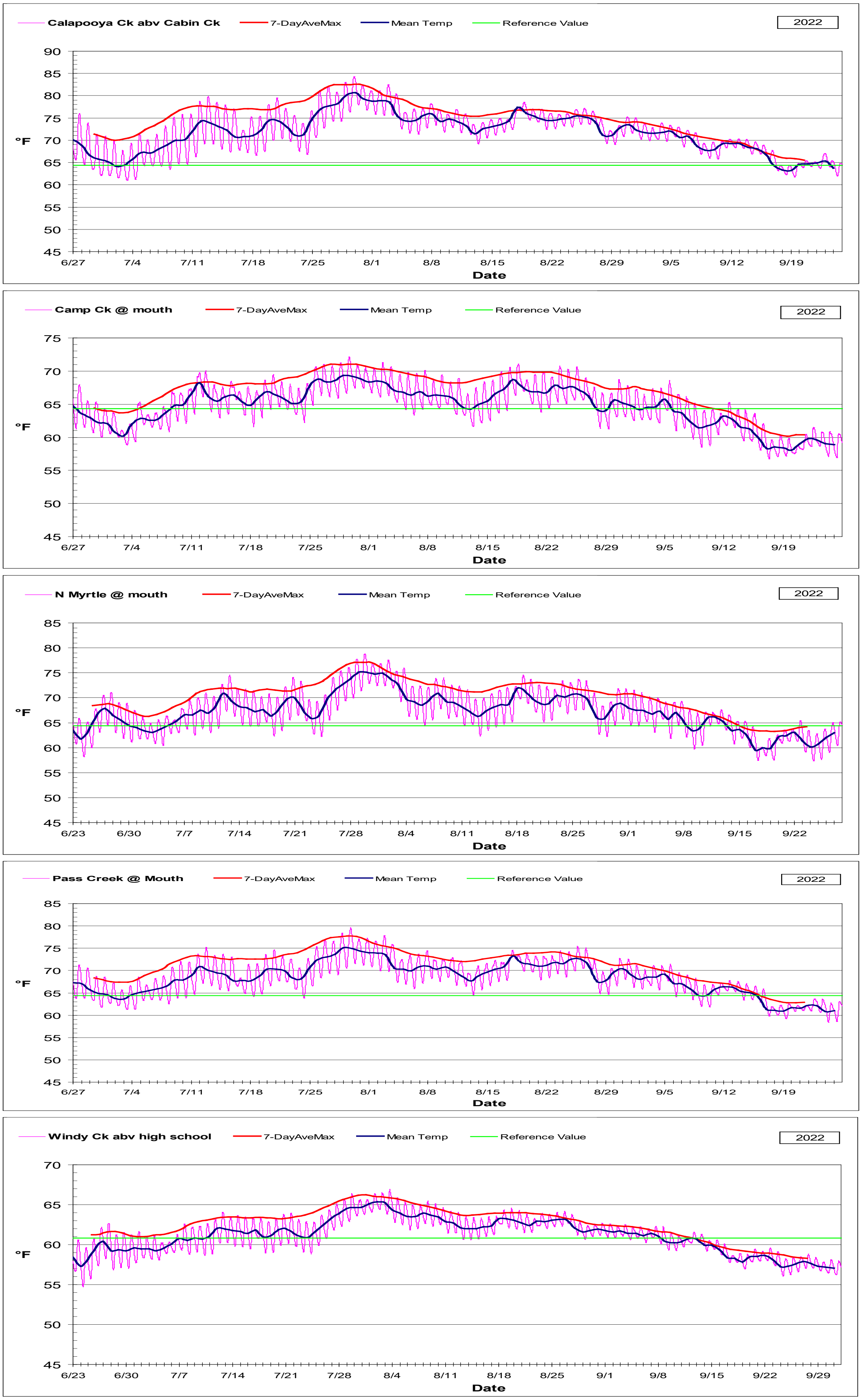


Figure 2. 2022 Umpqua Basin reference site and North Umpqua comparison site stream temperature data measured at 30-minute intervals. The reference value is 64.4°F for all sites except Windy Creek and the four North Umpqua sites which is 60.8°F (ODEQ 2003 & 2018). The 7-day average maximum (7DAM) stream temperature is centered on the date. (First page – reference sites; second page – North Umpqua comparison sites)

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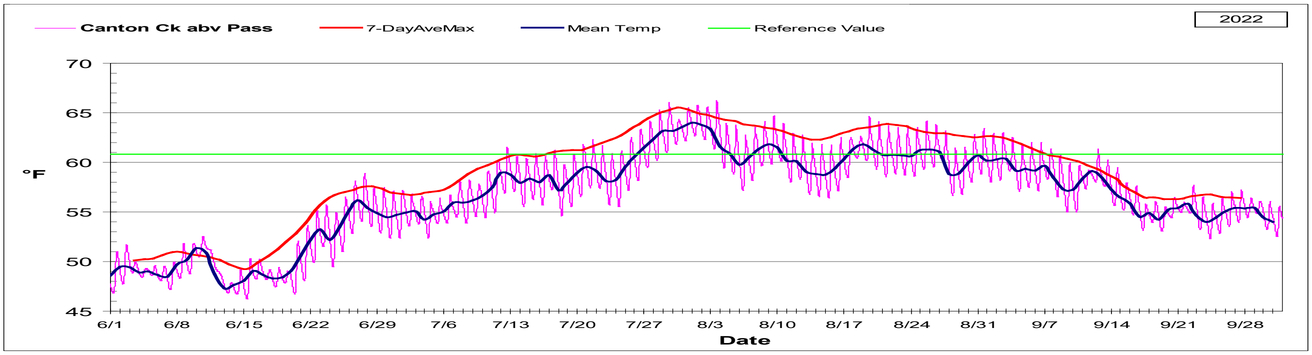
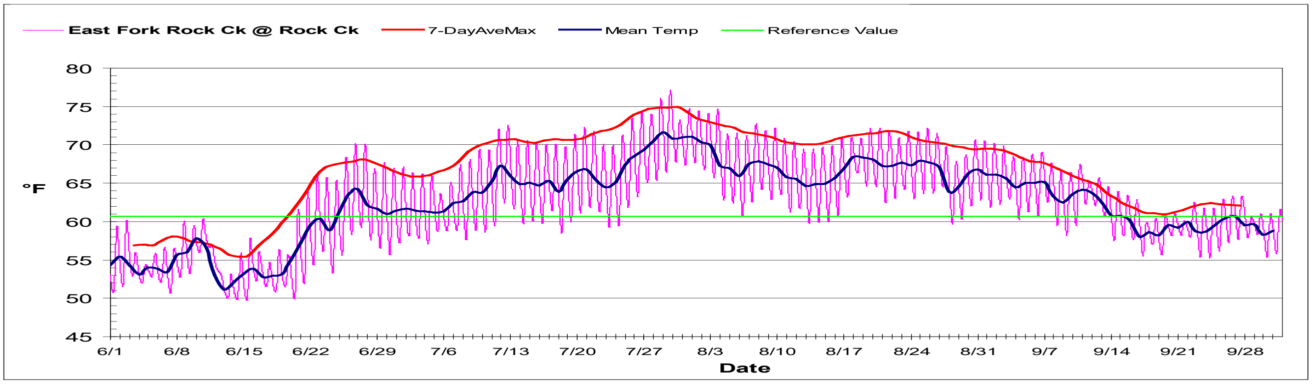
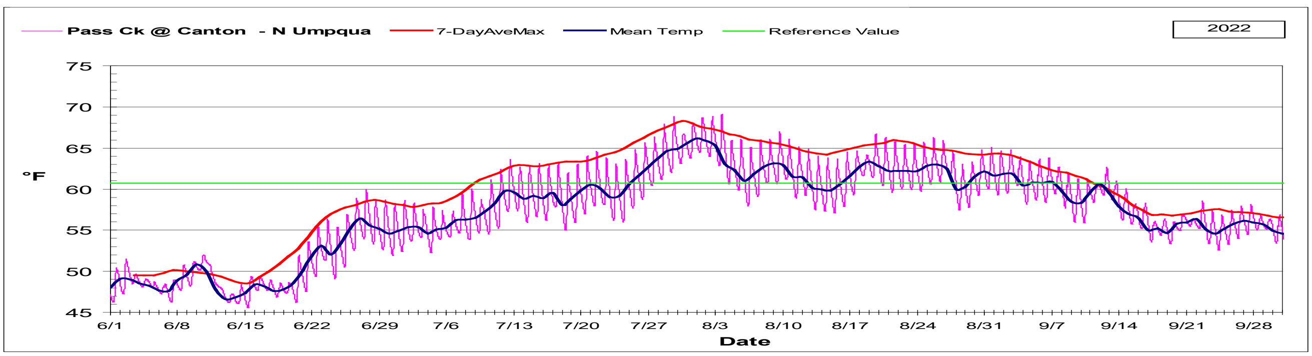
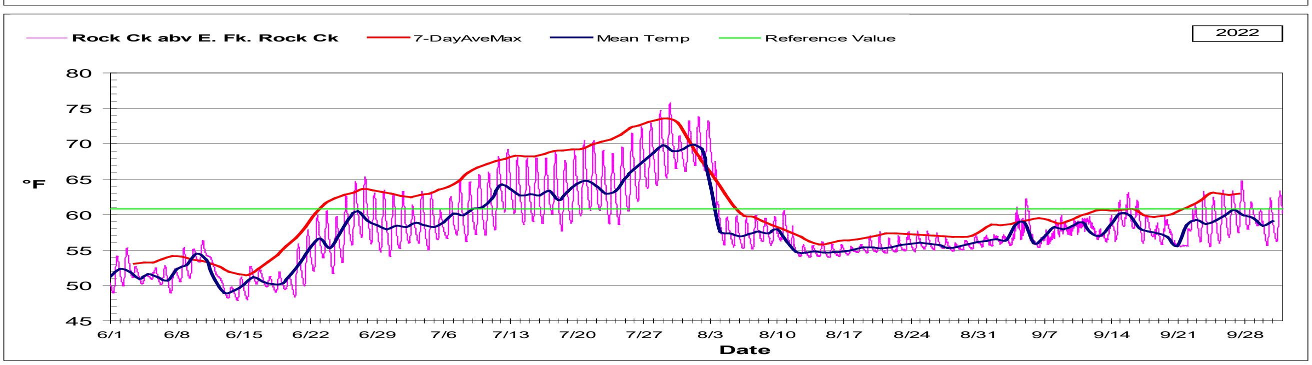








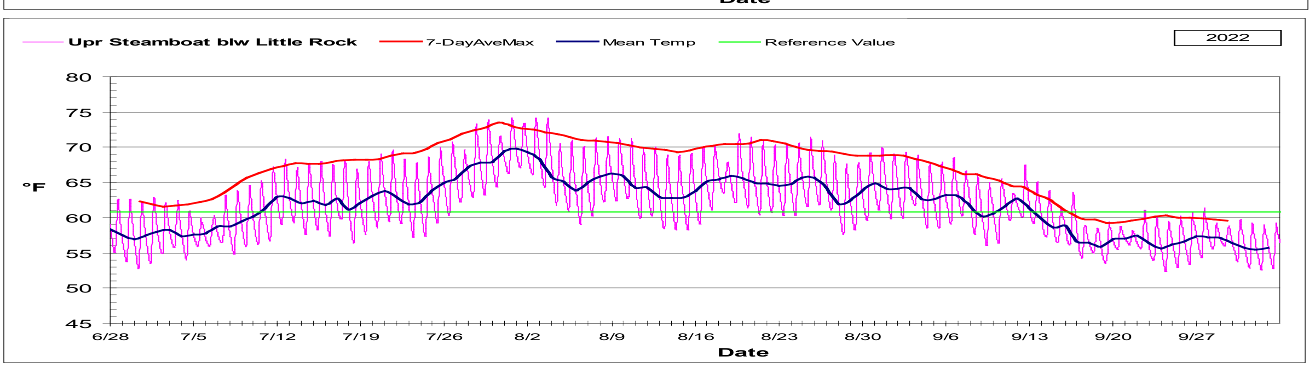


Figure 2. Continued. (Page 2 of 2)

Interannual Variability of 7-Day Average Maximum (7DAM) Stream Temperatures and Importance of Normalization of Short-term Data Sets:

In 2022, the 7DAM stream temperatures for the reference sites exhibited similar patterns to previous years in the 24 year period of record (Figure 3a and 3b). For the reference sites, Calapooya Creek has had the highest 7DAM stream temperatures for the entire period of record and Windy Creek has had the lowest (Figure 3a and 3c). Pass and North Myrtle Creeks continue to have similar 7DAM temperatures, varying from year to year on which is higher and which is lower (Figure 3a and 3c). Camp Creek has always had the second lowest 7DAM stream temperatures with the exception of in 2008 with no known explanation for the anomaly that year (Figure 3a and 3c). Windy Creek is typically much lower in stream temperature compared to the other sites. However, in 2020, the temperature at Windy Creek was much lower previously and was much lower than the other sites (Figure 3a and 3c). There is no known change to the site characteristics that would warrant this change. For the other reference sites, the 2021 7DAM stream temperatures at two sites (Calapooya and Pass) was the highest of the period of record and North Myrtle and Camp were the 2nd highest (Figure 3a and 3c and Table 4).

The North Umpqua comparison sites also display the same pattern of interannual variability and overall, the 7DAM stream temperatures show a similar pattern as the reference temperature sites (Figure 3b and 3c), which is supportive of using these for comparisons to other sites. The Steamboat Creek site has the largest drainage area and also the highest stream temperature. Rock Creek has the 2nd largest drainage area and the 2nd highest stream temperature for every year surveyed (Figure 3b and Table 4). Canton and Pass Creeks have the smaller drainage areas of the five sites and have the lowest stream temperatures (Figure 3b and Table 4). The 7DAM stream temperature for Rock and East Fork Rock Creeks increased markedly in 2021 as a result of canopy lost at the sites and upstream from the 2020 Archie Creek Fire (Dammann, 2020a). In 2022, the 7DAM stream temperature at these sites follows the same pattern as the other sites, where it decreased from 2021, but at a higher temperature. This will be the "new normal" for these burned over sites until the canopy is reestablished.

As a stream flows from its headwaters, its temperature will continue to change, as a result of several factors including increased solar radiation (Beschta, *et al.*, 1987) and increased flow. The Calapooya Creek site is furthest from the ridgetop divide and has the highest 7DAM temperatures. Windy Creek is closest to the divide and has the lowest 7DAM temperatures. Smith (2003) found that the cold limit line where the water temperatures typically exceed 64ºF is at 7 miles from the divide. The reference site data are consistent with that finding, except in 2008 at Windy Creek, which is 9.63 miles from the divide, when the 7DAM stream temperature dropped below 64ºF (Figure 3a). At the time this study was designed, distance to divide was used as a surrogate for drainage area (which was harder to calculate without the GIS tools of today). Drainage area is included in Table 1.

Since many of the factors affecting stream temperatures (surface area, flow, cloud cover, air temperature, and day length) vary daily and annually, this has resulted in annual variability in maximum stream temperatures. 7DAM stream temperature at the reference sites has varied annually as much as 6.34 to 8.28ºF depending on the site during the 24 year period of record (Figure 3a and Table 4). The 7DAM stream temperature at the BLM North Umpqua comparison sites has varied between 4.73 and 5.62ºF (Dammann, 2020a) until 2021 (post-fire), which the unburned sites (Canton and Pass) now range between 5.21 and 5.62 ºF and the burned sites range between 9.49 and 14.19 ºF; Upper Steamboat Creek, with a larger watershed, varies 8.4ºF (Figure 3b and Table 4).

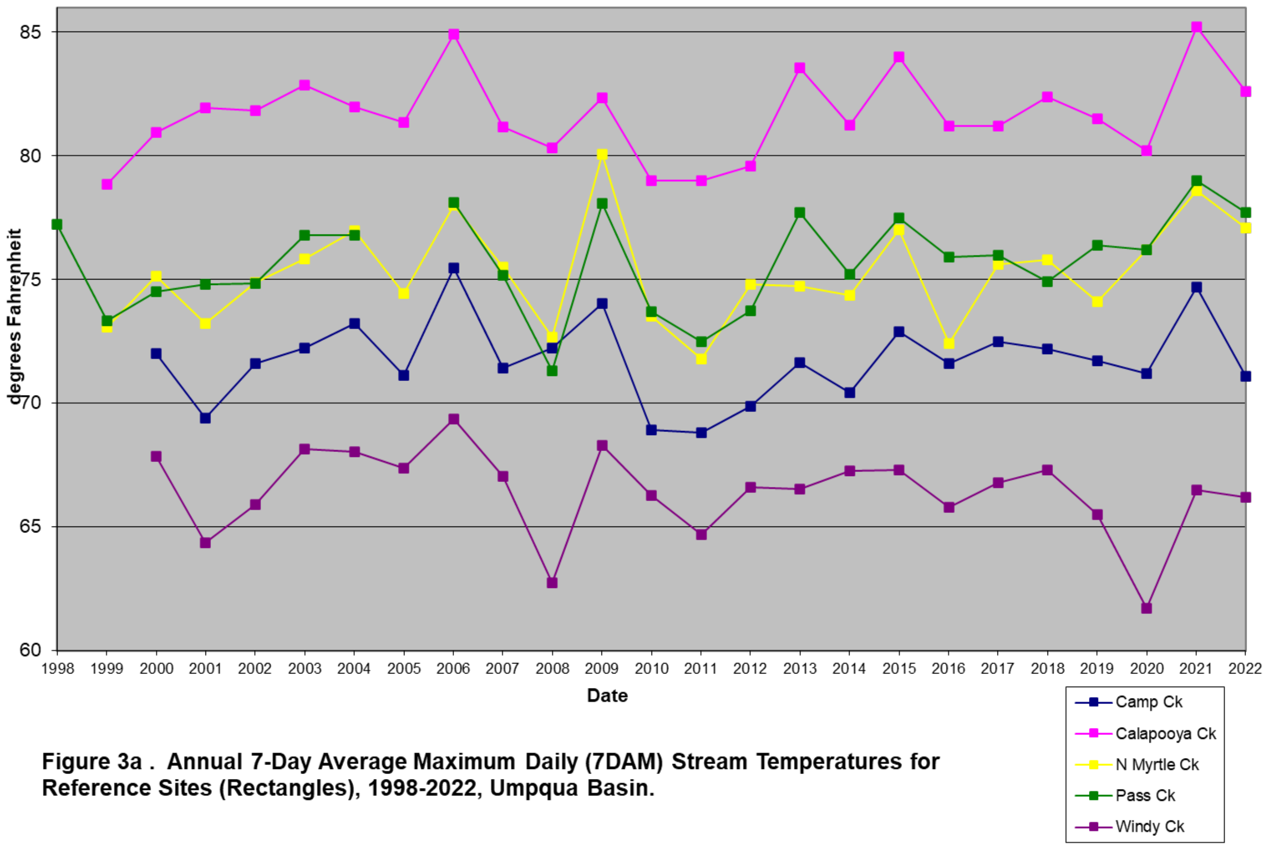


Figure 3a . Annual 7-Day Average Maximum Daily (7DAM) Stream Temperatures for Reference Sites (Rectangles), 1998-2022, Umpqua Basin.

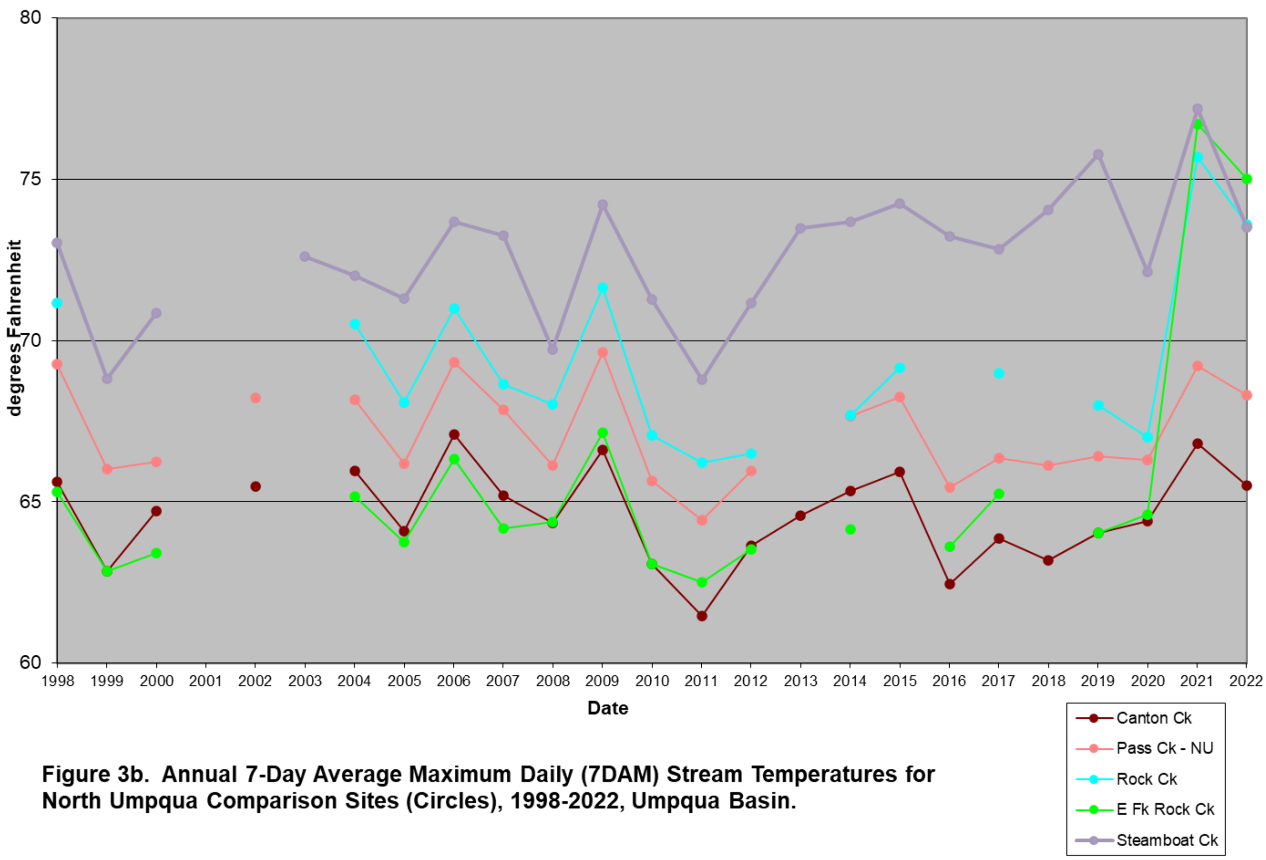


Figure 3b. Annual 7-Day Average Maximum Daily (7DAM) Stream Temperatures for North Umpqua Comparison Sites (Circles), 1998-2022, Umpqua Basin.

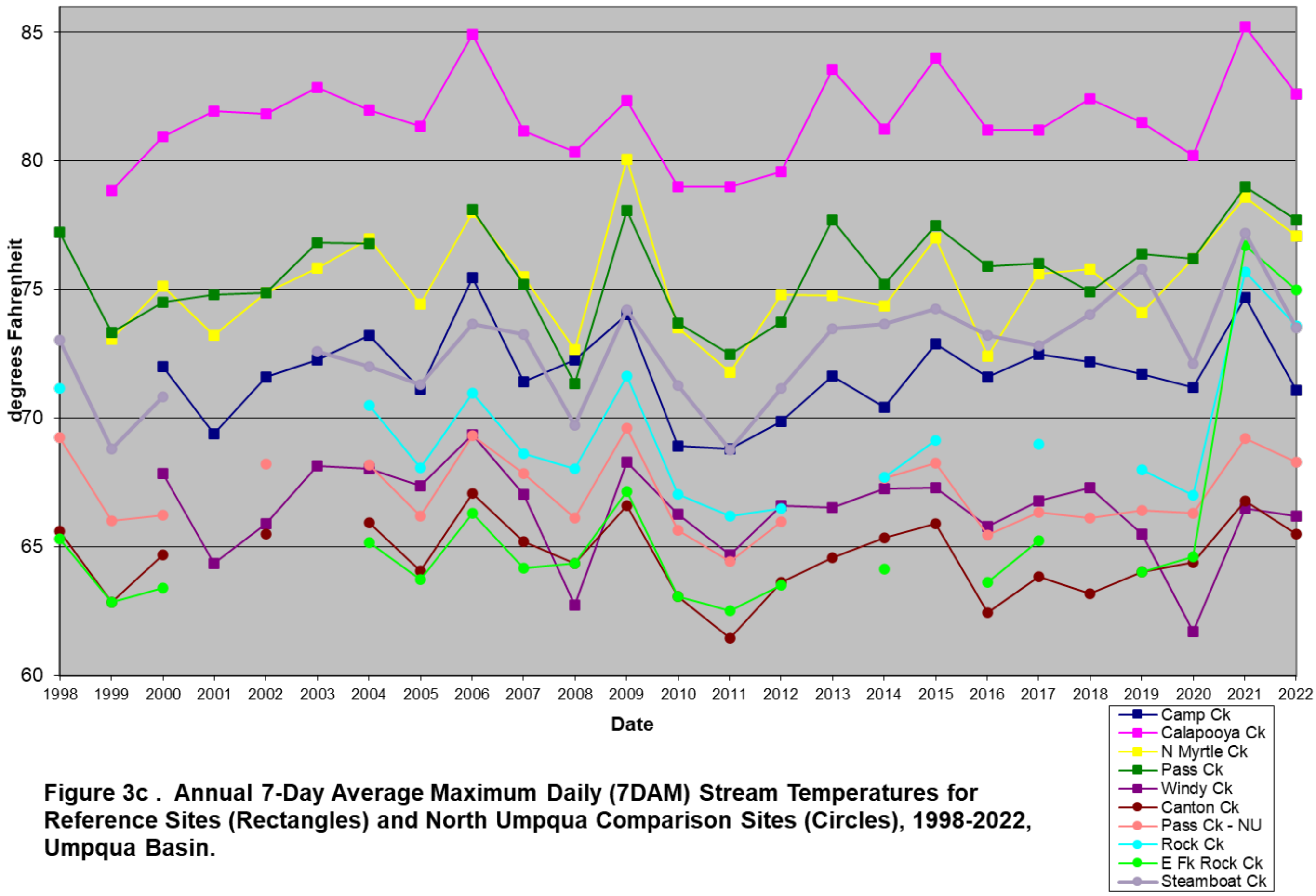


Figure 3c . Annual 7-Day Average Maximum Daily (7DAM) Stream Temperatures for Reference Sites (Rectangles) and North Umpqua Comparison Sites (Circles), 1998-2022, Umpqua Basin.

The North Umpqua sites (barring fire) had less interannual variability in stream temperature than the reference temperature sites in the mainstem Umpqua and South Umpqua Subbasins. This may be influence by the geology of the areas. Young volcanic landscapes, such as those in the High Cascades of Oregon, are characterized by springs and ground water-fed stream with less sediment (Jefferson, *et al*., 2010). In Tague and Grant (2004), the authors analyzed summer low flow regimes in the Willamette River basin based on geological type, specifically high Cascades, with younger volcanics, versus Western Cascades, with older geologic more weathered types. Low order streams that are predominately from the high Cascades have 4-5 times the summer streamflow volumes by unit drainage area compared to those primarily sourced in the Western Cascades. August streamflow (which is the time of some of the highest stream temperatures) was highly correlated with the proportion of High Cascade geology. Both timing and magnitude of flow regime have a strong linear relationship to percent High versus Western Cascade geology, regardless of mean basin elevation, which suggests that geology has a strong direct control. Western Cascades are dominated by a well-developed flow network of shallow subsurface flow paths, with little storage, whereas High Cascades behavior is consistent with a deeper groundwater system. (Tague and Grant, 2004). This is discussed further in Dammann (2020c).

Gordon Grant expanded this study to the Umpqua Basin (unpublished, presented by Gordon Grant to a Douglas Climate Change Coalition meeting on September 30, 2015). According to Grant, the North Umpqua has more basalt and deep pumice deposits which would result in a low drainage efficiency from groundwater being stored longer. The South Umpqua and Lower Umpqua subbasins have more Western Cascade / Tyee sandstone regions resulting high drainage efficiency as in Tague and Grant (2004). It would follow that there may be cooler temperatures and less interannual variability in stream temperatures in the North Umpqua sites compared to those in the mainstem and South Umpqua Subbasins.

Table 4. Umpqua Basin reference site and North Umpqua comparison site highest, lowest, and difference in 7-day average maximum (7DAM) stream temperatures from 1998-2022.

	Calapooya Ck	Camp Ck	N Myrtle Ck	Pass Ck	Windy Ck	Canton Ck above Pass	East Fork Rock Ck. above Rock Ck	Pass Ck above Canton Ck	Rock Creek above East Fork Rock Ck	Upper Steamboat Ck below Little Rock Ck
Drainage area (acres)	103,500	22,550	37,190	40,090	15,660	12,480	14,270	10,230	23,800	33, 540
Highest 7DAM temperature (Deg. F)	84.92	75.46	80.08	78.10	69.36	67.08	67.15	69.63	71.63	77.2
Lowest 7DAM temperature (Deg. F)	78.86	68.80	71.80	71.33	61.7	61.46	62.42	64.42	66.18	68.8
Difference in 7DAM temperatures (Deg. F) 1998-2020	6.06	6.66	8.28	6.77	6.61	5.62	4.73	5.21	5.45	7.0
Difference in 7DAM temperatures (Deg. F) 1998-2021 (and 2022)	6.34	6.66	8.28	7.67	7.66	5.62	14.19	5.21	9.49	8.4
Mean 7DAM temperature (Deg. F)	81.43	71.65	75.01	75.49	66.42	64.47	64.24	66.98	68.49	72.6
Highest 7DAM Temp.	2021	2006	2009	2021	2006	2006	2021	2009	2021	2021
2nd High 7DAM Temp	2006	2021	2021	2006	2009	2021	2022	2006	2022	2019
3rd High 7DAM Temp	2013	2009	2006	2009	2003	2009	2009 (4th 2006)	2021	2009 (4th 2006)	2009
Ranking of 7DAM temp. in POR	6th	18th	4th	4th	16th	7th	2nd	5th	2nd	6th
Number of years of data analyzed	24	23	24	24	23	23	19	22	17	23
Subbasin	Umpqua	Umpqua	S. Umpqua	Umpqua	S. Umpqua	N. Umpqua	N. Umpqua	N. Umpqua	N. Umpqua	N. Umpqua

The approximately 5.21-14.19ºF interannual variability in 7DAM stream temperature for monitoring sites during the period of record (Figures 3 and Table 4) indicates the importance of long-term monitoring or using another method (such as those discussed further below) to reduce the effects of annual variability, since it would be difficult to discern trends in the data from annual variability when using a data set with only a few years of stream temperature data. If climatic conditions are such that stream temperatures were warmer or cooler after a restoration project is completed without the use of reference data, it may appear that the restoration project was successful or unsuccessful in lowering stream temperatures which may be inaccurate. By using tools to correlate with the reference temperature data, project data can be normalized for annual variability. For instance, if a restoration project had post-project monitoring from 2009-2011, one may determine that the project was effective at reducing stream temperature; whereas streams throughout the basin had temperature reductions at that same time period (Figure 3a) and only closer examination normalizing the data for annual variability can determine if stream temperatures were actually reduced. Similarly, if post project monitoring was conducted from 2001-2003, a period when temperatures were increasing (Figure 3a), one may determine that the project was not effective at reducing stream temperature, whereas normalization for annual variability using reference temperature data would give more insight into the actual trends.

The Effects of Minimum (Nighttime) Temperatures on Summer Stream Temperatures:

Summer, 2015 was the hottest summer on record for all three cities surrounding the study sites (Roseburg, Medford, and Eugene, Oregon) until 2021 when Medford exceeded its highest summer of record (Dammann, 2021). The next two hottest summers for Roseburg and Medford were 2014 followed by 2013. (The News-Review, September 2, 2015; The Register-Guard, September 2, 2015; and Mail Tribune, September 1, 2015).

Interestingly, even though Summer 2015 was the hottest summer on record for the three cities that surround the study sites, it did not result in the hottest stream temperatures at that time. The 7DAM stream temperatures were not the highest, but between the 2nd and 7th highest for the period of record (Dammann, 2015). The years 2014 and 2013 had the 2nd and 3rd hottest summers on record respectively, but also did not have the hottest stream temperatures on record. Similarly, 2014 had more days exceeding 90°F compared to 2015, but 7DAM stream temperatures were higher in 2015 compared to 2014. Until 2021, the hottest stream temperatures in the period of record actually occurred in 2009 and 2006. In 2009, all five reference sites had the highest air temperatures July 28 and 29 (Dammann, 2009) which corresponds with record breaking air temperatures in the region (The Oregonian, July 29 and 30, 2009 and The News-Review, July 29 and 30, 2009). In 2006, four of the sites had their highest 7DAM stream temperature for the period of record of this study. In late July that year, there were the highest minimum air temperatures ever recorded (Taylor and Hale, 2006) which resulted in very high stream temperatures for the study sites due to the lack of nighttime cooling. These examples show how other factors than simply high daily air temperatures can influence the maximum stream temperatures, such as when the maximum air temperatures occur in conjunction with day length, the magnitude of the high maximum air temperatures, and minimum air temperatures. This was explored further in "The Effects of Minimum Air Temperature and Maximum Air Temperature on Summer Stream Temperature at Reference Temperature Sites, Umpqua Basin." (Dammann, 2020b). The analysis showed mixed, site-specific results in relation to significant correlation between the effects of minimum or maximum air temperature on stream temperature. However, this was a preliminary study that examined the data in one way; the connection between minimum air temperatures and maximum stream temperatures is just beginning to be explored. The paper suggests several other possible ways of analyzing the data in the future (Dammann, 2020b).

In 2021, there were record high maximum air temperatures in late June throughout the region. The maximum 3-day mean maximum air temperature in Roseburg was 106.7ºF in 2021 (NWS, 2021a) which broke the record of 106 (2009 and tied in 2015 and 2017) (NWS, 2019a). However, the nighttime temperatures in 2021 were also high with a maximum 3-day mean minimum temperature of 68.3ºF in Roseburg (NWS, 2021a) which is tied for the 6th highest nighttime 3-day mean minimum temperature following higher temperatures in the summers of 2006, 2009, and 2015 (NWS, 2019a). The highest 7DAM stream temperatures occurred in 2021 (for 5 sites), 2006 (for 3 sites) and 2009 (for 2 sites) (Dammann, 2021). Is the driving factor the high daytime air temperatures or the high nighttime air temperatures? More investigation is warranted.

Understanding what influences stream temperatures is an important factor for aquatic resource specialists to be able to effectively manage streams and cold-water fisheries. The connection between nighttime temperatures and stream temperature is just beginning to be explored. While there was no general conclusion of a strong effect in the analysis performed in this study that does not necessarily indicate that there wouldn't be if the data were analyzed another way. There are many ways to compare the data that couldn't all be explored in this preliminary study.

Timing of 7DAM Stream Temperatures:

For the 24 year period of record, the dates of the 7DAM stream temperatures for the reference temperature sites have been between June 27 and August 26, but most commonly between late July and early August (Figure 4) which are times of long day lengths, high air temperatures, and decreasing flows (and consequently decreasing surface area). This year the 7DAM stream temperatures were July 30, July 31, and August 1, all within that timeframe. The combination of these three characteristics: day length, air temperature, and flow and the annual variability in the temperatures and flow interrelate to determine the maximum stream temperatures, the date it occurs, and other patterns related to summer stream temperatures. Currently, there is a large bell curve in Figure 4 around July 21– August 6 in the center, indicating a high concentration of 7DAM stream temperatures occurring during that time period. The graph shows possibly two bells around June 27 – July 19 and August 9-26. With more years of data, we will learn if a typical bell curve will be established or if another pattern will emerge.

The pattern in 7DAM dates for the North Umpqua comparison sites is very similar to that of the reference temperature sites for both 2021 and for the period of record. All five sites had 7DAM stream temperatures on either July 30 or 31 in 2022. When the ten sites are combined onto one graph (Figure 6), the bell curve pattern looks very similar to that of the reference temperature sites. If we just compare the North Umpqua sites to the reference temperature sites (Mainstem and South Umpqua) (Figure 7), there doesn't appear to be any pattern, which indicates that subbasin doesn't appear to affect date of the 7DAM stream temperature.

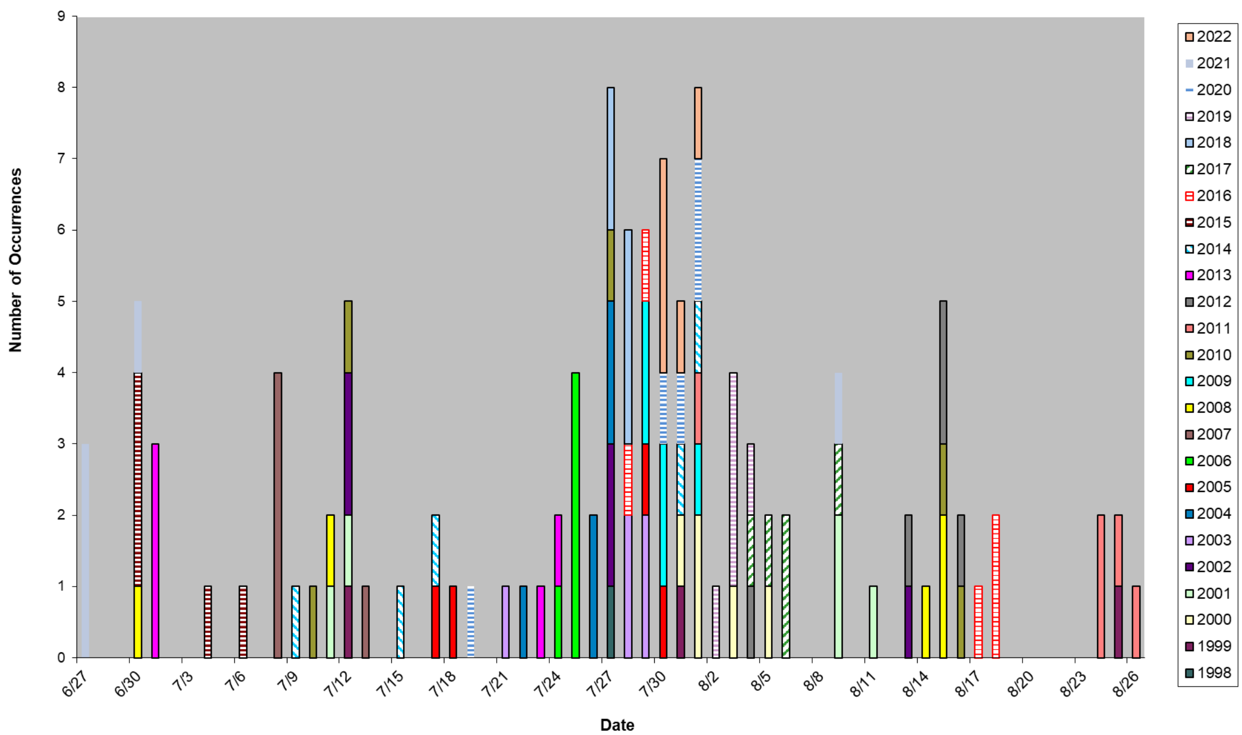


Figure 4: Dates of 7-day average maximum stream temperatures for the Umpqua Basin reference sites from 1998-2022 (center date of rolling 7 day period).

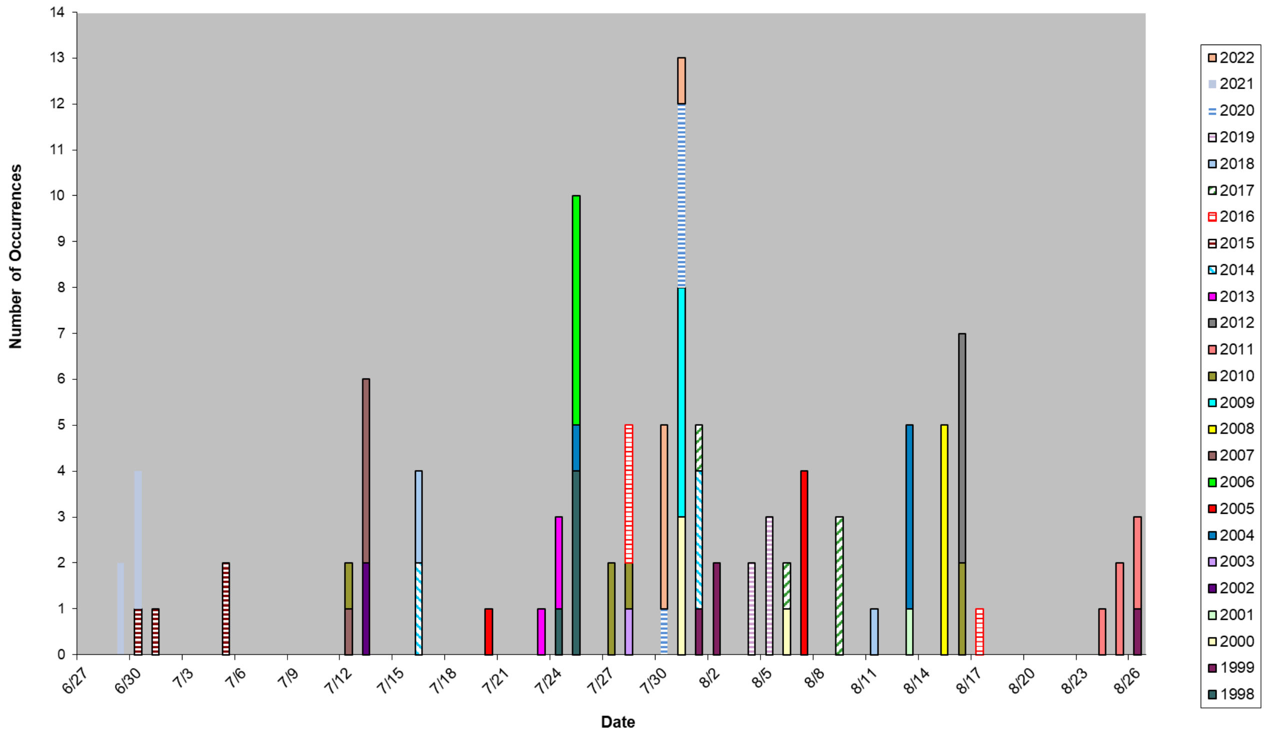


Figure 5: Dates of 7-day average maximum stream temperatures for the North Umpqua comparison sites from 1998-2022 (center date of rolling 7 day period).

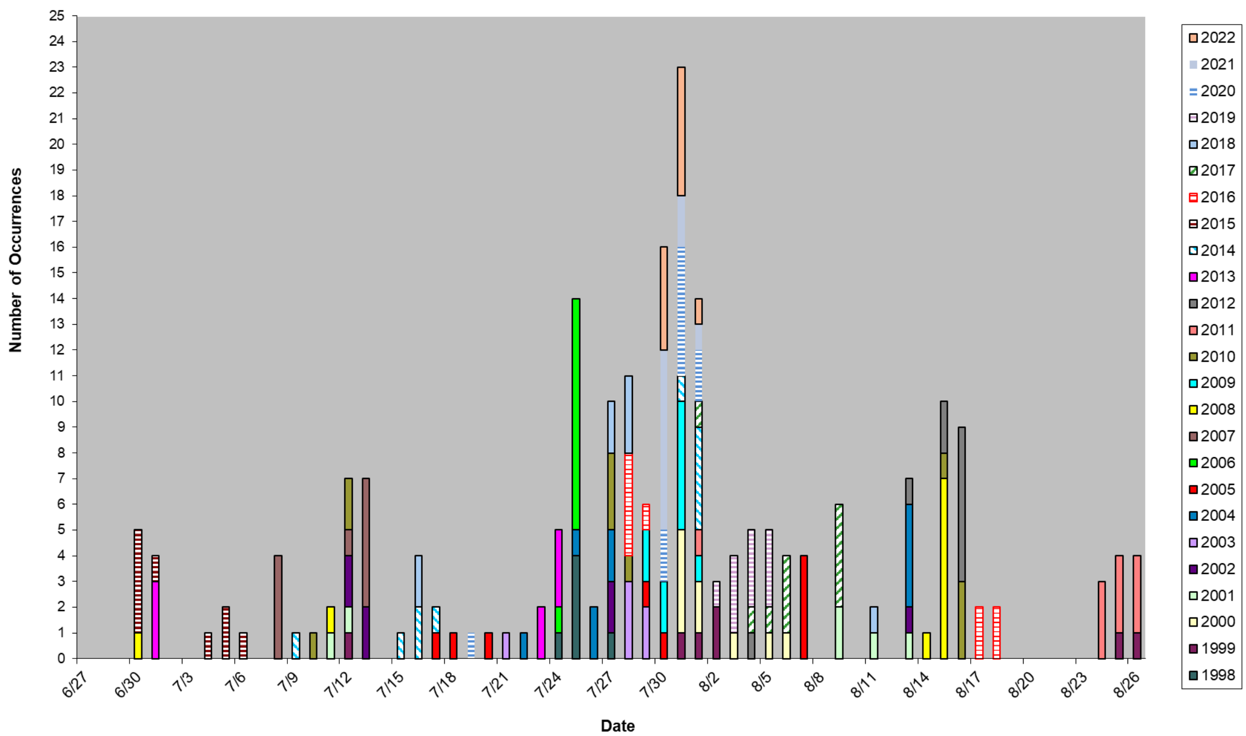


Figure 6: Dates of 7-day average maximum stream temperatures for the Umpqua Basin reference sites and North Umpqua comparison sites from 1998-2022 (center date of rolling 7 day period).

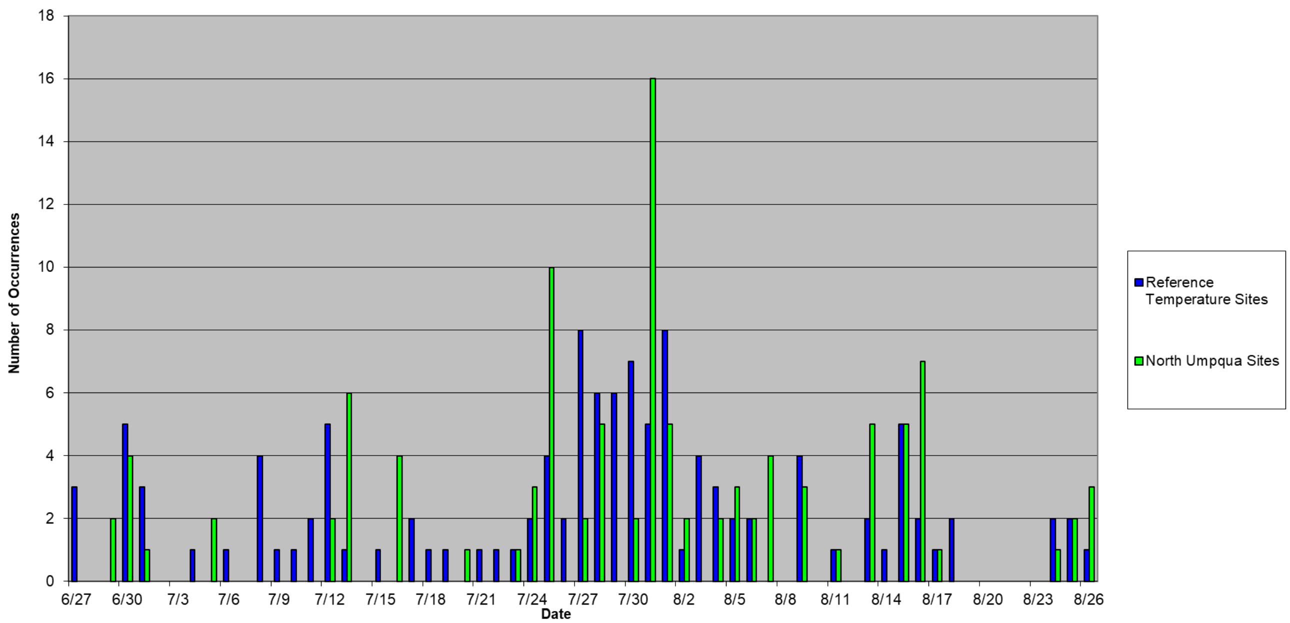


Figure 7: Dates of 7-day average maximum stream temperatures for the Umpqua Basin reference sites and North Umpqua comparison sites from 1998-2022 (center date of rolling 7 day period).

Some years, air temperatures (either high daily temperatures or high nighttime temperatures) in a certain week have been the dominant factor affecting the timing of 7DAM stream temperatures for the season, resulting in the high temperatures for all five reference sites to be within a few days (Figure 4). That was the case in 2021 with the exception of Camp Creek. This was also the case in such years as 2009 when, as previously mentioned, all five reference sites had the highest air temperatures on July 28 or 29; all reference temperature sites had 7DAM stream temperatures following that heat wave (Dammann, 2009) and the North Umpqua sites as well (Figure 5). In 2006 there were record breaking high minimum temperatures in late July (Taylor and Hale, 2006 and Dammann and Smith, 2006) which also resulted in all reference temperature and North Umpqua sites having 7DAM stream temperatures around the dates of the high nighttime temperatures. In contrast, some years, such as 2014, had no defining hot period that drove the maximum stream temperatures resulting in 7DAM stream temperatures for the reference temperature sites to be spread throughout several weeks (Figure 4), though the majority of the North Umpqua comparison sites had their 7DAM stream temperatures during the same heat wave (Figure 5). The North Umpqua sites are in closer proximity to each other so localized weather would affect them more similarly compared to the more geographically dispersed reference temperature sites.

A hot September with low stream flows could result in a September 7DAM stream temperature, but this is very unlikely given that day lengths are decreasing. In 2014, there were high temperatures in September that were similar to temperatures earlier in the summer; however, none of the 7DAM stream temperatures occurred during the September heat waves when stream flows were at the lowest, possibly due to the fact that shorter day lengths mean that the streams are heated for a shorter period of time each day than they are earlier in the summer closer to the solstice (Dammann, 2014).

A hot June with low flows is unlikely to result in 7DAM stream temperatures being earlier. However, this has more potential to occur than a high 7DAM stream temperature in September due to the long day lengths in June. In late May and early June 2016 there were very low stream flows and high air temperatures. In Roseburg, from May 31 to June 7, maximum air temperatures ranged between 85°F and 97°F (NWS, 2016a and Dammann, 2016). It would be highly unlikely that the 7DAM stream temperatures would be in early June given that flows are usually moderate but still decreasing at this time, but given these extremely high early summer air temperatures, long day lengths, and low flows, there was a stronger likelihood in 2016 than in other years (Dammann, 2016). That year, partners had a combined total of 12 water temperature recorders out in small streams (of similar size to the reference temperature sites) throughout the Umpqua Basin in May or the beginning of June. Out of these 12 sites, only one had the 7DAM stream temperature occur early in the season (in early June) (Dammann, 2016). The lesson learned here is that while 7DAM stream temperatures are unlikely to occur in early June, under very low flows and very high stream temperatures they can. (For more detailed information refer to Dammann, 2016.)

Stream Temperature Variability Holding Day Length Constant:

As previously stated, the highest stream temperatures are typically between mid-July and mid-August when temperatures are usually high and flows are decreasing. Since the solar position is the same on any given day for each year, in order to hold day-length constant, the temperatures on August 1 at 4pm (typically the hottest time of the day) is graphed for each year and site (Figure 8). August 1, 4pm temperatures (Figure 8) show a similar pattern as the 7DAM stream temperatures (Figure 3c), with Calapooya Creek being the highest each year and Windy Creek the lowest of the reference temperature sites (rectangles, with one exceptional year for each) (Figure 8). Camp Creek is typically the second lowest except in 2015 and 2016; and North Myrtle and Pass Creeks have had similar temperatures varying year to year which is warmer (Figure 8).

The North Umpqua sites (circles) historically had lower temperatures on August 1 at 4pm compared to the reference temperature sites (with the exception of Steamboat and Rock Creeks (Figure 8), which are larger streams with larger drainage areas). Lower stream temperatures are to be expected given the elevation of the drainage and the geology of these sites. The pattern of the North Umpqua sites is very similar to that of the reference temperature sites overall. There are some years that the temperature is dampened on that day, possibly due to a lack of solar radiation (cloud cover or smoke layer) affecting temperatures in one subbasin. Since the Archie Creek Fire in 2020, the Rock and East Fork Rock Creek sites, which now has a heavily burned watershed upstream of the site, has had increased temperatures overall and on August 1st as well.

Since day length is held constant in this graph, the pattern shows the significance of solar output and flow volume in the temperature pattern throughout the basin. It also demonstrates the difference between using actual data instead of statistics (such as 7DAM stream temperatures). This is also something to consider when using the reference temperature data for comparisons. It is best to use a time period for comparisons that has a stable weather pattern.

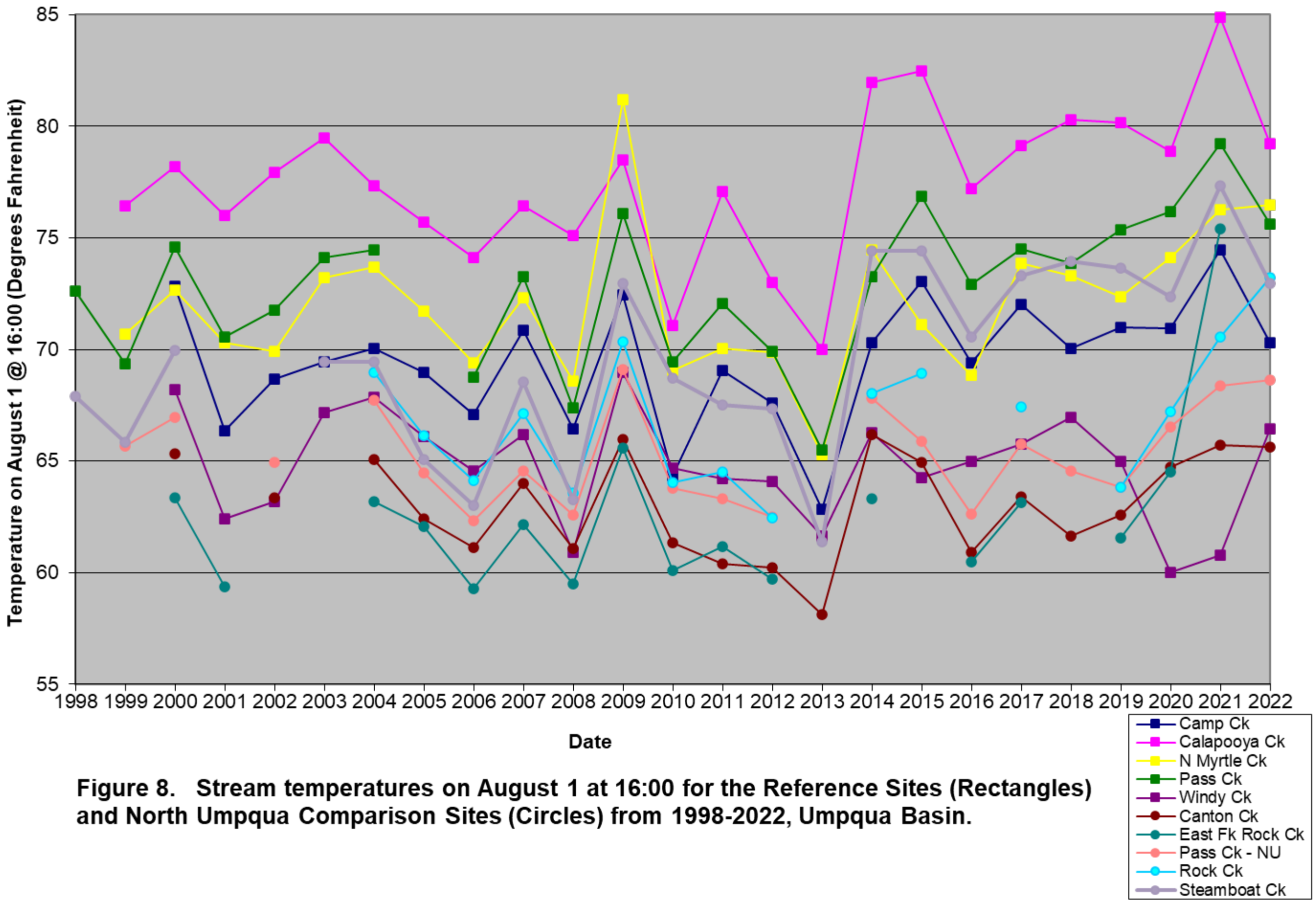


Figure 8. Stream temperatures on August 1 at 16:00 for the Reference Sites (Rectangles) and North Umpqua Comparison Sites (Circles) from 1998-2022, Umpqua Basin.

Trend Analysis of Reference Temperature and North Umpqua Comparison Site Data:

In 2015, the DEQ conducted a trend analysis of stream temperature of sites with continuous hourly summer temperature data throughout Oregon (Michie and Bryant, 2015). This analysis looked at sites (mainly gaged sites) with at least 8 years of continuous hourly summer temperature data (June through October) and analyzed each month separately. The criteria for site selection for analysis was 8 years of continuous hourly temperature data for the month and no more than one day without observations in a month and each day must have had at least one observation in a minimum of 22 hours during the day. (Michie and Bryant, 2015)

Pritchard (2017) modified this analysis to look at stream temperature trends at the five project sites for the entire period of record for Dammann (2017). Since the 2017 Report, the DEQ has updated the trend analysis annually to include the subsequent data (Pritchard, 2018 and Pritchard and Doak, 2019). Since 2020 the trend analysis also includes the North Umpqua comparison sites (Pritchard, 2020, Mahoney and Pritchard, 2021, and Nowlin and Mahoney, 2022). The results of these trend analyses were included in the annual updates (Dammann, 2018, 2019, 2020a, and 2021 and the 2022 results are displayed in Table 5 and Figure 9.

Since this project has data for sites from mid-June to mid-September, the only months with complete data sets were July and August. Also, since the dataset began on July 1 for many of the earlier years of survey, for this project, the 7-day average daily maximum stream temperature is described as the first date in the rolling period. Otherwise, many years of data would have been thrown out of the study. Pritchard (2017) and those after him, have used the seasonal Kendall trend analysis (Hirsch and Slack, 1984), an extension of the Mann-Kendall test for trend (HydroGeoLogic, Inc., 2005) which is a better tool for looking at seasonal data (Meals, *et al.*, 2011). The seasonal Kendall analysis conducted on the reference temperature data looked at both months (July and August) combined when comparing trends, whereas Michie and Bryant (2015) compared each month separately. The analysis was done in R using the wql package (Jassby and Cloern, 2017).

Table 5. Results of DEQ trend analysis of reference stream temperature data and BLM North Umpqua comparison sites using a seasonal Kendall trend analysis as described in Hirsch and Slack (1984). Specific results are in Figure 9. (Nowlin and Mahoney, 2022)

Site	Study	Years	Seasonal Kendall Trend Significance	p-value
Calapooya Ck.	ReferenceTemp	1999-2022	No Trend	0.37
Camp Ck.	ReferenceTemp	2000-2022	Positive Trend – Sen. Slope (0.045)	0.06
North Myrtle Ck.	ReferenceTemp	1999-2022	No Trend	0.17
Pass Ck.	ReferenceTemp	1998-2022	Positive Trend – Sen. Slope (0.040)	0.02
Windy Ck.	ReferenceTemp	2000-2022	Negative Trend – Sen. Slope (-0.043)	0.001
Canton Ck.	NU-Comparison	2000-2022	No Trend	0.92
E. Fk. Rock Ck.	NU-Comparison	2000-2022	Positive Trend – Sen. Slope (0.062)	0.02
Pass Ck. – NU	NU-Comparison	1999-2022	No Trend	0.31
Rock Ck.	NU-Comparison	2004-2022	No Trend	0.67

Note: There are some years with missing data (see Figure 9). Steamboat Creek data was not included in this analysis due to time constraints and differences in data storage.

The sites that had significant trends were Camp, Pass, and East Fork Rock Creeks with positive trends and Windy Creek with a negative trend (Table 5, Figure 9, and Nowlin and Mahoney (2022)). While this analysis does not sort out the cause of the significant decrease in 7DAM stream temperatures during the period of record, it could be due to any number of factors including climate change, changes in flow conditions, natural disturbances, and/or anthropogenic actions. There is no known change at the site level for Pass that would warrant a change in stream temperature. However, at East Fork Rock Creek and Camp Creek, they did not have a change in trend until 2021. Ninety-six percent of the watershed above East Fork Rock Creek burned in the Archie Creek Fire in 2020 with 38% of that being high severity and 35% moderate burn severity. This loss of canopy upstream would be anticipated to affect stream temperature. The negative trend in Windy Creek has a very strong significance with a p-value of 0.001. Earlier in this report, it was noted the increase in hyporheic flow at the site in the past several years which may be the possible cause. The cause of the temperature increase at Camp Creek needs further investigation.

Trend analysis of this stream temperature data is integral start to potentially understanding the effects of climate change on streams in the basin when there has been no land management change that can warrant a change in stream temperature.

In this analysis, the DEQ would typically only include A & B quality data. However, several years of BLM data included were E quality (unknown) level because they were missing field and warm/ice water baths due to reasons such as changes in personnel or a lack of ice/warm bath audits and deployment and retrieval audits on year-round term monitoring sites. Onset tidbits have very little drift and it is doubtful there is any associated drift error with this equipment, so in addition to A & B quality data, E quality data was included in this analysis on a case-by-case basis.

At the Rock Creek temperature site on August 3, 2022, excavation occurred that affected the stream temperature for rest of the season. For this reason, August, 2022 data is excluded from this trend analysis. For more information, see "2022 Results - Air and Stream Temperatures" section.

Stream Temperature Relative to Flows (2004-2018):

Flows were collected during the summer low flow season at North Myrtle and Pass Creek reference sites by Oregon Water Resources Department (OWRD) and partners from 2004-2018 and at Calapooya, Camp, and Windy Creeks from 2010-2018 (UBWC {later renamed PUR} 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2013; PUR 2014b, 2015, 2016b, 2017, and 2018). (The compiled data is also available in Dammann, 2020c.) The linear regressions of the flow data at the North Myrtle, Pass, and Windy Creek indicate varying strengths of negative linear correlation between flow and 7DAM stream temperature at these sites (Figure 10). Due to budget limitations, these flow measurements have been limited since 2018.

Data indicates a strong negative correlation between flow and 7DAM stream temperature at Windy Creek (r^2= 0.3079) (Figure 10) which indicates that as flow increases, 7DAM stream temperature decreases. This is the strongest correlation of any of the sites in this study (Figure 10). Windy Creek typically has the lowest diurnal fluctuation in stream temperatures (Figure 2 and previous reports) and appears to have built up more gravel substrate in recent years.

At North Myrtle Creek (r^2=0.1058) and Pass Creek (r^2=0.0704) sites, there is very weak or no correlation between 7DAM stream temperatures and flow (Figure 10). However, for Pass Creek, if the outlier at very low temperatures and flow were removed, r^2=0.3802, which is a strong negative correlation (Figure 10). It appears that flow and 7DAM stream temperatures are negatively correlated at Pass Creek, except in the situation with the outlier when there was a very low flow and very low stream temperatures possibly due to hyporheic flow at the low flows (Figure 10).

Flow data collection at Calapooya and Camp Creeks began midsummer in 2010. However, the 7DAM stream temperature occurred early in the summer and flows had not yet been collected, so there is no data available to compare 7DAM stream temperature with flows that year. The linear regression indicates that there is a very weak correlation at Camp Creek (r^2=0.1994). Also, at Calapooya Creek in 2015, flow data was not collected early enough to have data at the time of the 7DAM stream temperature as well. With only six years of data for Calapooya Creek and a low r^2, it is difficult to ascertain any trend (r^2=0.0395) but there appears to be no correlation. If more flow data were available in future years, it may provide more insight into the relationship between flow and 7DAM stream temperature at these sites. (Figure 10)

More on the (Combined) Effects of Air Temperature, Day Length, and Flows on Stream Temperature at the Reference Sites:

From 2010-2018, the summer flows at the five reference sites were compared with maximum daily air temperatures and maximum daily stream temperatures collected at the sites (Figure 11 and Dammann, 2019: Appendix contain two representative graphs). In each stream, the trends in the water temperature reflect those in the air temperature, showing how stream temperature is partially dependent on air temperature. At all five sites, as flow was decreasing, the stream temperatures still reflected the changes in the air temperature, but they were also overall slowly decreasing as the flow decreased throughout the season. This is likely due to decreased day lengths, a higher percentage of hyporheic flow in the stream or a combined effect of the two. The pattern is most evident in years where there are higher air temperatures later in the summer, which was 2011-2014 for Calapooya, North Myrtle, Pass, and Windy Creeks and 2011, 2014, and 2017 for Camp Creek (Figure 11 and Dammann, 2019 - Appendix).

A study of unregulated streams in the Western Continental United States, containing streams with comparable drainage areas and elevations as our study streams, found that from 1950-2010, the timing of minimum stream flows became earlier, while the timing of maximum stream temperatures has not changed (Arismendi, *et al*., 2013). This has resulted in a decrease in the time between the two biggest summer stresses to fish, maximum stream temperatures and the minimum stream flows (Arismendi, *et al.*, 2013). The responses of high temperatures and low flows on aquatic organisms have been studied separately, but there's only limited data on the combined effect of the two (Arismendi, *et al.*, 2013 and Clews, *et al.*, 2010). As more years of data are collected at the reference temperature study streams, it would be interesting to observe the relationship between stream flow and stream temperatures and the timing of the two which could give more insight into how air temperature and flow affect stream temperature. There are many ways to analyze this long term dataset depending on future needs.

Examples of How Reference Temperature Data Is Used:

The past reference temperature data and analyses have been widely used by PUR, ODFW, DEQ, three BLM Districts, USFS, NOAA – Fisheries, PacifiCorp, South Umpqua Rural & Community Partnership, and the Elk Creek Watershed Council for:

- corroborating regional timing and trends of stream temperatures in the basin
- comparing interannual variability in stream temperature
- developing fishing regulations during low-flow periods01
- investigating stream resiliency in terms of climate change, which can help better manage the fishery
- supporting effectiveness monitoring of salmon and steelhead habitat restoration projects
- normalizing short term data sets from other baseline monitoring or areas of disturbance/restoration (such as restoration projects, burned areas, and timber harvests)
- TMDL (total maximum daily load) development and implementation for the beneficial use of salmonid spawning, rearing, and migration, aquatic habitat and recreation
- understanding the relationship between flow, stream temperature, and hyporheic flow at comparable monitoring sites
- developing strategic plans for water quality
- reviewing coho stock status and developing coho strategic plans

As discussed in the "Interannual Variability…" section, often times with project level monitoring data, there are short data sets that only encompass a few years. With limited data sets, it's difficult to tell if a change in temperature from year to year is a response to work that has been done in a watershed or annual variability. The stream temperature records from these reference temperature sites can be used as a model to account for annual variability in other streams lacking that long-term data. There are several ways that one could use this reference temperature data to compare to other sites. One way the data can and has been used, is the SB Ratio method (Smith, 2001b) which uses the average of ratios of the daily maximum and minimum temperatures for the reference temperature data in order to calculate a theoretical temperature for years with no data. Another is to use synoptic temperature data method (Smith, 2010) which utilizes the ratios of raw data rather than ratios of statistics. Utilizing reference temperature data to complete temperature records at sites that lack long term data sets and to normalize temperature data is being done by partners for restoration projects, reference sites, and burned area recovery areas. Other methods of comparison that have been used include using ratios of 7DAM stream temperatures, completing gaps in data sets, adding to existing sites in area, and simple direct comparisons. Some examples are cited in Dammann (2019) and OWEB Completion Report for the Umpqua Basin Stream Flow and Temperature Monitoring Project: 2017-18 (Grant #217-2054) (PUR, 2020).

The North Umpqua Steamboat, Canton, Pass, Rock and East Fork Rock sites will work well as comparison sites, as with the reference sites. The five North Umpqua sites also display the same pattern of interannual variability (though less pronounced) and the 7DAM stream temperatures show a similar pattern as the reference temperature sites (Figure 3), which is supportive of using these for comparisons to other sites. Location (Map 2), drainage area (Table 1) and other metadata on Table 1 can be used to help determine which sites would be a better comparison. Having the North Umpqua site data available opens up the opportunity for many more uses of this data in the North Umpqua as well as the Frank and Jeanne Moore Wild Steelhead Special Management Area. Additionally, data from the long-term BLM sites affected by the 2020 fires analyzed in this report will be critical for evaluating the effects of the fires in relation to the other sites and to post-fire restoration effects.

Oregon State Temperature Criteria:

Under the Oregon State temperature criteria, the 7DAM stream temperature for streams designated as core cold-water habitat may not exceed 60.8ºF (16.0ºC) and streams designated as salmon and trout rearing and migration areas may not exceed 64.4ºF (18.0ºC) (ODEQ, 2006, 2011, 2014, and 2018). Calapooya, Camp, North Myrtle, and Pass Creeks have all been designated as salmon and trout rearing and migration fish use (64.4ºF threshold) and Windy Creek and the North Umpqua sites have been designated as core cold-water habitat (60.8ºF threshold) (ODEQ, 2003). Figure 2 shows the daily summer stream temperature fluctuation for the reference sites with the reference value line drawn at the ODEQ threshold for each stream. All of streams exceeded the ODEQ temperature criteria for every year at every site (Figures 3).

Invasive Crayfish:

The only native crayfish species in Oregon and in the Umpqua Basin is the signal crayfish (*Pacifastacus leniusculus*). Ringed crayfish (*Faxonius neglectus* – formerly *Orconectes neglectus)* were introduced to the Rogue Basin and have subsequently been found in the Umpqua Basin. Within the last several years, we have been finding ringed crayfish in more of the reference temperature sites (as of 2022: 4 of the 5). Ringed crayfish are from the Great Plains and are identified by characteristics such as the orange tips on their claws with black bands (Oregon Department of Fish and Wildlife (ODFW), 2018). For instance, less than a decade after ringed crayfish were discovered at the Calapooya Creek site, a stream that historically was abundant with native signal crayfish, the ringed crayfish have outcompeted the signals and subsequent surveys have failed to find any signal crayfish at that site; colleagues in the Rogue Basin have encountered the same scenario with ringed crayfish displacing signals within a decade in several streams throughout the Rogue Basin (personal communication Dr. Michael Parker (SOU) and Dr. Stewart Reid (Western Fishes)). The ecosystem effects of introduced crayfish in SW Oregon are unknown. A global meta-analysis of the ecological impacts of non-native crayfish consistently found negative effects on the ecosystem; in this meta-analysis, Twardochleb, et al. (2013) found that non-native crayfish prey on native fish and other native species, spread diseases to native crayfish, compete with native animals for food resources, and are better adapted to avoid predation.

At the Camp Creek study site since 2018, both signal crayfish and adult and juvenile ringed crayfish have been seen. Downstream from the Camp Creek study site below the confluence with Mill Creek, several juvenile ringed crayfish have also been found each year.

Since 2019, in North Myrtle Creek there were also several ringed crayfish along with the native signal crayfish. In 2022, there were no signal crayfish seen but many juvenile ringed crayfish.

Photo 3. Invasive Ringed crayfish (*Orconectes neglectus*) found at the Calapooya Creek site. (Photo courtesy of Katie Dammann)

In Windy Creek, in October, 2022 there were the first sightings of ringed crayfish. Signal crayfish were also seen there this year.

As of 2022, we have had no sightings of ringed crayfish at the Pass Creek reference temperature site, only signal crayfish.

Invasive crayfish sightings have been reported to the local ODFW office as well as the Oregon Invasive Species Hotline.

Acknowledgments:

This analysis is funded by the Western Oregon Bureau of Land Management (BLM) Resource Advisory Committee (RAC), the North Umpqua Foundation, and the Steamboaters.   Previous work on this project has been funded by Oregon Watershed Enhancement Board (OWEB), the SW Oregon Bureau of Land Management Resource Advisory Committee (RAC), the North Umpqua Foundation, the Steamboaters, and Roseburg and Coos Bay BLM. Historically, it has been in cooperation with the stream flow monitoring conducted by the Oregon Water Resources Department and Douglas County Watermaster's Office with previous and current Watermasters, Dave Williams and Susan Douthit. Thanks to specialists from the BLM and USFS for input on site selection of the historic North Umpqua sites. Thanks as well to Roseburg BLM and Umpqua National Forest hydrology staff for continued monitoring at the North Umpqua sites. Thanks to the DEQ for conducting the trend analysis, specifically, thanks to Steve Hanson, Nick Haxton-Evans, Travis Pritchard, Sam Doak, Kat Mahoney, and Kayla Nowlin. Thanks as well to Roseburg Resources, Glendale Education Service District, and Larry and Diana Mathis for access across their properties; and thanks to Kent Smith for designing and conducting the original study.

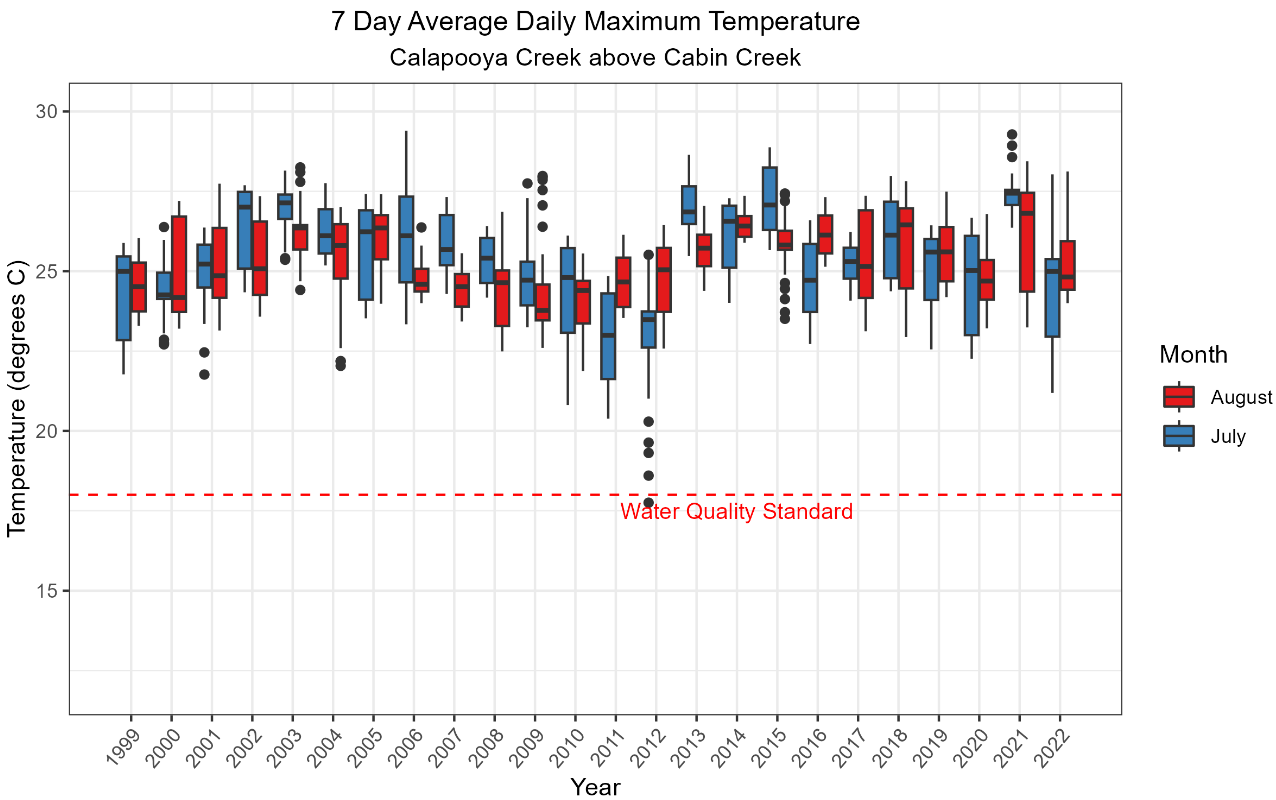
How to Obtain the 2022 Update Data or Previous Data and Reports:

An electronic copy of this report is available on PUR's website (www.umpquarivers.org). In addition, some of the recent previous Reference Temperature Report annual updates and the paper: "The Effects of Minimum Air Temperature and Maximum Air Temperature on Summer Stream Temperature at Reference Temperature Sites, Umpqua Basin" (Dammann, 2020b) are also on the website.

All previous reports, annual updates, and data for the length of this project can be obtained from PUR or from Denise Dammann Consulting or are located annual Umpqua Basin Stream Temperature and North Umpqua Comparison Analysis Update CDs. The annual updates provide more analysis of that year's data combined with a discussion of patterns over the period of record.

All reference temperature and BLM North Umpqua comparison site data can be found in DEQ's AQWMS database. All USFS data is housed by the Region 6 USFS in a MS Access database. Additionally, all historic data was included in the NorWeST stream temperature study (Isaak, *et al.,* 2017). Previous OWRD "grab sample" flow data from Douglas County has been compiled in the "Umpqua Basin Low Flow Monitoring Report of 1998-2018 data" (Dammann, 2020c) and is available from PUR's website or from Denise Dammann Consulting. All flow data is also available through the Douglas County Watermaster's Office or on the OWRD website.

Denise Dammann Consulting
ddammann@jeffnet.org



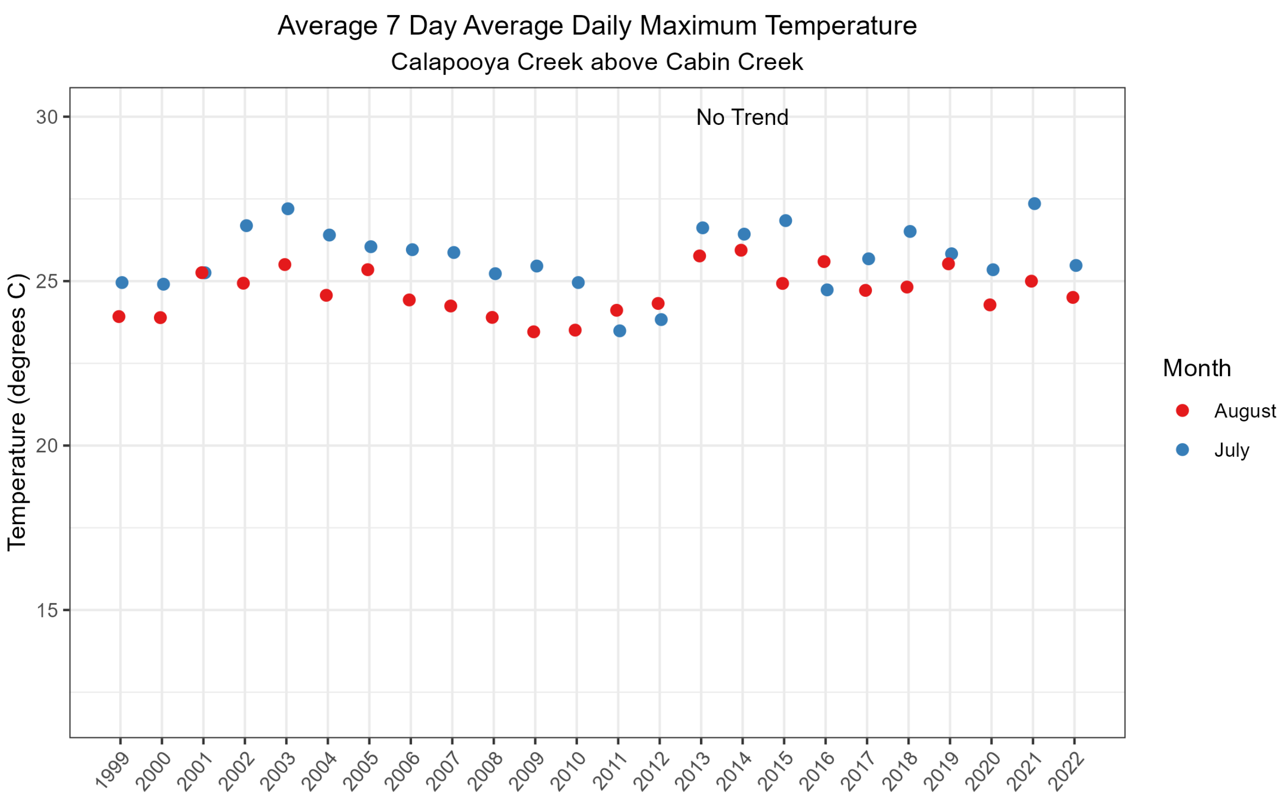
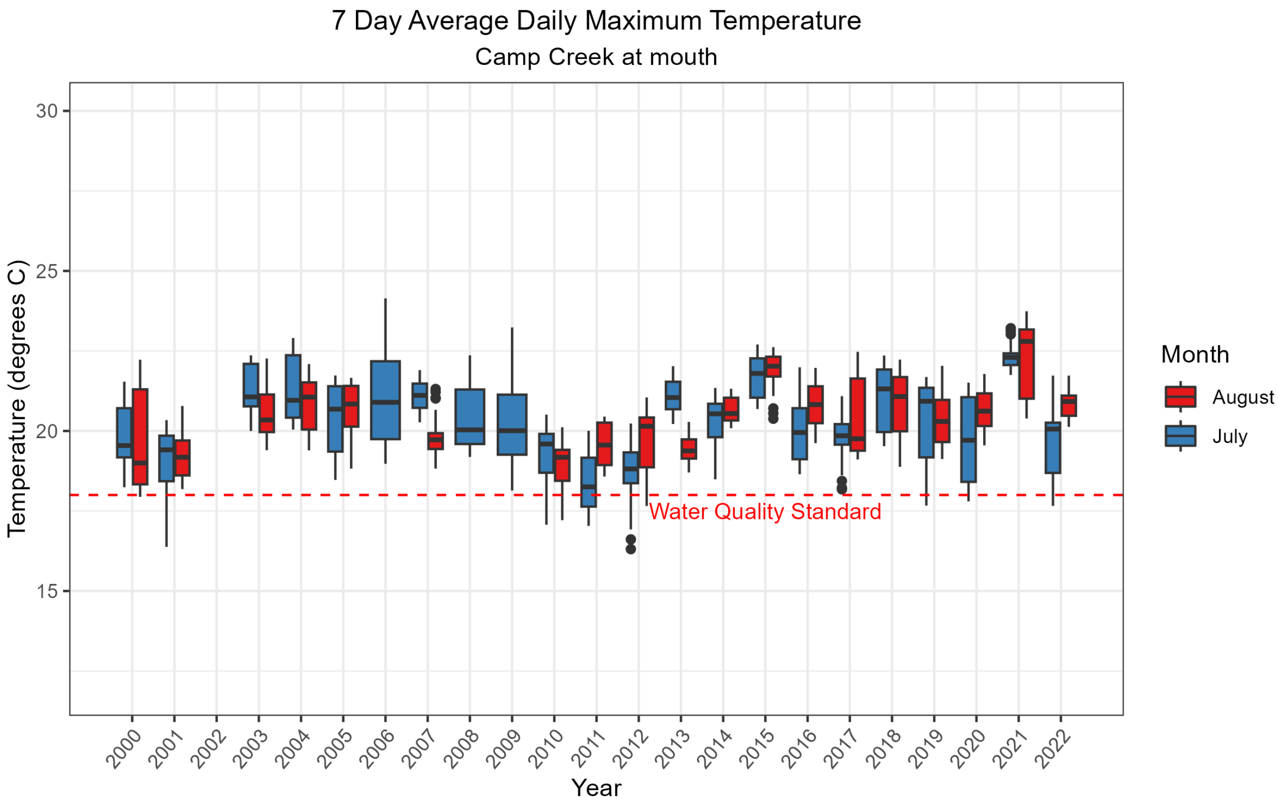
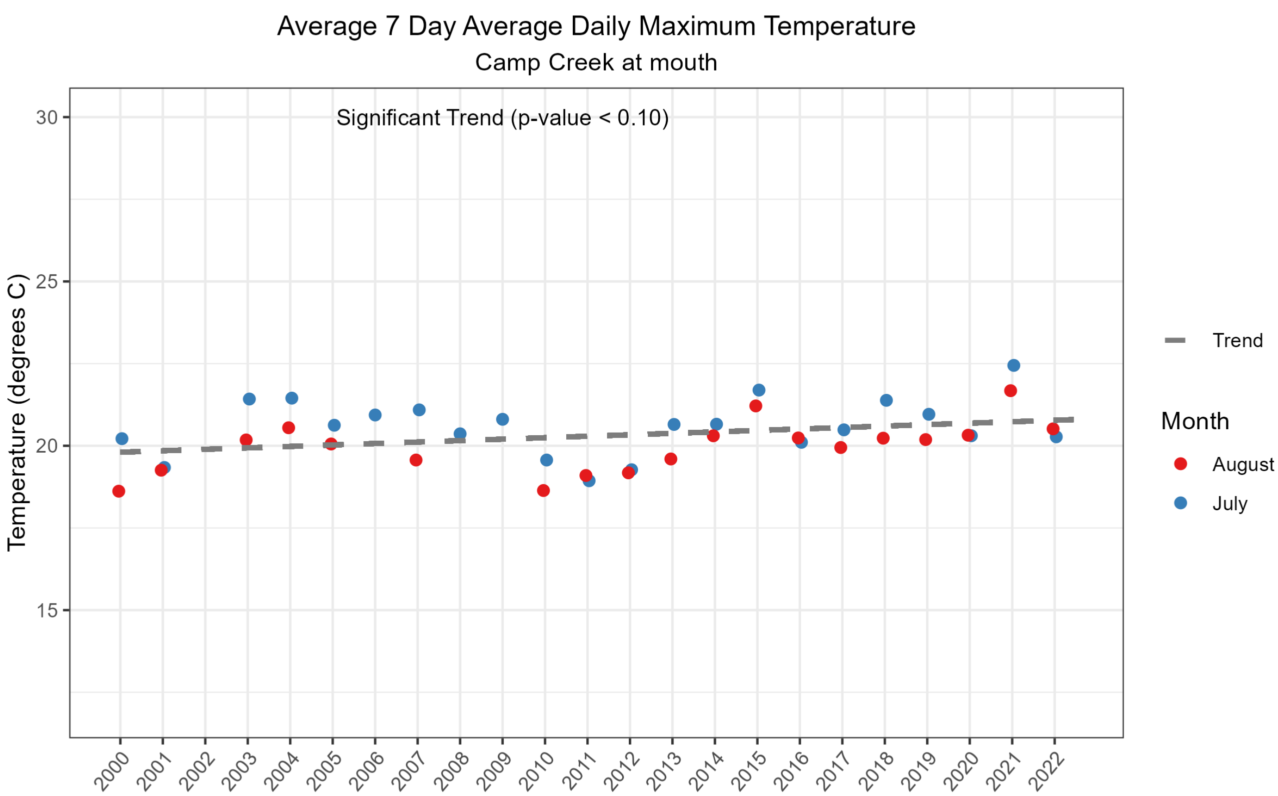


Figure 9. Nowlin & Mahoney (2022) DEQ trend analysis of reference stream temperature data using a Seasonal Kendall trend analysis (Hirsch and Slack, 1984). Since the dataset began on July 1 for many of the early years of project monitoring, the seven day average daily maximum stream temperature is described as the first date in the rolling period. (Note: If more than one day of data is missing or did not meet DEQ criteria, the entire month was removed from the trend analysis, but not necessarily from the 7DAM stream temperature graphs. Some North Umpqua data years were excluded due to lack of bracketing quality control data. (Page 1 of 9)





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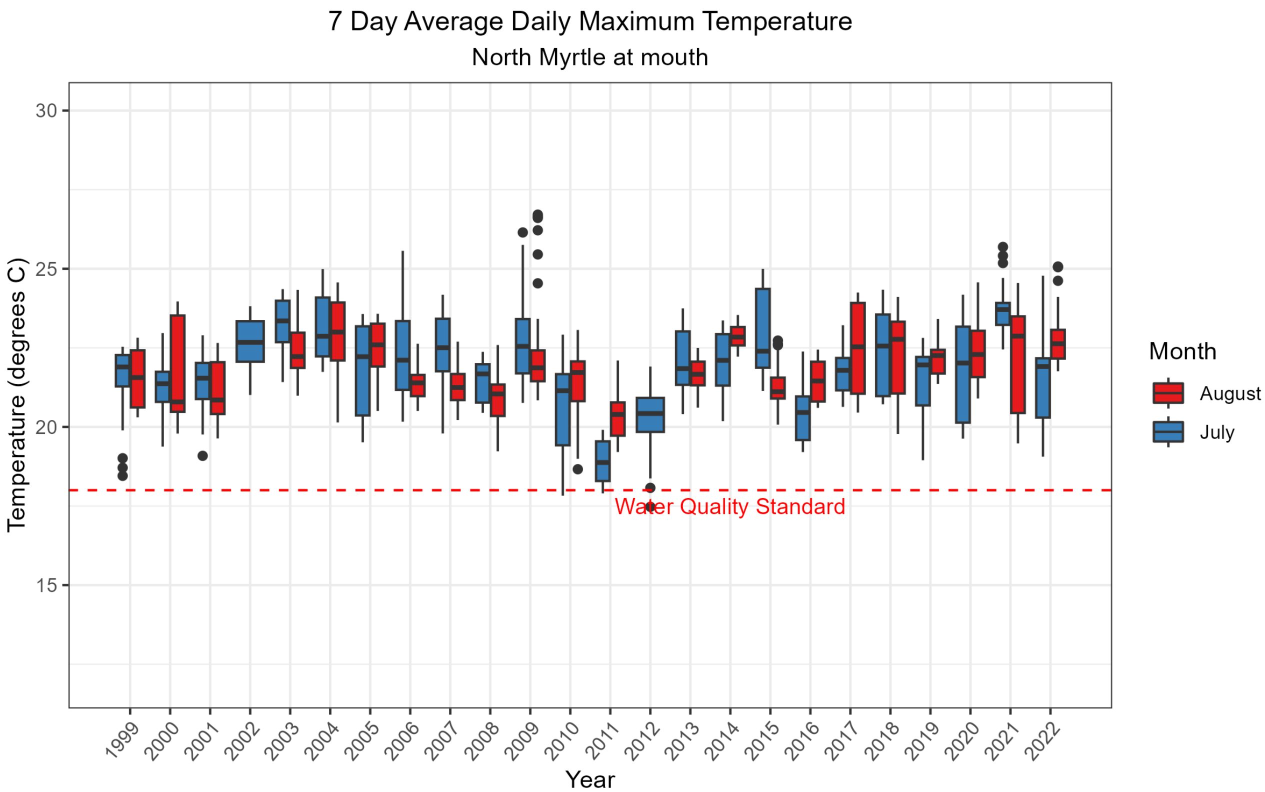

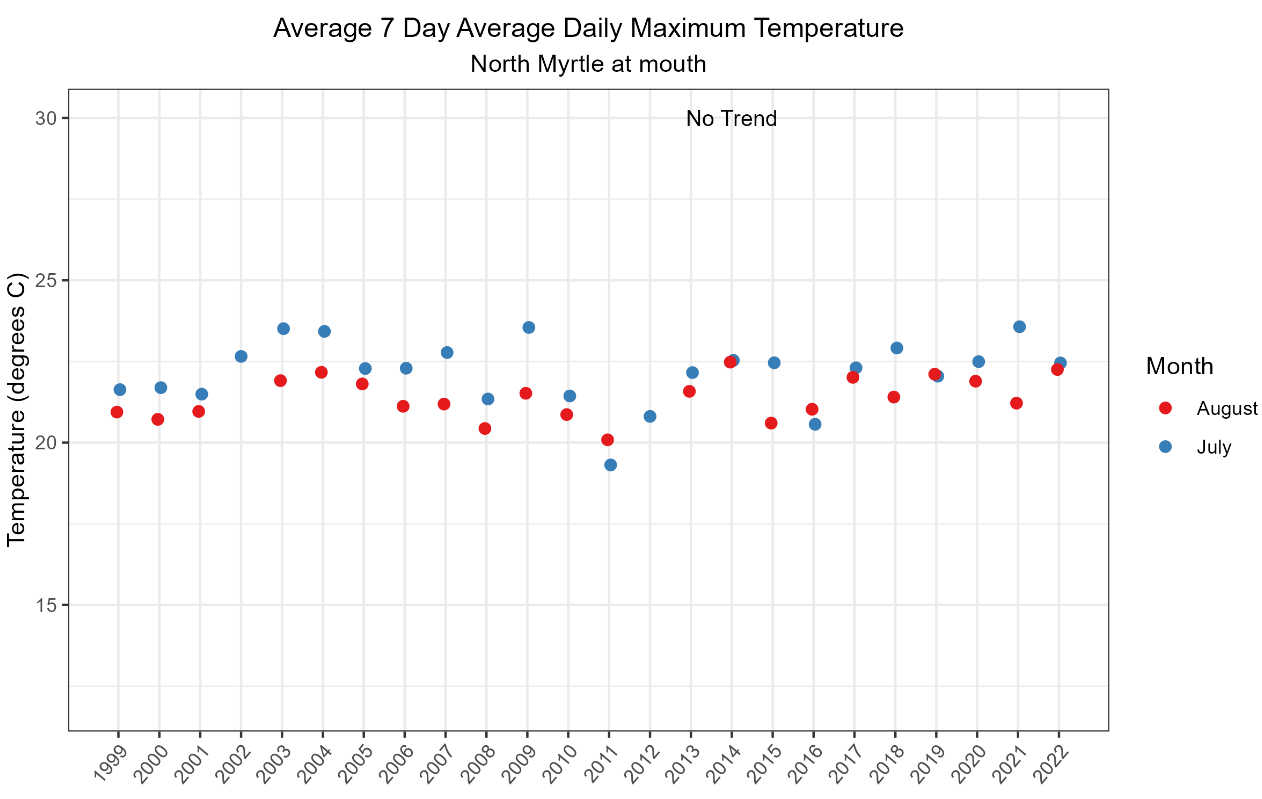

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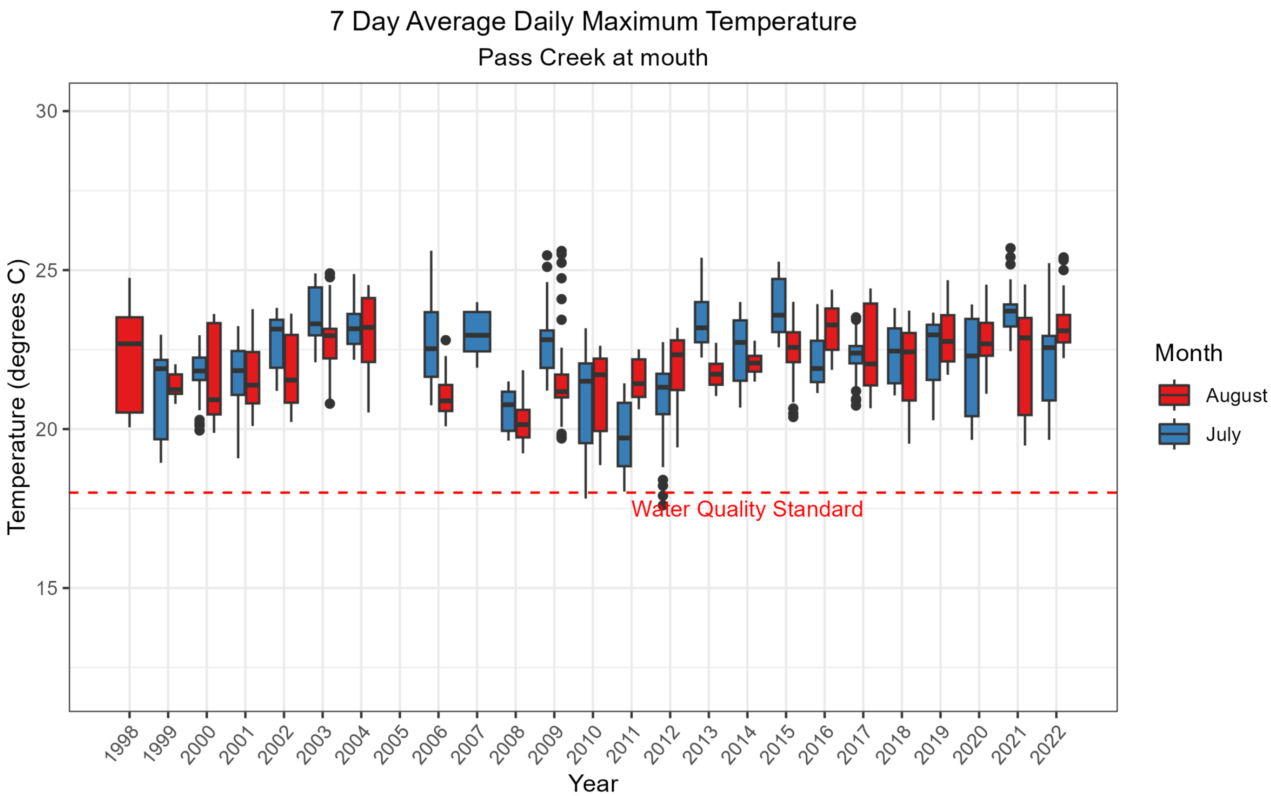

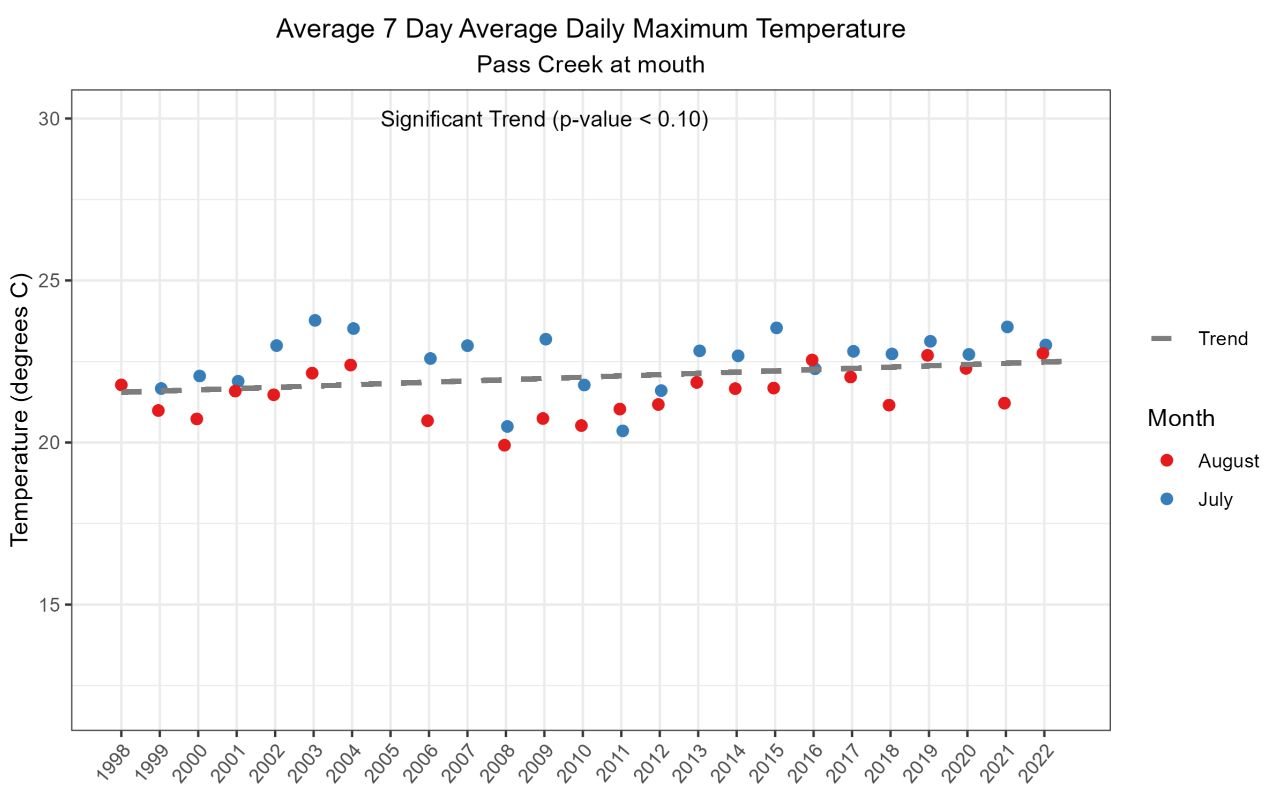

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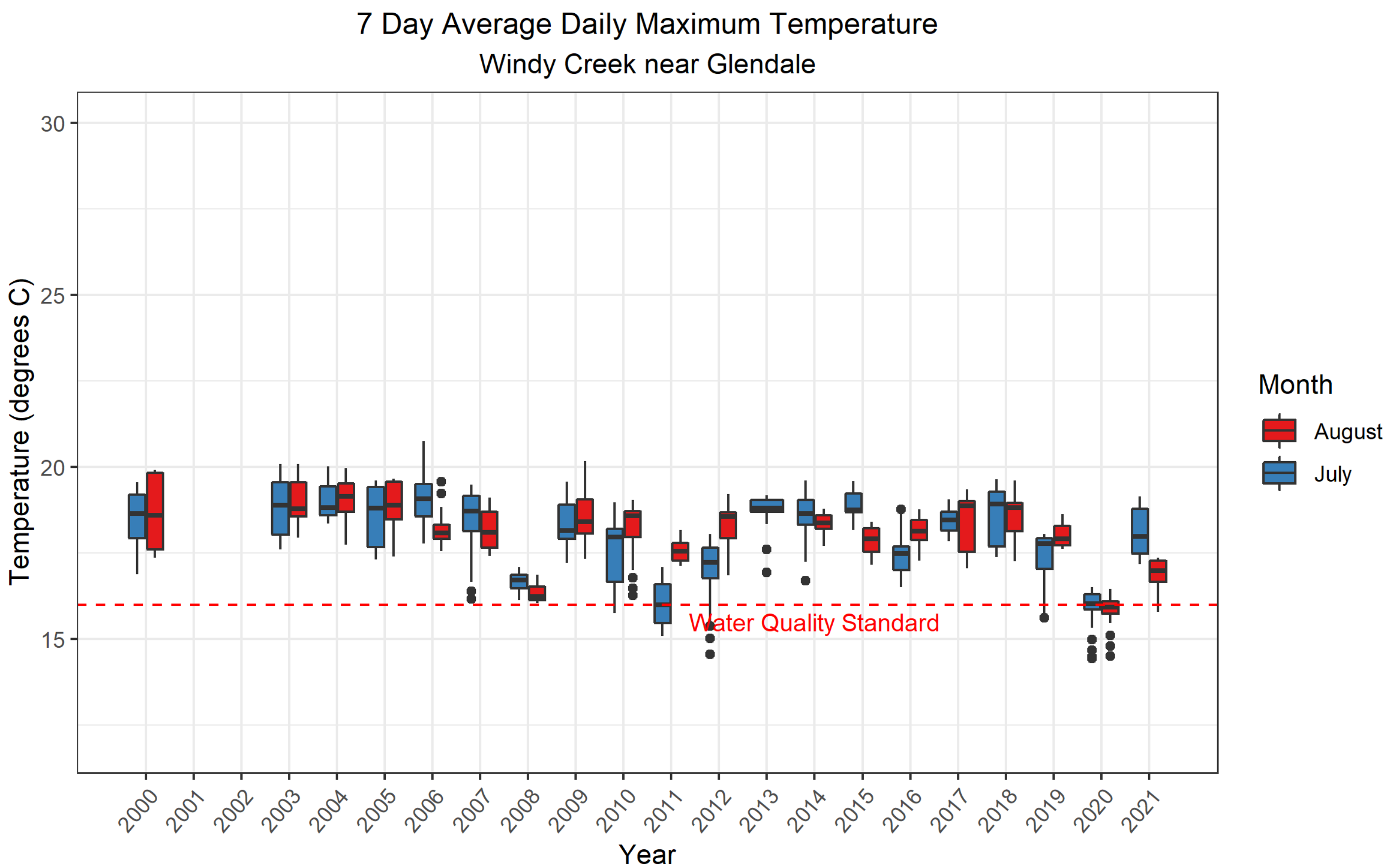

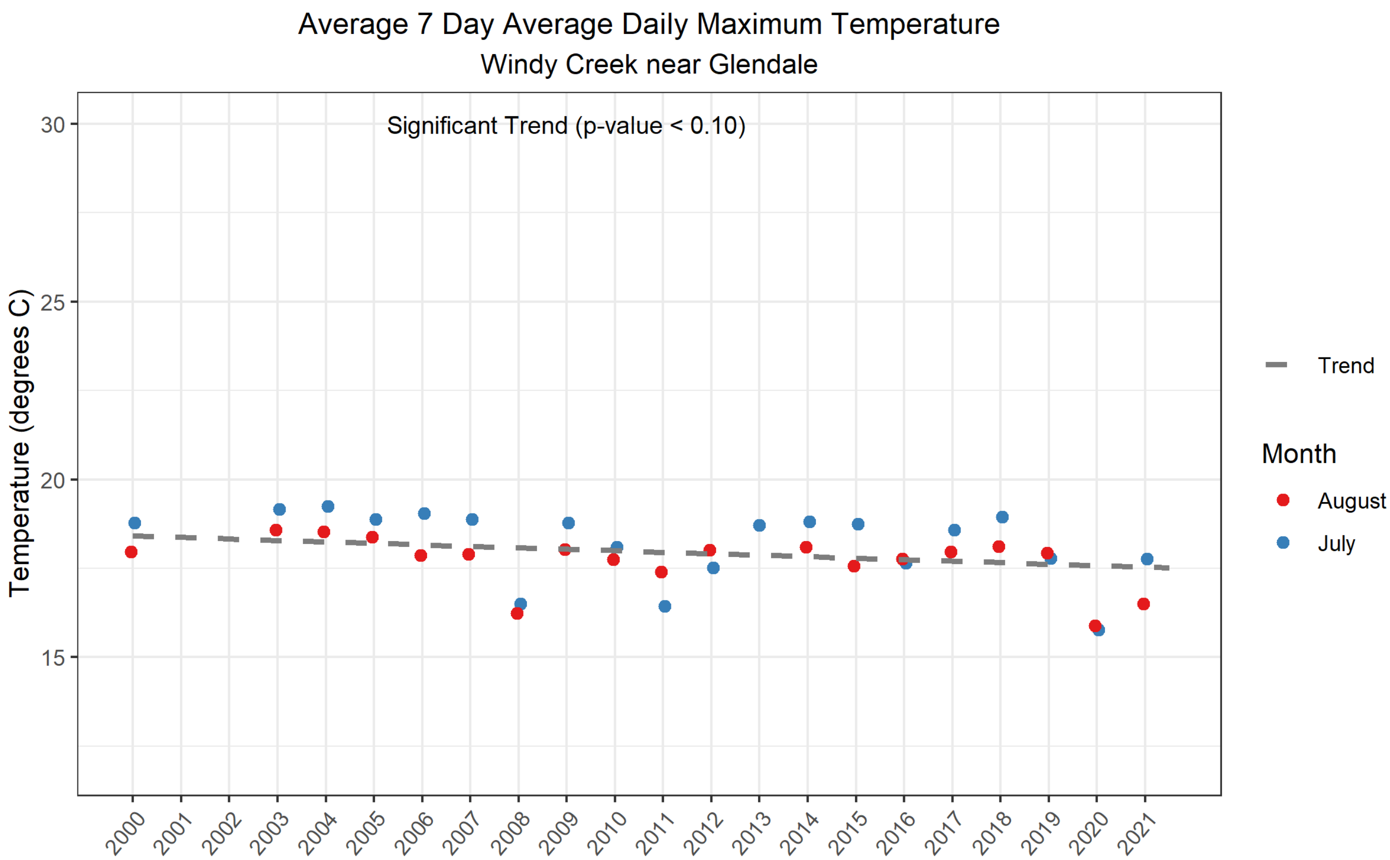

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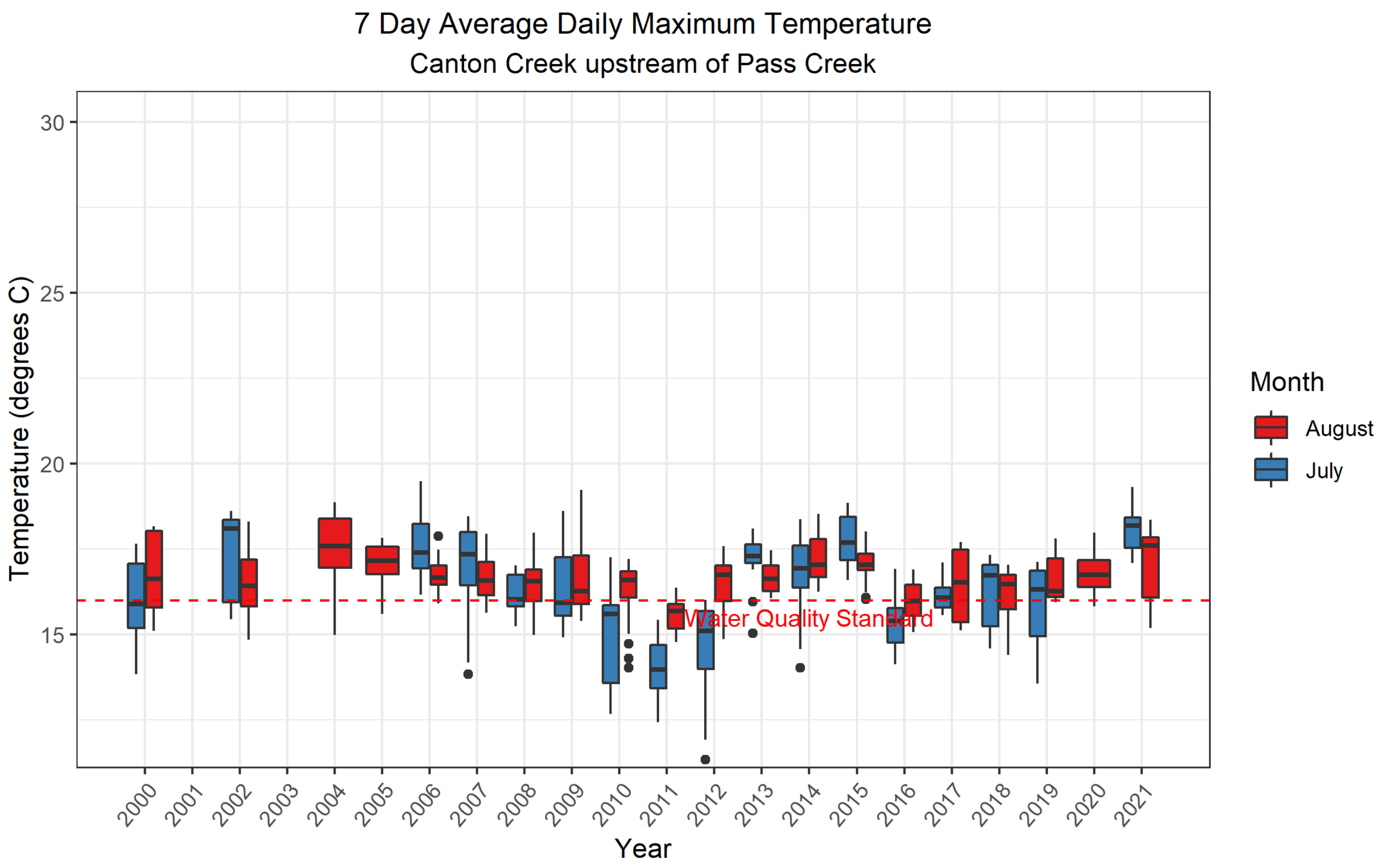

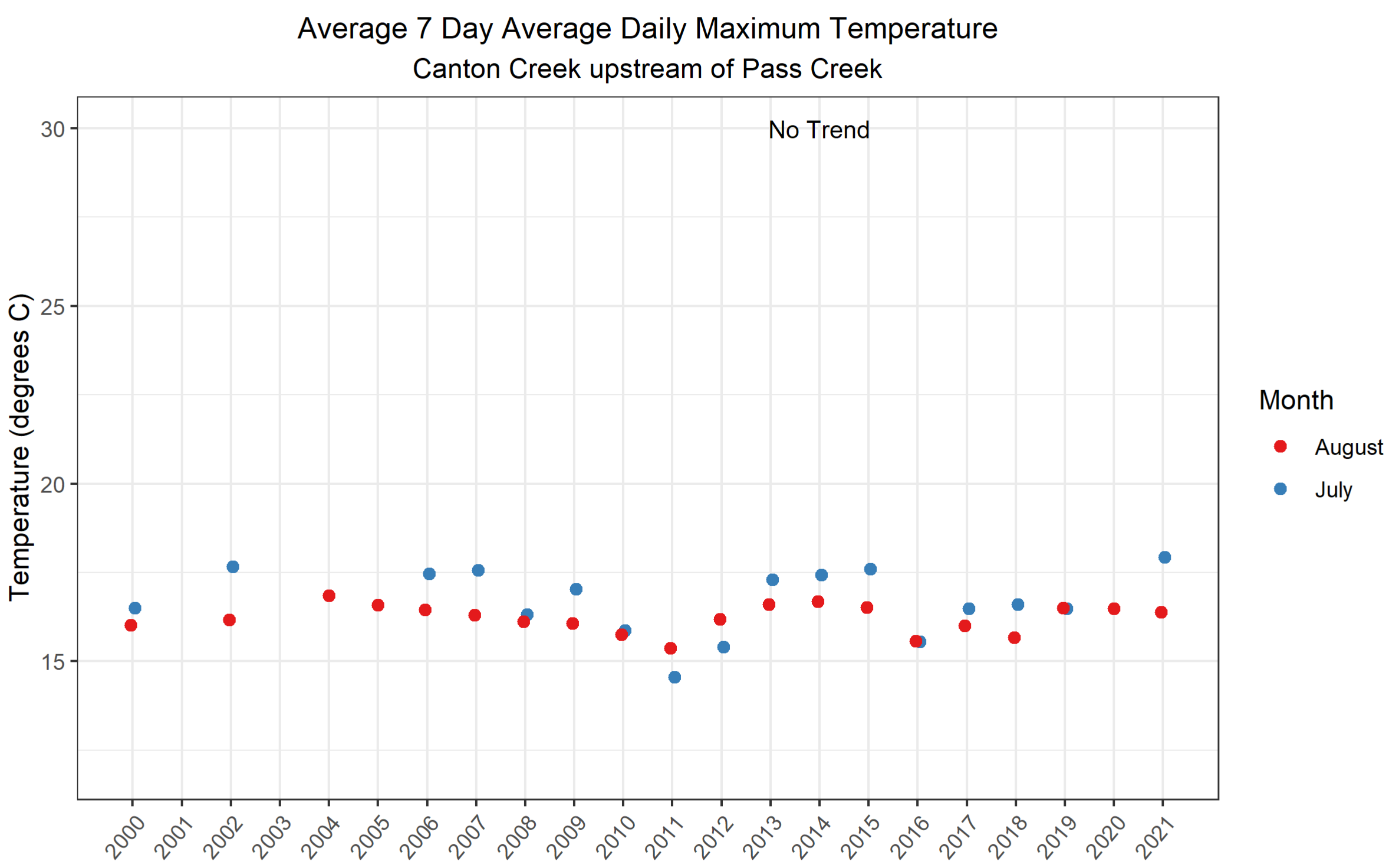

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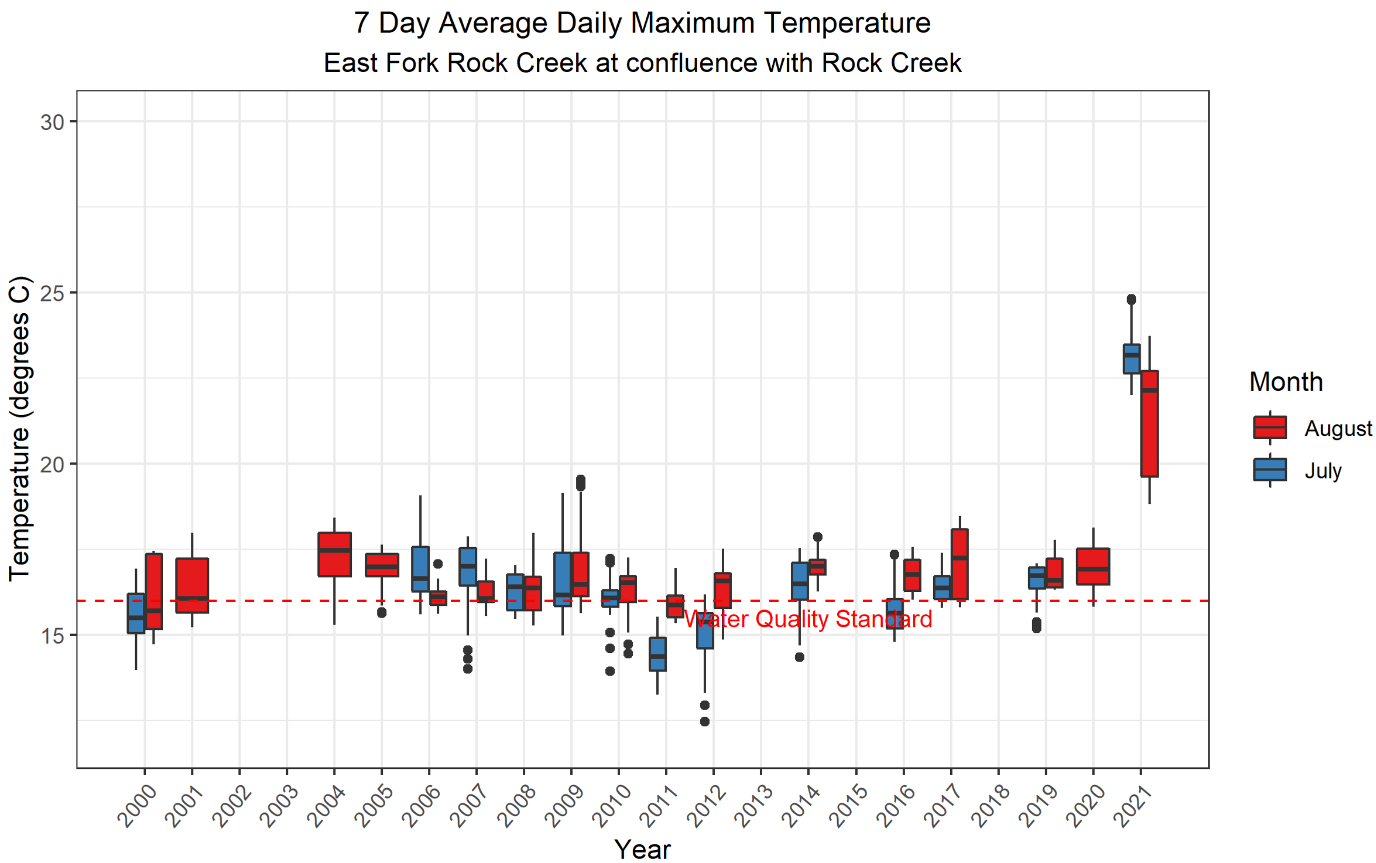

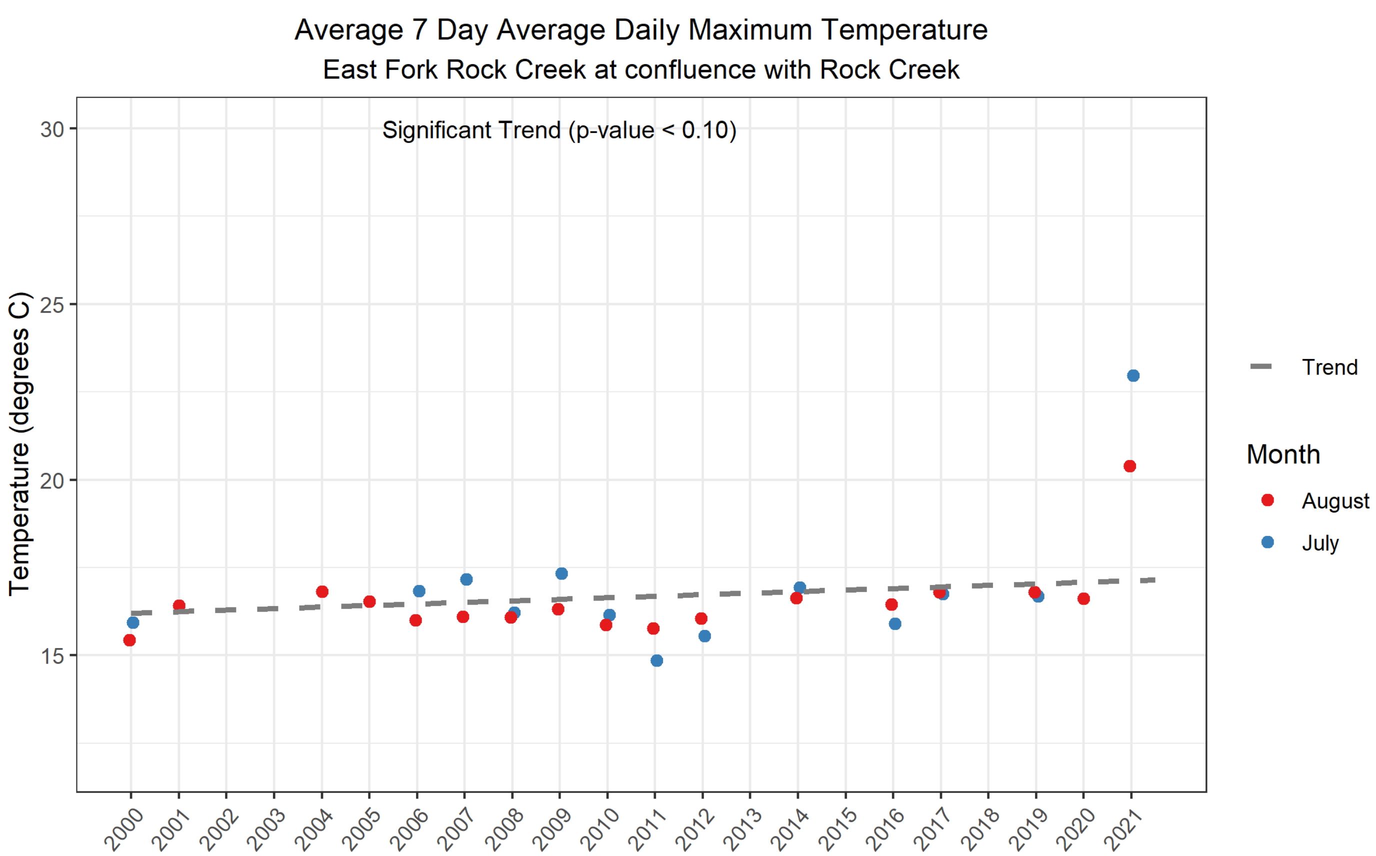

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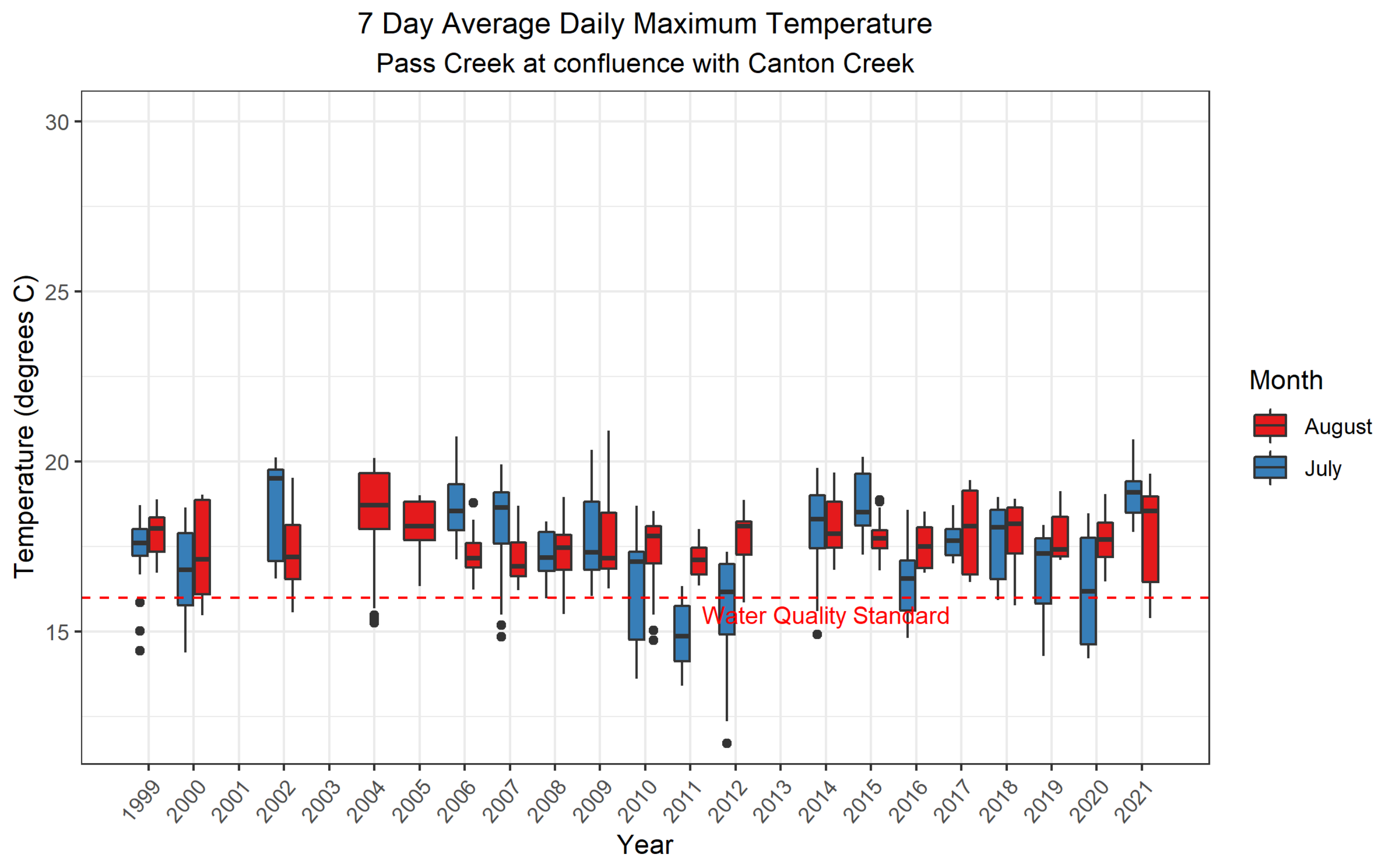

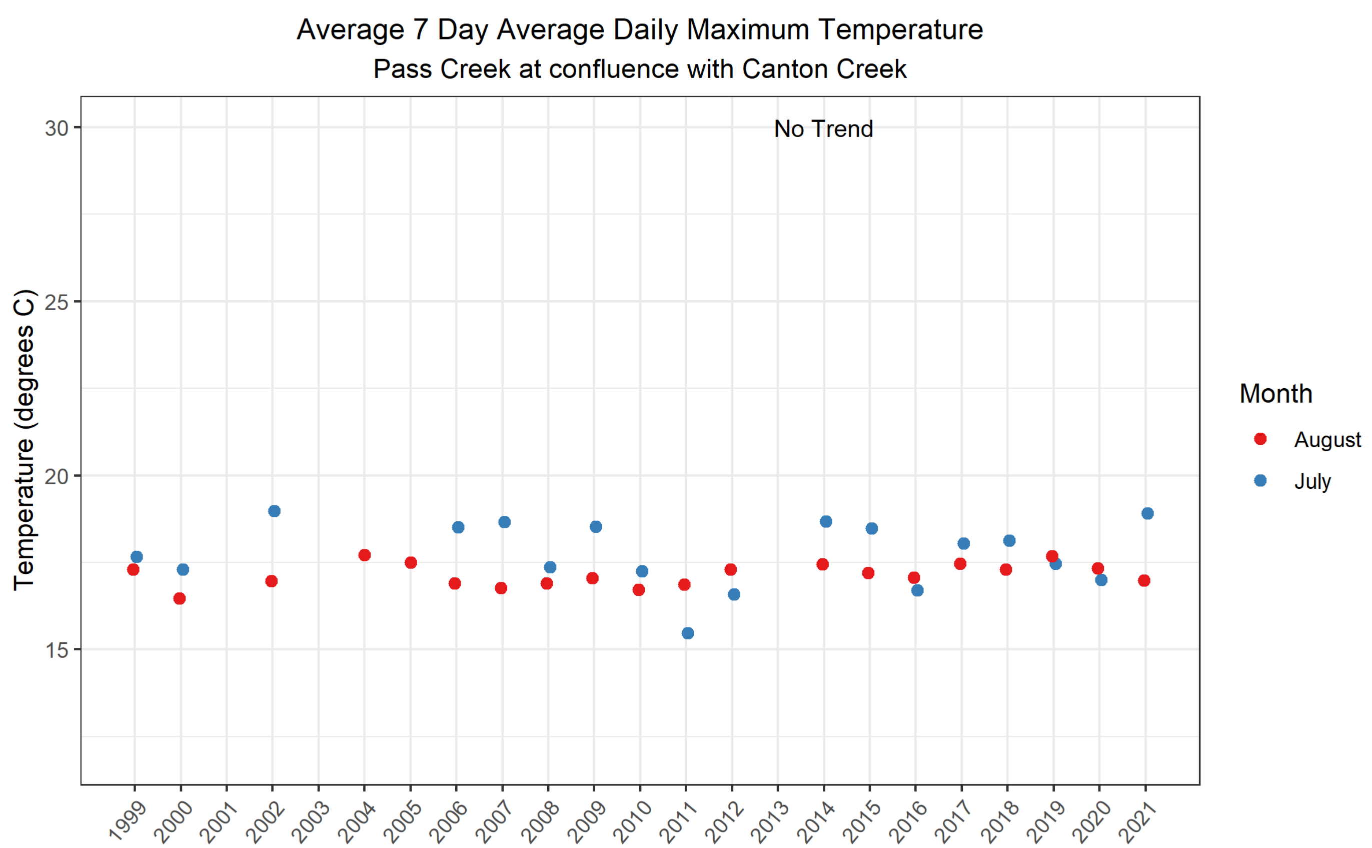

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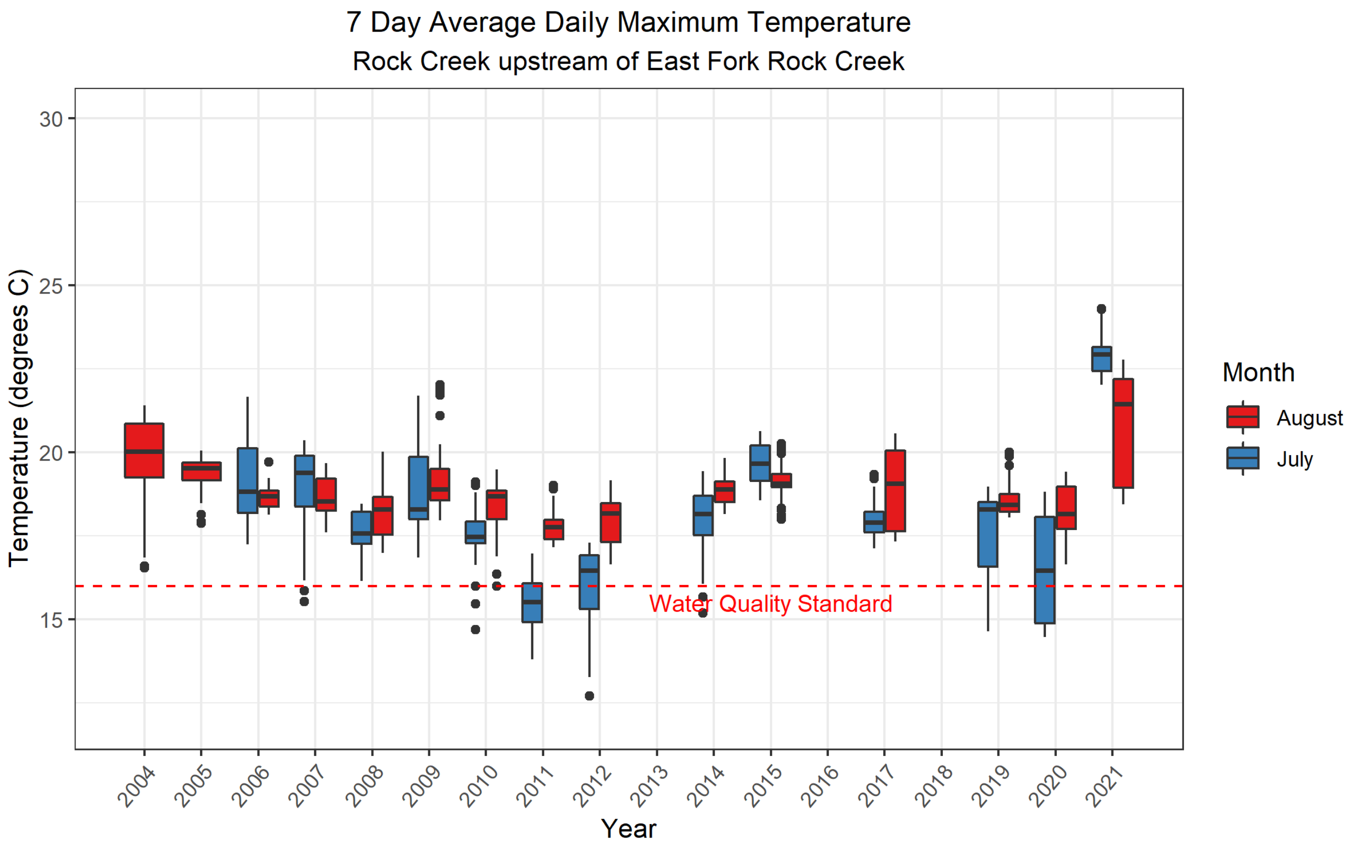

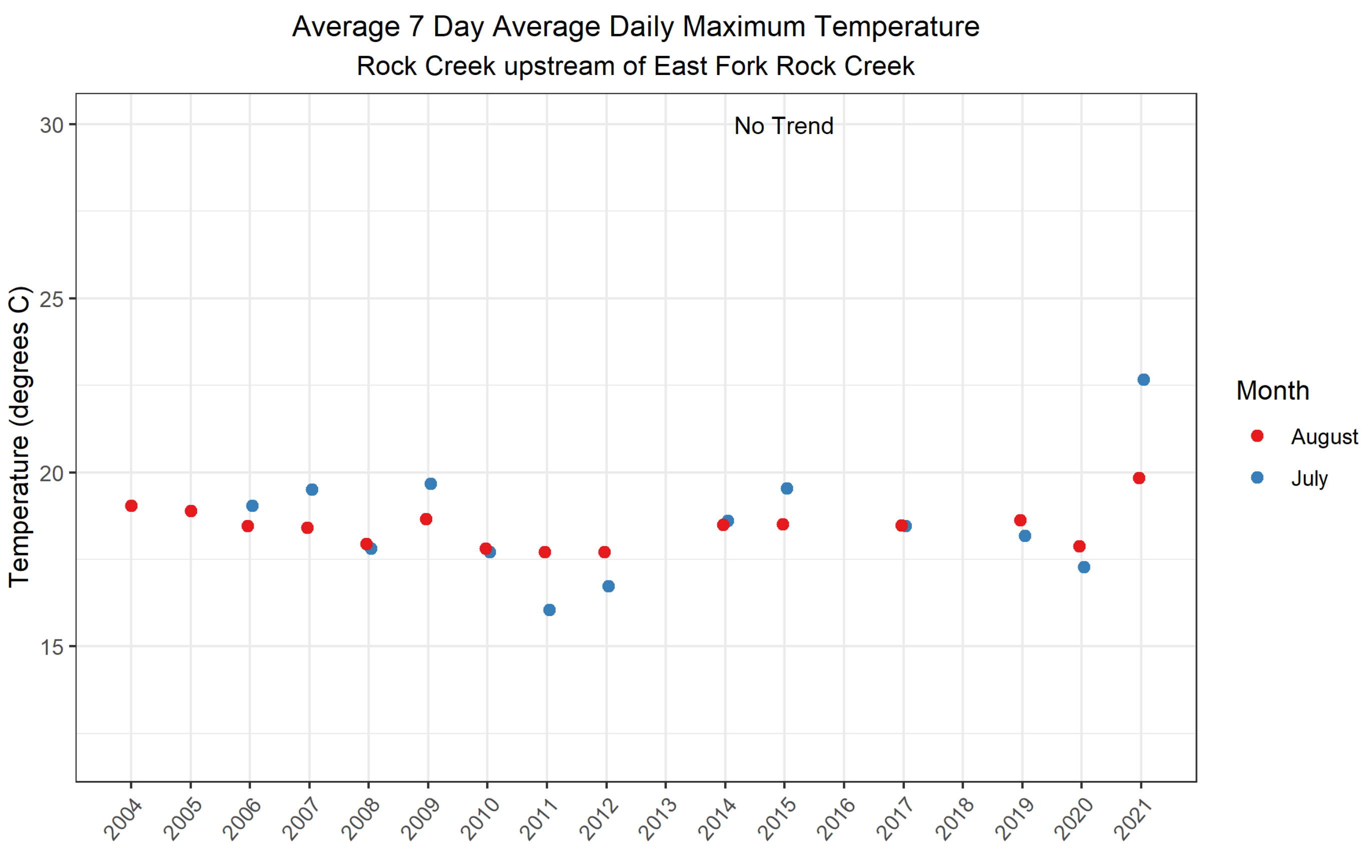

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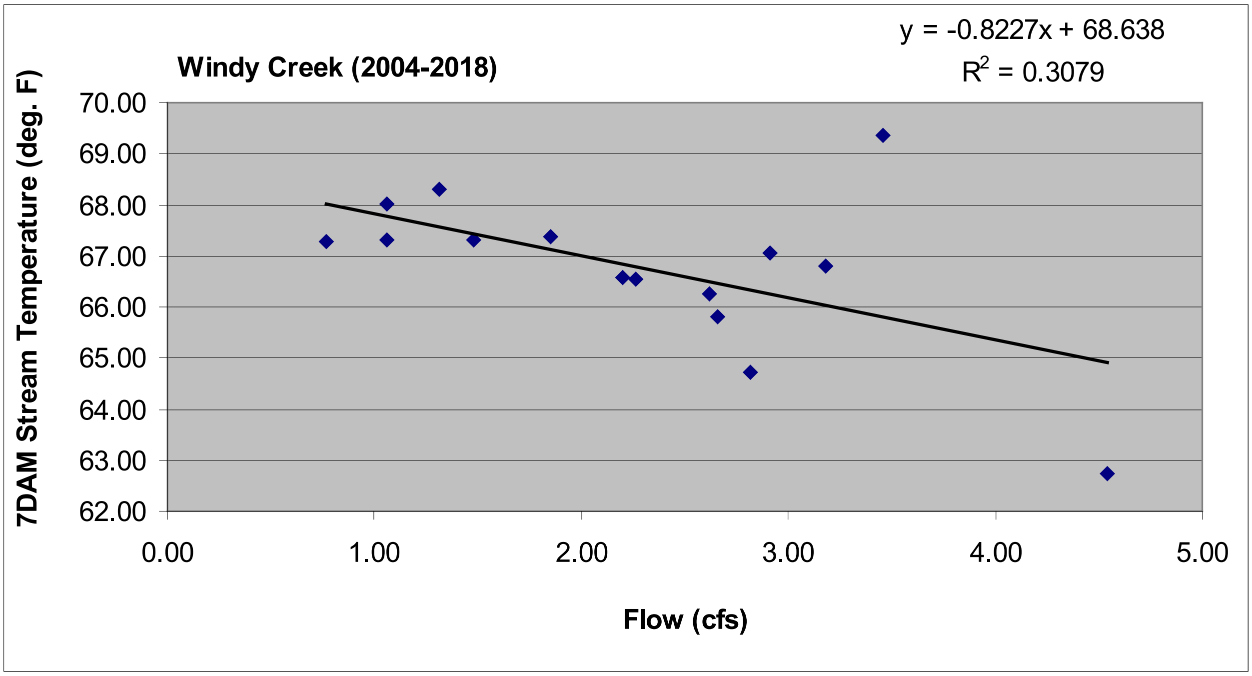


Note: In previous reports through 2016, Windy Creek flow data from 2004-2009 were included. This was actually data from Windy Creek but a few miles away and was erroneously included.

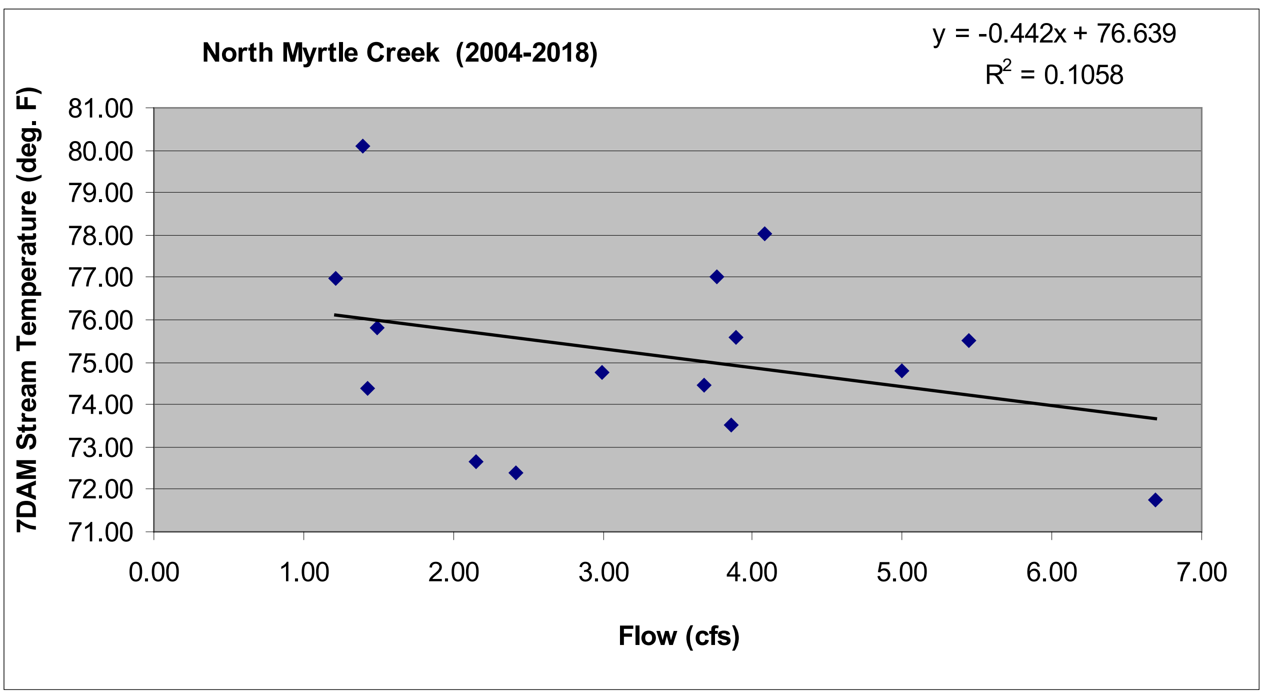
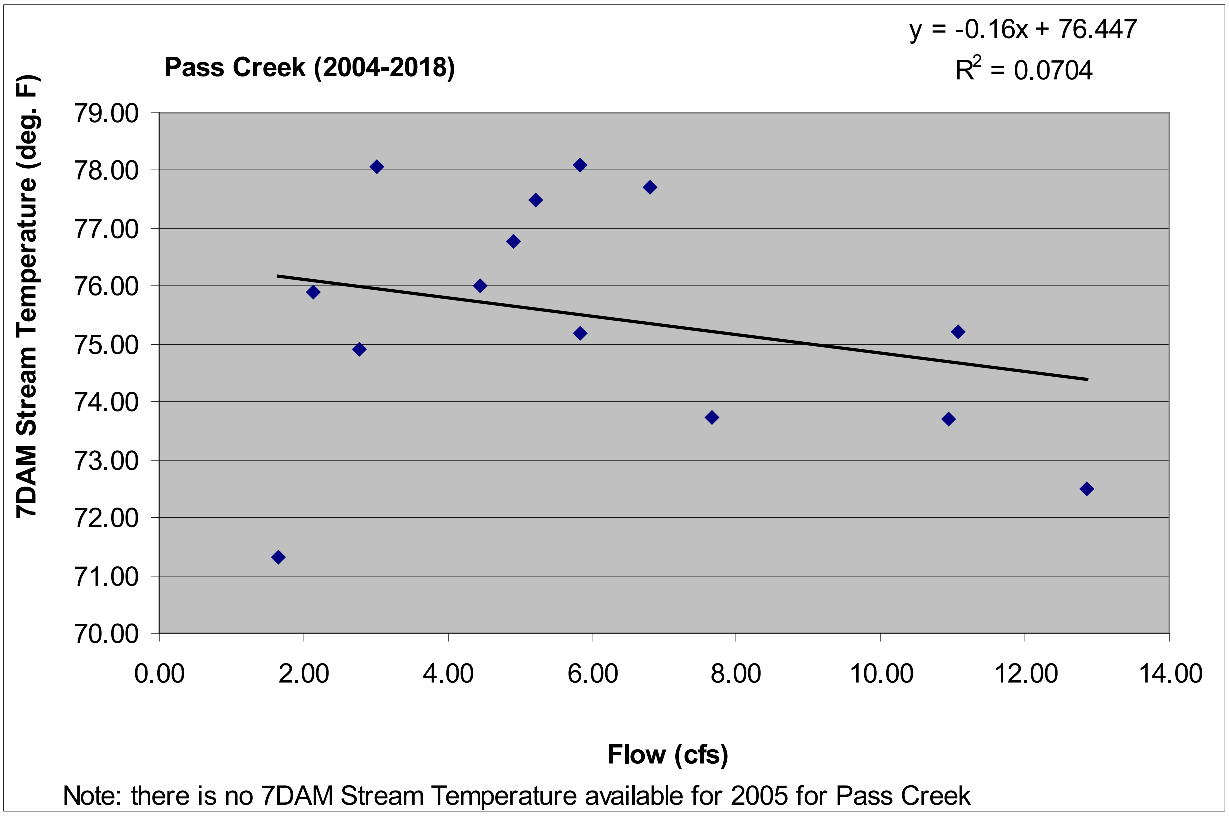
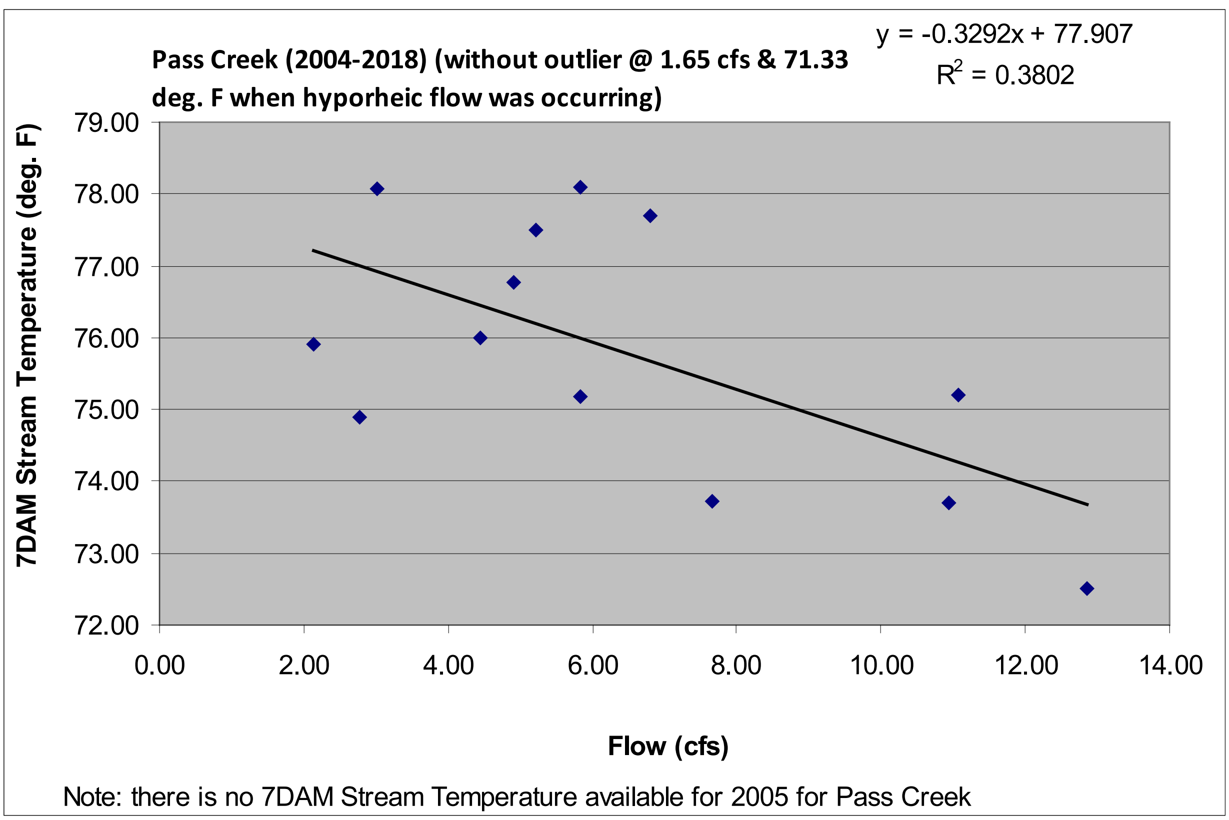


Figure 10. 2004-2018 Reference site 7DAM stream temperatures compared to flows on that day. Stream flows from OWRD and partners (Umpqua Basin Watershed Council {PUR}, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2013; PUR, 2014b, 2015, 2016b, 2017, and 2018). Note that flows were not taken consistently at the reference sites in 2019, therefore 2019 data is not included. (Page 1 of 3)





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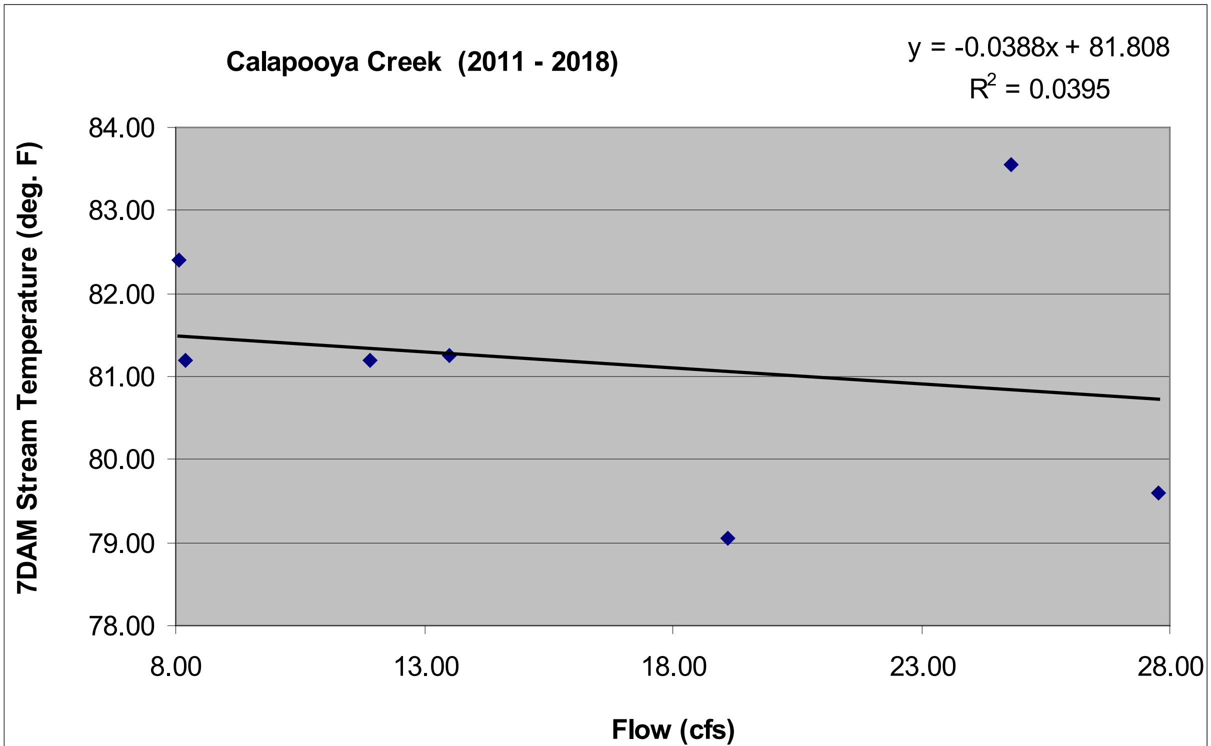
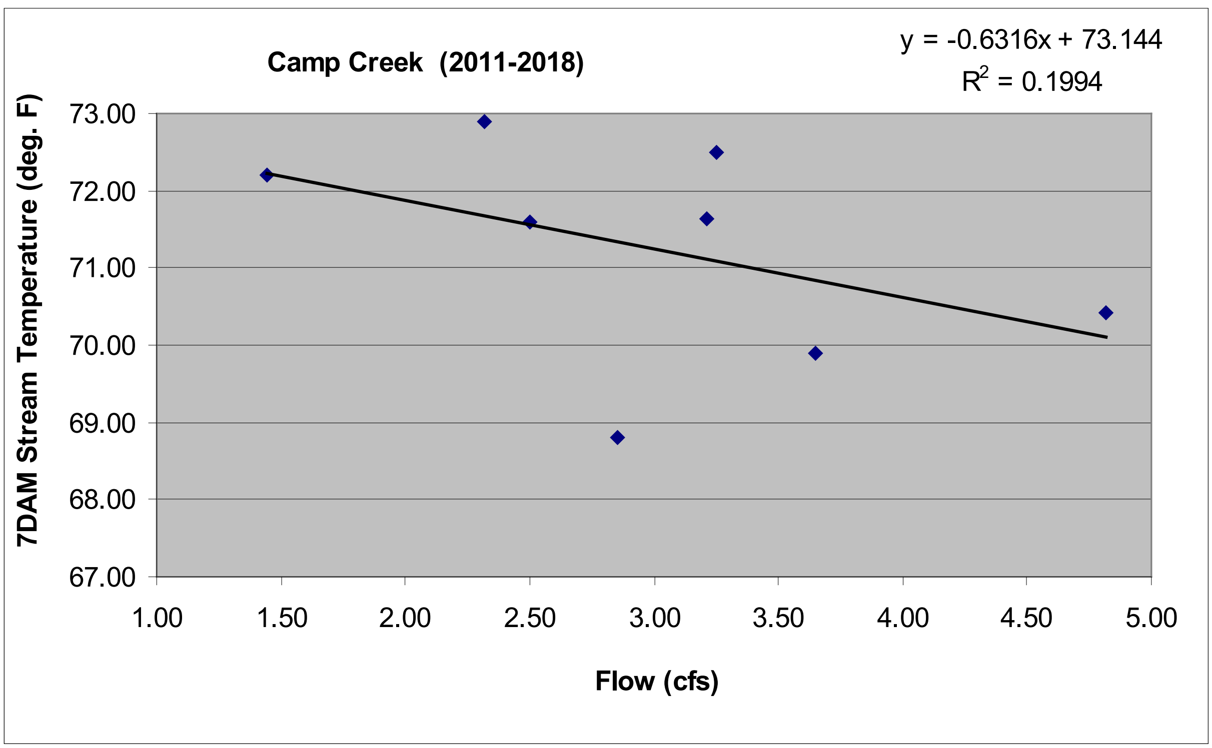


Note: In 2015, there is no flow data during the time of the 7DAM Stream Temperature.



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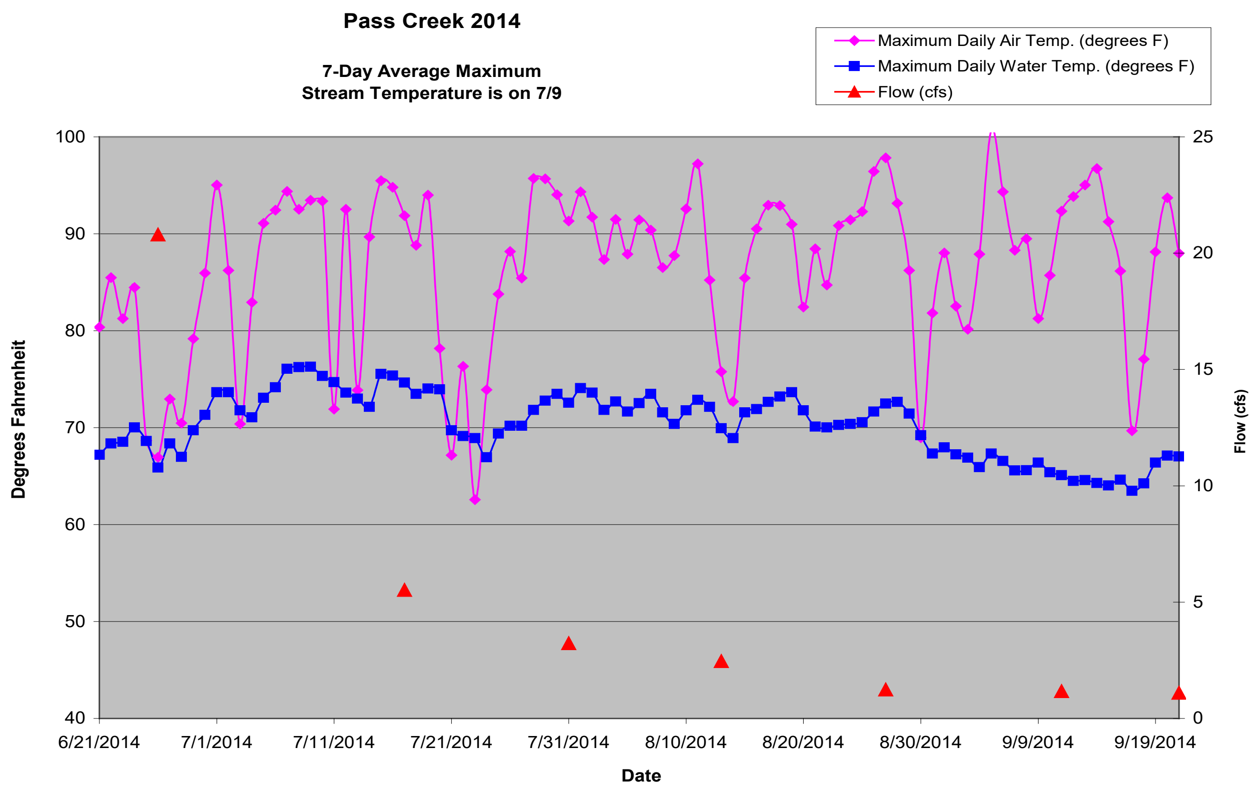

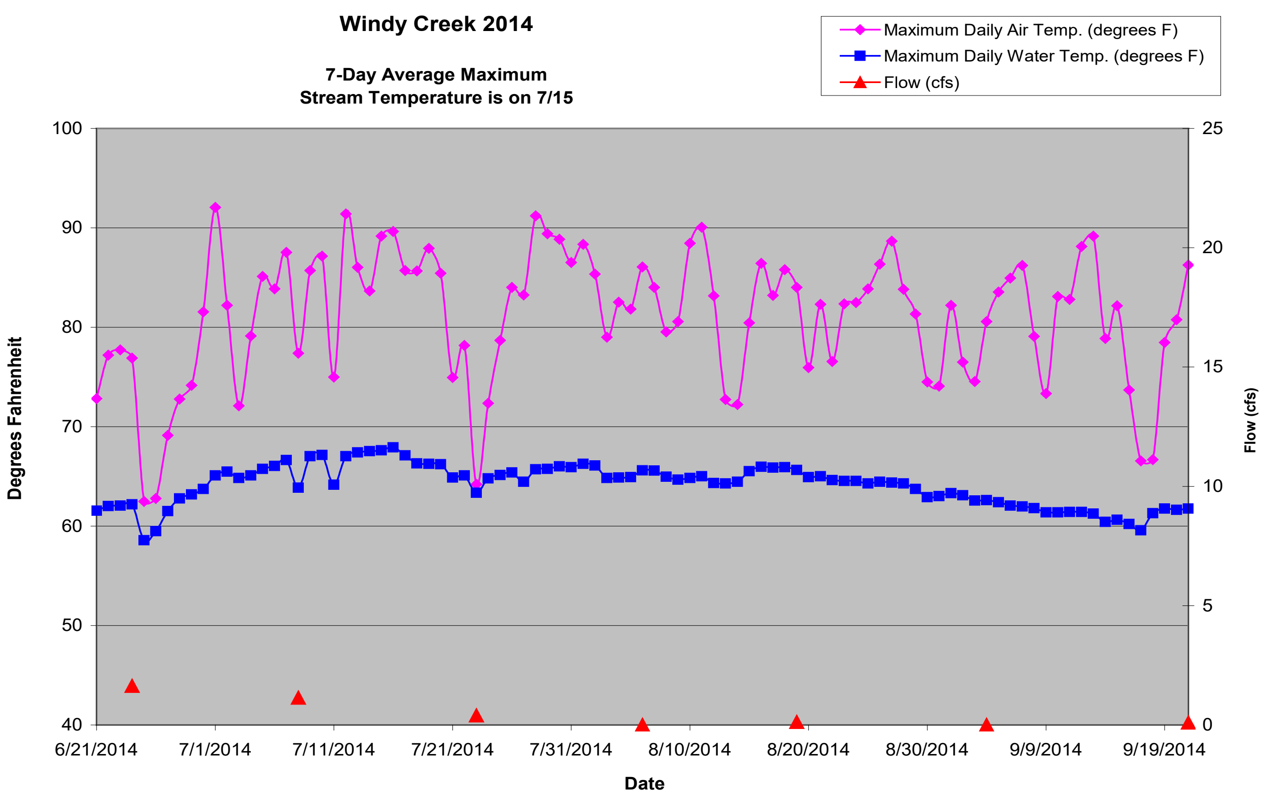

Figure 11. Pass and Windy Creek Maximum daily air temperature and flow compared to maximum daily stream temperature for 2014. These two site years were depicted because they had high air temperatures throughout the summer, but the stream temperatures decreased as flow and daylength decreased later in the summer (which was a typical pattern seen). Graphs of this data for all five sites from 2010-2019 is in the Appendix of Dammann (2019).

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