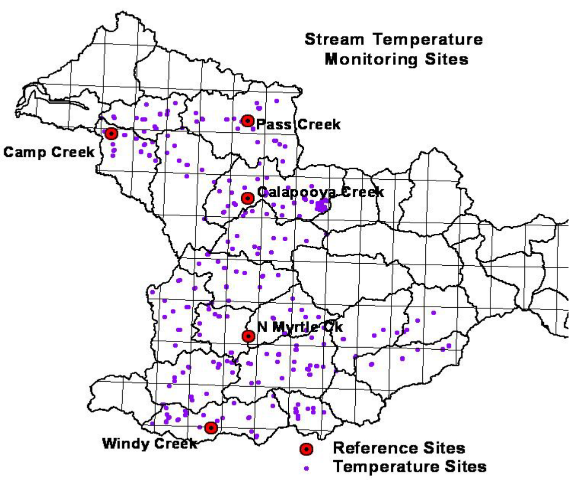
Umpqua Basin Stream Temperature Characterization – Reference Site 2020 Update and North Umpqua Comparison Site Analysis

(Covering Project Duration 1998-2020)

Prepared by:
Denise Dammann Consulting
for Partnership for the Umpqua Rivers (PUR)

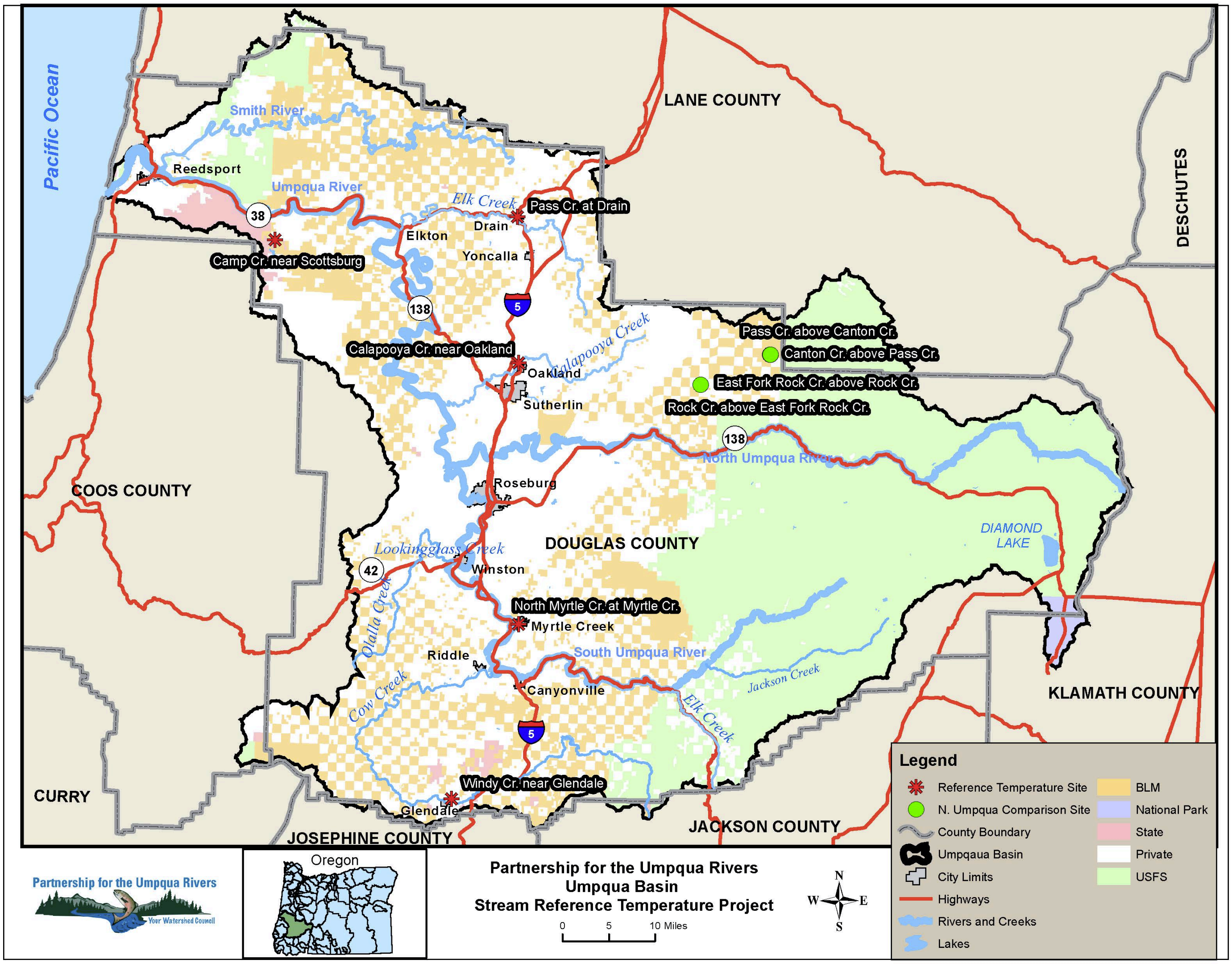
This is the continuation of a long-term summer stream reference temperature monitoring project in the Umpqua Basin of Southwestern Oregon. This report is an update of that project focusing on 2020 stream temperature conditions and comparing that to the air and stream temperature data collected since 1998. This year, the project was expanded into the North Umpqua Subbasin and this report will include analysis of the temperature monitoring in the North Umpqua 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, and 2019). This long-term data set, with 22 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. *Monkeyflower (Erythranthe cardinalis)* at Calapooya 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 if the results from the reference temperature project would apply to streams in the North Umpqua Subbasin and therefore the same models and relationships can be used for comparison. For this reason, four 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 (1999-2019) and current (2020) data from the BLM North Umpqua monitoring sites were analyzed in the same manner as the reference temperature sites.



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

This report will (1) look at 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 2020 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 data from the North Umpqua "comparison" sites to determine trends and feasibility of using similar analysis tools for data in this subbasin.

Site characteristics are shown in Table 1. The original five reference temperature sites are in the left columns and the North Umpqua sites added this year 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 Creek**
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 2018)	1998-present (no 2001, 2003 & 2013)	1998, 2004-present (no 2013, 2016, 2018)
Additional Historic Data (not included)	-	-	-	-	-	1991-1997 (no 1993)	1994, 1996, 1997	-	1996-1997
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)
Previous Data Analysis	Annual report	Annual report	Annual report	Annual report	Annual report	Completed 2021	Completed 2021	Completed 2021	Completed 2021
Drainage area (acres)	103,500	22,550	37,190	40,090	15,660	12,480	14,270	10,230	23,800
Maximum elevation in drainage (ft)	4400	2560	3300	1960	3700	4800	4600	4200	4700
Tributary to	Umpqua R	Mill Ck	Myrtle Ck	Elk Ck	Cow Ck	Steamboat Ck	Rock Ck	Canton Ck	N. Umpqua R
Subbasin	Umpqua	Umpqua	S. Umpqua	Umpqua	S. 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).

2020 Regional Weather Summary:

The reference temperature sites are surrounded by the cities of Roseburg, Eugene, and Medford in Western and Southwestern Oregon; therefore, the temperature patterns and extremes at these sites follow those of these three cities (Tables 2, 3, and 4 and NWS, 2020a and 2020b, and Iowa State University of Science and Technology, 2020). In addition, while the reference temperature study sites do not have headwaters in the snow zone, their headwaters are in the transient snow zone and flows are not typically impacted by the snowpack. The North Umpqua sites 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, 2020 brought dramatic swings in weather starting off warm, then turning cool and rainy (NWS, 2020c). This was followed by early season heat from the 7th through the 11th, then cooler and rainy the next two weeks, followed by a heat wave and ending with more precipitation (NWS, 2020c). June began warm and dry until the 6th, when cooler wet weather arrived (NWS, 2020d). By mid-month warm, dry weather returned with a few days in the 90's (NWS, 2020d). The cool weather at the very end of June continued into July, but heated up by the middle of the month and was into the high 90's and over 100 by July 26th, and there was only a trace of precipitation all month (NWS, 2020e). It was a typical August, hot and and dry (NWS, 2020f). September, on the other hand, started in the mid to high 80's to 90's with dry weather but September 7th was very low humidity and unseasonably strong east winds (NWS, 2020g). The Archie Creek Fire started early morning on Sept. 8th in the North Umpqua Subbasin east of Rock Creek and south of Canton Creek watersheds and spread quickly to the west (travelling 15 miles in the first 12 hours). A blanket of smoke covered the region for weeks which moderated air temperatures throughout the region. By mid-September there was also measurable precipitation returned to the area (NWS, 2020g).

May through August, 2020 had both higher daily minimum and maximum temperatures compared to normal (Table 2). May was wetter and June through August were somewhat dryer (Table 2). There were several "heat waves" throughout the summer, but the longest period with the maximum temperatures exceeding 85°F was late July to early August and in early September (Table 3).
In 2020, there were two days with temperatures that exceeded 100°F in Roseburg (July 26 and August 15) as opposed to three in 2019 (NWS, 2019a and 2020a). Medford had 18 days with temperatures exceeding 100°F in 2020; for comparison, in 2019, Medford only had two days exceeding 100°F; whereas since 2012 they have had had greater than ten days per year in the 100's (NWS, 2019a and 2019b). The temperature on August 15th in Roseburg tied 1946 for the highest maximum temperature ever recorded (NWS, 2020a). Other record weather events occurred in the region were mainly for maximum temperature and maximum rainfall throughout the summer (Table 4).

Table 2. Monthly Average Maximum Temperatures and Monthly Precipitation for Roseburg, Oregon from May to September, 2020. All National Weather Service (NWS) data are preliminary and have not undergone final quality control. (NWS, 2020c, 2020d, 2020e, 2020f, and 2020g)

Month	Average Maximum Temperature	Departure from Normal	Average Minimum Temperature	Departure from Normal	Monthly Precipitation	Departure from Normal
May, 2020	72.6°F	+2.7°F	47.9°F	+0.9°F	3.22"	+0.95"
June, 2020	76.9°F	+0.9°F	54.3°F	+2.5°F	0.98"	-0.15"
July, 2020	86.8°F	+2.6°F	58.6°F	+2.4°F	Trace	-0.42"
August, 2020	88.7°F	+4.0°F	58.5°F	+2.9°F	0.02"	-0.45"
Sept., 2020	74.8°F	-3.8°F	54.9°F	+3.7°F	2.55"	+1.59"

Table 3. Heat waves with at least three consecutive high maximum daily air temperatures above 85°F in Roseburg, Oregon from May to September, 2020. All National Weather Service (NWS) data are preliminary and have not undergone final quality control. (NWS, 2020a)

Date Range	Location	Daily Maximum Air Temperatures
July 13-16	Roseburg	85-94°F
July 25 – August 4	Roseburg	86-102°F (July 26-30 above 96°F)
August 13-17	Roseburg	87-98°F + 109°F on August 15
August 23-29	Roseburg	86-91°F
September 1-9	Roseburg	85-99°F

Table 4. Record weather events for Roseburg, Medford, and Eugene, Oregon from May to September, 2020. All National Weather Service (NWS) data are preliminary and have not undergone final quality control. (Iowa State University of Science and Technology, 2020 and NWS, 2020a, and 2020b)

Date	Location	Record Broken
May 8, 2020	Roseburg	Highest maximum temperature for this date (90°F)
May 28, 2020	Roseburg	Highest maximum temperature for this date (93°F)
May 30, 2020	Roseburg	Highest daily maximum rainfall for this date (1.19 inches)
May 30, 2020	Medford	Highest daily maximum rainfall for this date (1.47 inches)
June 7, 2020	Medford	Lowest maximum temperature for this date (58°F)
June 10, 2020	Eugene	Highest minimum temperature for this date (58°F)
June 16, 2020	Eugene	Highest daily maximum rainfall for this date (0.73 inches)
June 23, 2020	Roseburg	Highest maximum temperature for this date (97°F)
August 15, 2020	Roseburg	Highest maximum temperature for this date (109°F)
August 15, 2020	Eugene	Highest maximum temperature for this date – tie (108°F)
August 15, 2020	Medford	Highest maximum temperature for this date (109°F)
September 3, 2020	Roseburg	Highest maximum temperature for this date (99°F)
September 28, 2020	Roseburg	Highest maximum temperature for this date (96°F)
September 28, 2020	Medford	Highest maximum temperature for this date (98°F)

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

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. (Figures 1 and 2)

In 2020, 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 prior to June 21. 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 stream temperature monitoring data is 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. BLM data also undergoes 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).

2020 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 four 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, 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. 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 East Fork (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). The Archie Creek Fire did not burn into the Canton and Pass Creek drainages. The PUR water temperature recorder at East Fork Rock Creek showed noticeable increase in stream temperature at the time of the fire (Figure 2). The BLM Rock Creek water temperature recorder showed no noticeable signature at the time the fire went through (Figure 2). Rock Creek is a larger stream system, which may explain why there was no noticeable temperature increase. For all four North Umpqua sites, the 2020 stream temperatures and the diurnal fluctuation dampened after the fire started due to the increased smoke blanketing the region reducing solar radiation, until the rains began in the middle of September. The air temperature and stream temperatures of the reference sites were also affected by the blanket of smoke reducing air temperatures in the region (Figures 1 and 2).

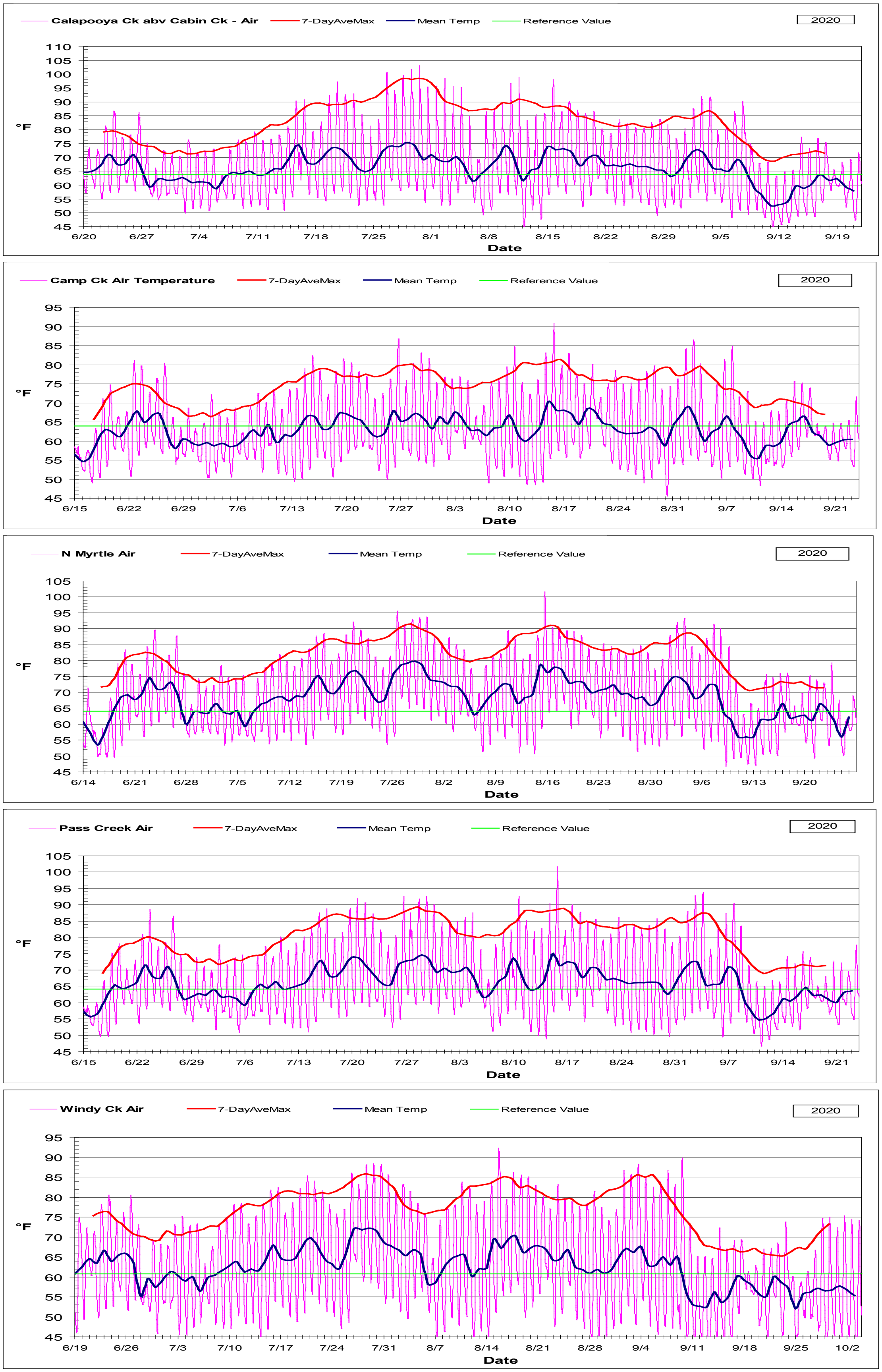


Figure 1. 2020 Umpqua Basin reference site air temperature data measured at 30-minute intervals. The reference value is set at the Oregon Department of Environmental Quality (ODEQ) temperature standard for stream temperature (64.4°F for all except Windy Creek which is 60.8°F (ODEQ 2003 & 2018)). The 7-day average maximum (7DAM) air temperature is centered on the date of the rolling 7-day period.

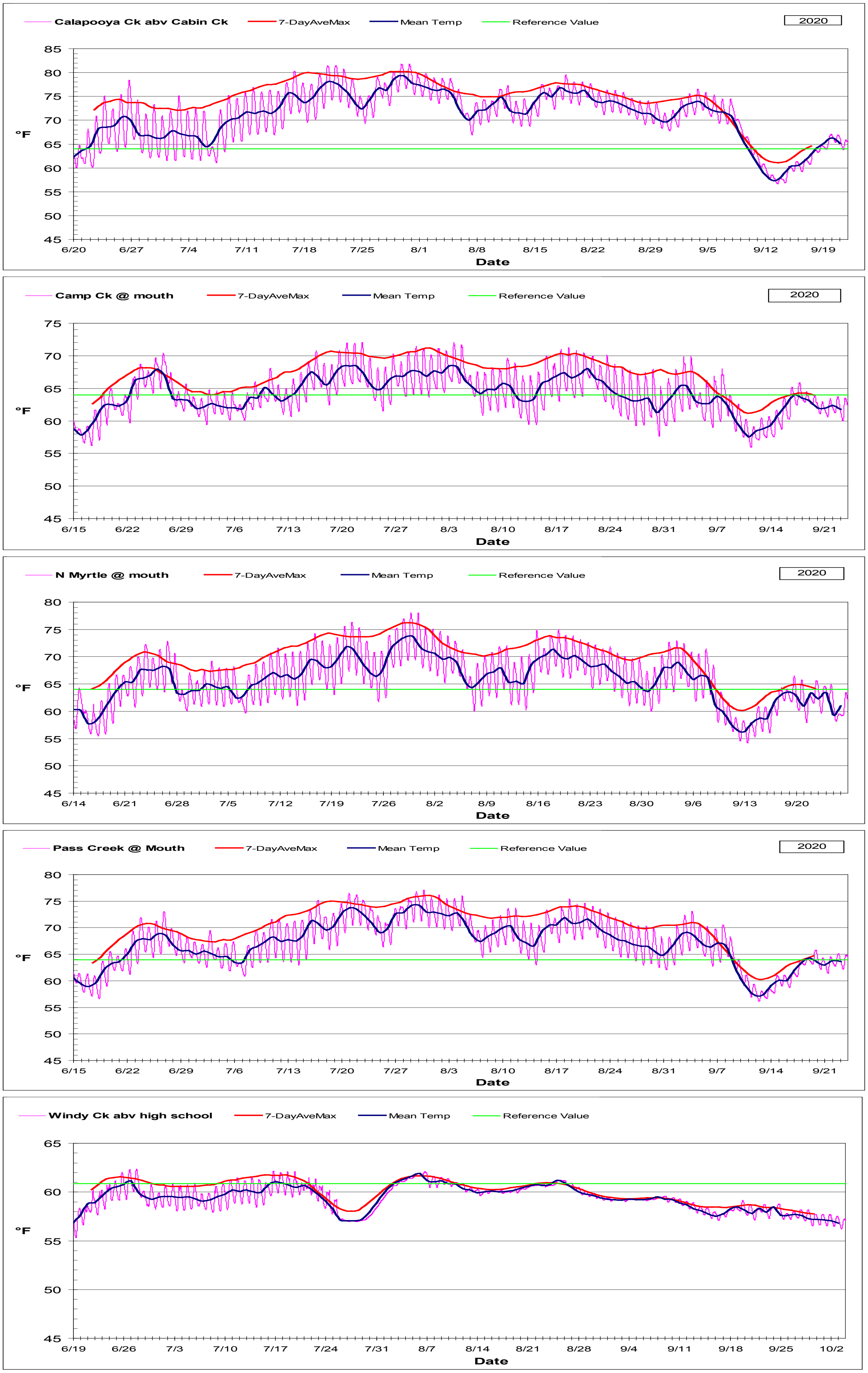


Figure 2. 2020 Umpqua Basin reference site and North Umpqua comparison site stream temperature data measured at 30-minute intervals. The reference value is 64.4°F for all sites except Windy Creek and the four North Umpqua sites which is 60.8°F (ODEQ 2003 & 2018). The 7-day average maximum (7DAM) stream temperature is centered on the date. (First page – reference sites; second page – North Umpqua comparison sites) (Page 1 of 2)

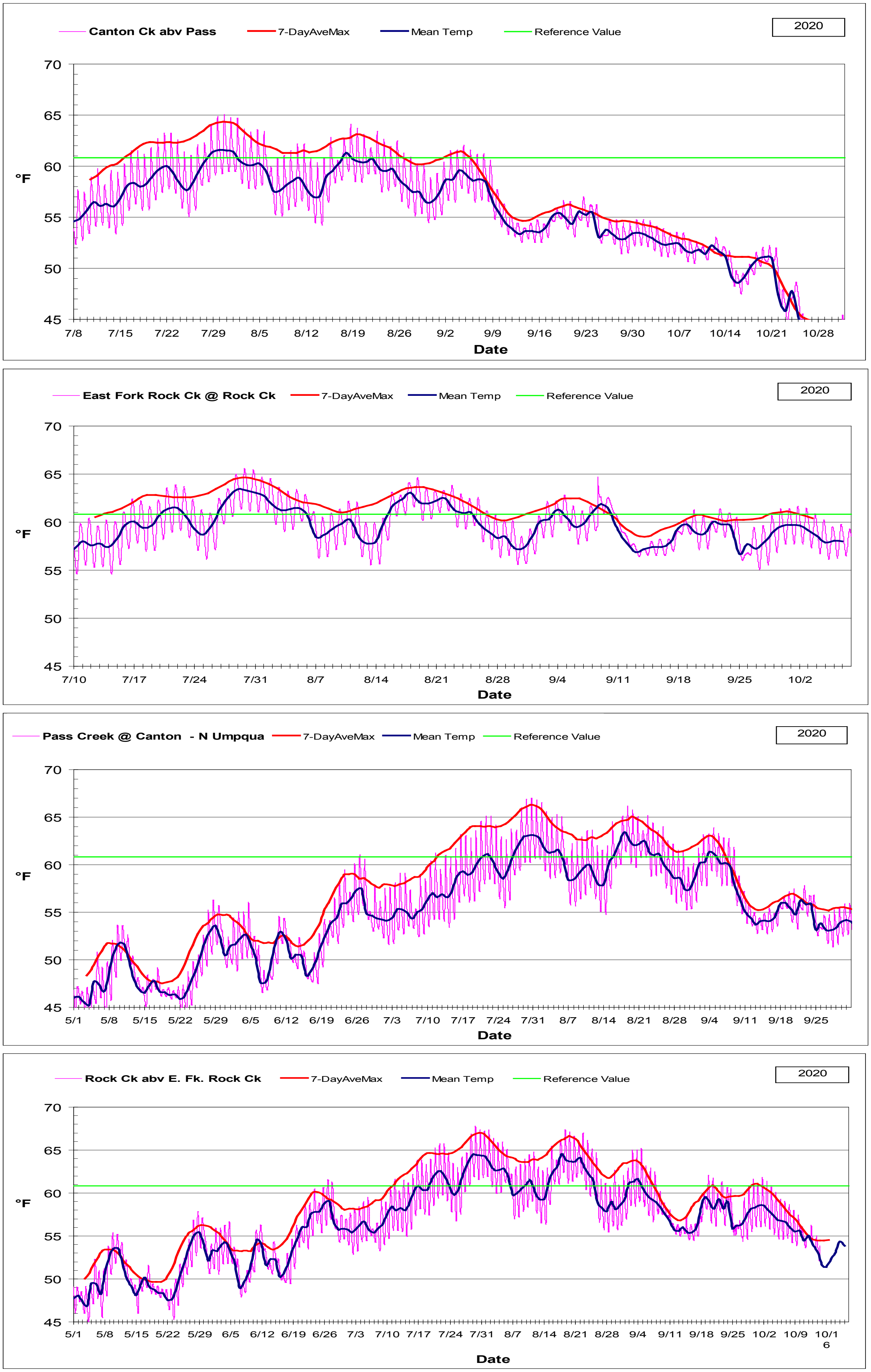


Figure 2. Continued. (Page 2 of 2)

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. 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 2 and Figure 1). One of the longest heat waves of the summer occurred in late July and early August with temperatures exceeding 90°F for six consecutive days in Roseburg. (Table 2). 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). In 2020, the 7DAM stream temperature occurred during the late July/early August for most of the reference sites (July 30 for North Myrtle, July 31 for Calapooya, and August 1 for Camp and Pass) This was consistent with the 7DAM stream temperatures for the North Umpqua sites which were all on July 31 except East Fork Rock Creek which was July 30. The 7DAM stream temperature for Windy Creek, on the other hand, was during the mid-July heat wave on July 19. The elevated stream temperature during the time of the Archie Creek Fire did not reflect in the 7DAM stream temperature.

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

In 2020, the 7DAM stream temperatures for the reference sites exhibited similar patterns to previous years in the 22 year period of record. Calapooya Creek has had the highest 7DAM stream temperatures for the entire period of record and Windy Creek has had the lowest (Figure 3). 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 3). 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 3). 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 3). There is no known change to the site characteristics that would warrant this change. Time will tell if this is an anomaly or a new pattern. For the other reference sites, the 2020 7DAM stream temperatures at two sites (Calapooya and Camp) ranked as some of the lowest; whereas the North Myrtle and Pass Creek sites ranked in the middle when compared to the period of record (Figure 3 and Table 4).

The North Umpqua 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 3), which is supportive of using these for comparisons to other sites.

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 (Table 4). Smith (2003) found that the cold limit line where the water temperatures typically exceed 64^{o}F 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 64^{o}F (Figure 3).

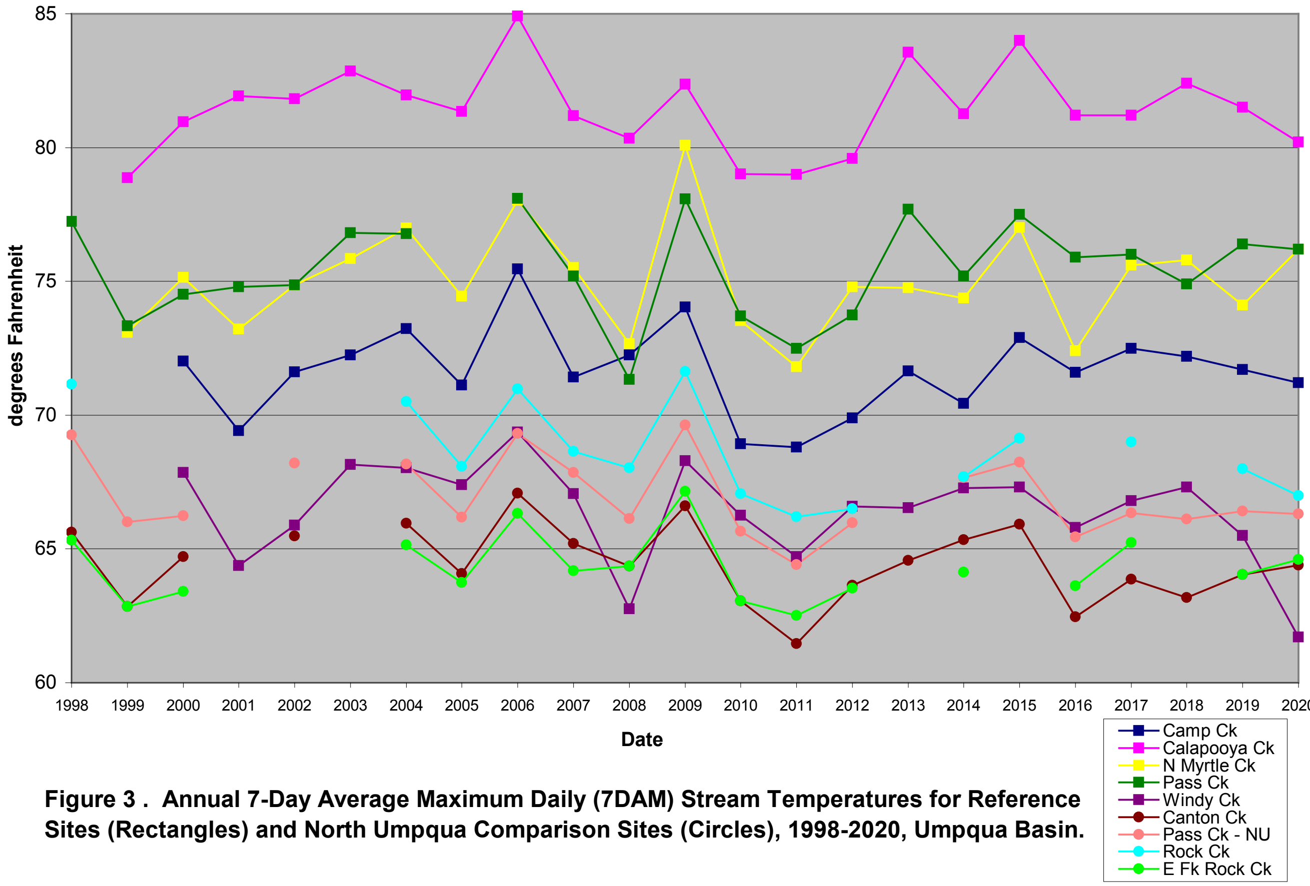


Figure 3 . Annual 7-Day Average Maximum Daily (7DAM) Stream Temperatures for Reference Sites (Rectangles) and North Umpqua Comparison Sites (Circles), 1998-2020, Umpqua Basin.

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 6.06 to 8.28ºF depending on the site during the 21-22 year period of record (Figure 3 and Table 4). The 7DAM stream temperature at the North Umpqua comparison sites has varied between 4.73 and 5.62ºF depending on the site during the 15-21 year period of record (Figure 3 and Table 4).

The North Umpqua sites 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 (2020b).

Table 4. Umpqua Basin reference site and North Umpqua comparison site highest, lowest, and difference in 7-day average maximum (7DAM) stream temperatures from 1998-2020.

	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	Rock Creek above East Fork Rock Creek
Drainage area (acres)	103,500	22,550	37,190	40,090	15,660	12,480	14,270	10,230	23,800
Highest 7DAM temperature (Deg. F)	84.92	75.46	80.08	78.10	69.36	67.08	67.15	69.63	71.63
Lowest 7DAM temperature (Deg. F)	78.86	68.80	71.80	71.33	61.7	61.46	62.42	64.42	66.18
Difference in 7DAM temperatures (Deg. F)	6.06	6.66	8.28	6.77	6.61	5.62	4.73	5.21	5.45
Mean 7DAM temperatures (Deg. F)	81.43	71.65	75.01	75.49	66.42	64.47	64.24	66.98	68.49
Ranking of 2020 data	18th	15th	6th	9th	Lowest (prev. 62.8)	11th	7th	11th	11th
Number of years of data analyzed	22	21	22	22	21	21	19	20	15
Subbasin	Umpqua	Umpqua	S. Umpqua	Umpqua	S. Umpqua	N. Umpqua	N. Umpqua	N. Umpqua	N. Umpqua

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.

The approximately 4.7-8.3ºF interannual variability in 7DAM stream temperature for monitoring sites during the period of record (Figure 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 3) 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 3), 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) (NWS, 2015a and 2015b, NWS, 2016a and 2016b, NWS 2017a and 2017b, NWS 2018a and 2018b). 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, August, 2017 broke three records in Roseburg: (1) the record run of 90°F days (14 days), (2) the most consecutive days at or above 100°F in Roseburg (102°F, 108°F, 108°F, and 101°F on August 1-4, respectively), and (3) the hottest August on record, breaking the record set in 2014 (Table 2) (Dammann, 2017).

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. 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. The hottest stream temperatures in the last 22 years 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, 2020a). 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, 2020a).

Timing of 7DAM Stream Temperatures:

For the 21-22 year period of record, the dates of the 7DAM stream temperatures for the reference temperature sites have been between June 30 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). It’s interesting to look at how 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 July 8-19 and August 9-19 and an increase from June 30 – July 1 as well. In 2020, four of the five monitoring sites had 7DAM stream temperatures that occurred between July 30 and August 1, which is within that time period and one on July 19. With more years of data, we will learn if a typical bell curve be established or if another pattern will emerge.

With the addition of the analysis of the North Umpqua comparison sites, the same graph was made with North Umpqua data (Figure 5). The pattern in 7DAM dates is very similar to that of the reference temperature sites for both 2020 and for the period of record. All four sites had 7DAM stream temperatures on either July 30 or 31 in 2020. When the nine 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.

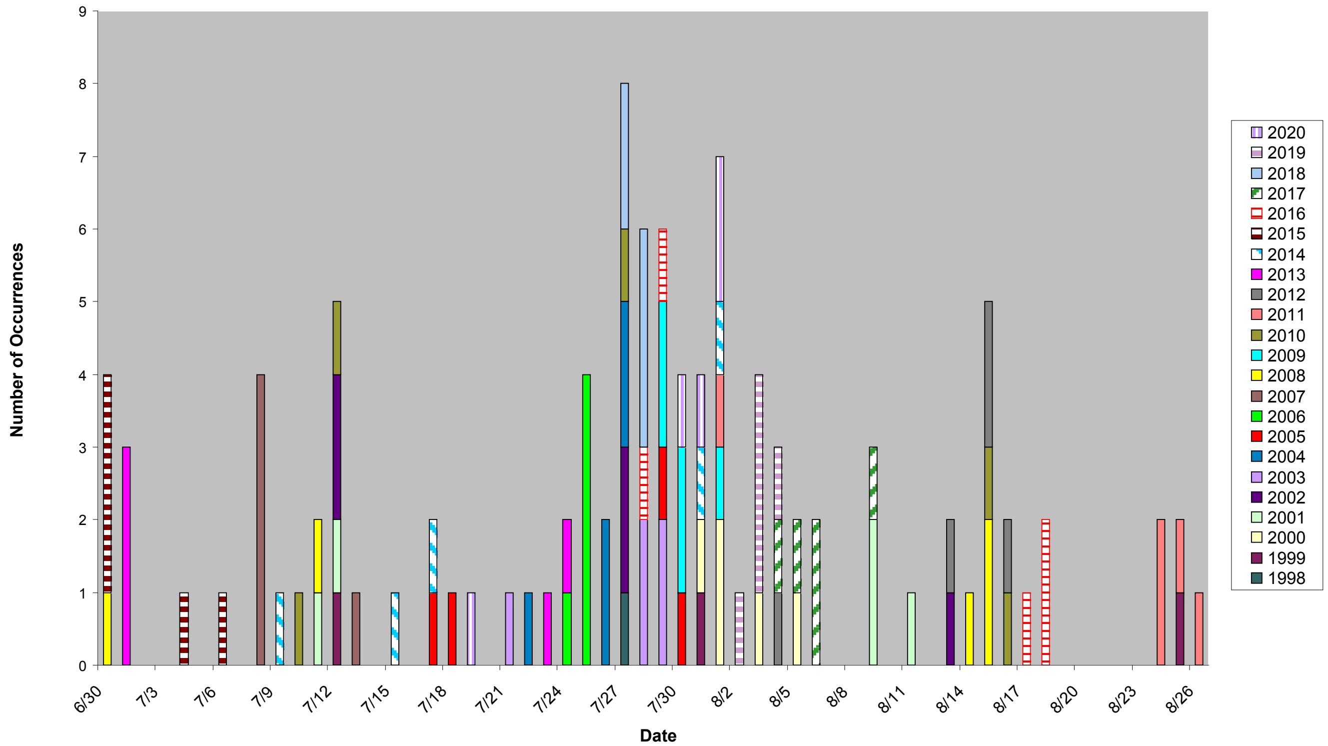


Figure 4: Dates of 7-day average maximum stream temperatures for the Umpqua Basin reference sites from 1998-2020 (center date of rolling 7 day period).

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 2020 with the exception of Windy 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 associated with 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 spread out reference temperature sites.

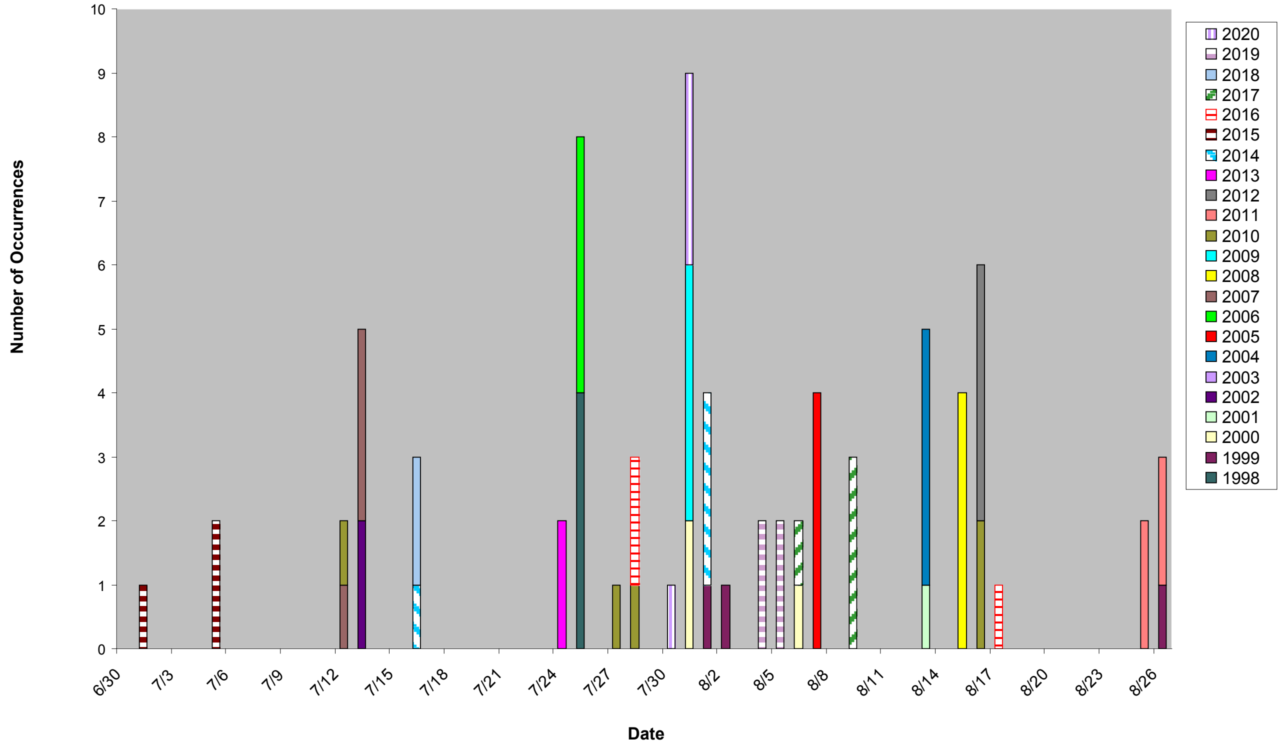


Figure 5: Dates of 7-day average maximum stream temperatures for the North Umpqua comparison sites from 1998-2020 (center date of rolling 7 day period).

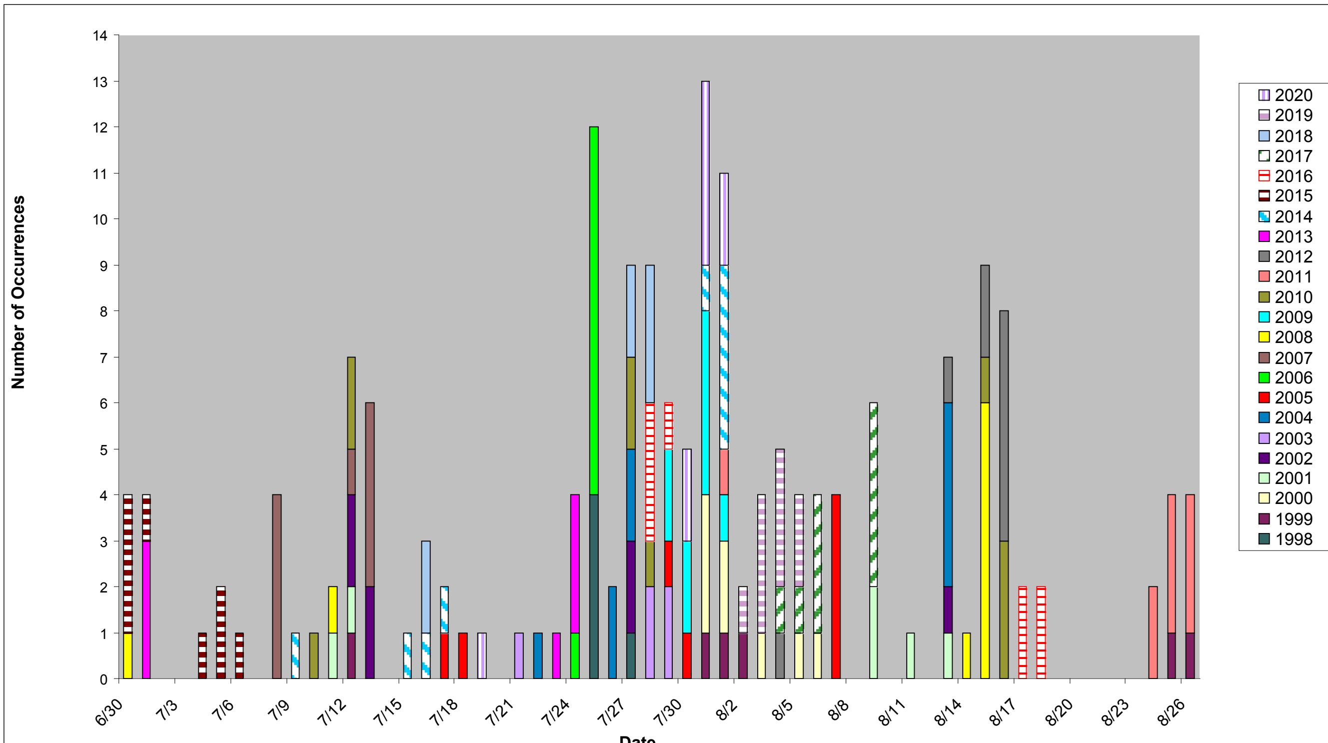


Figure 6: Dates of 7-day average maximum stream temperatures for the Umpqua Basin reference sites and North Umpqua comparison sites from 1998-2020 (center date of rolling 7 day period).

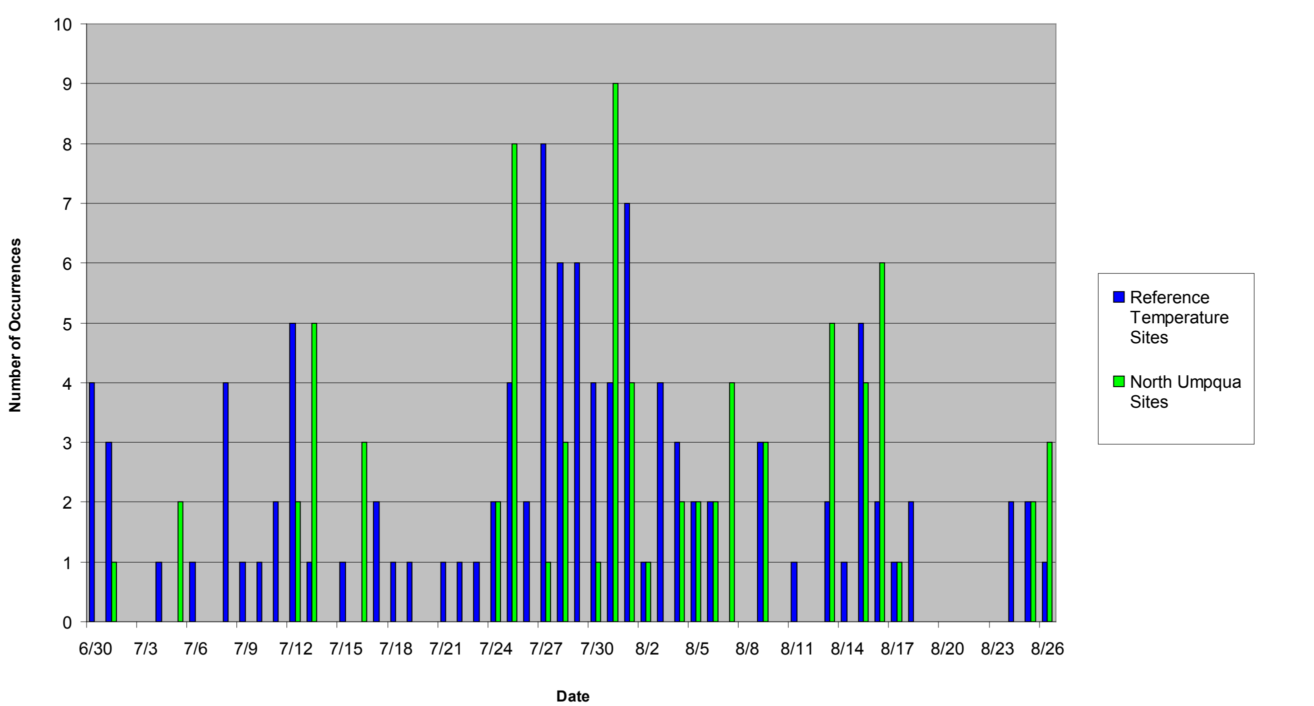


Figure 7: Dates of 7-day average maximum stream temperatures for the Umpqua Basin reference sites and North Umpqua comparison sites from 1998-2020 (center date of rolling 7 day period).

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, 2016 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 5) show a similar pattern as the 7DAM stream temperatures (Figure 8), with Calapooya Creek being the highest each year and Windy Creek the lowest of the reference temperature sites (rectangles, with one exception 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) had lower temperatures on August 1 at 4pm with the exception of Rock Creek (a larger stream). This is 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 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.

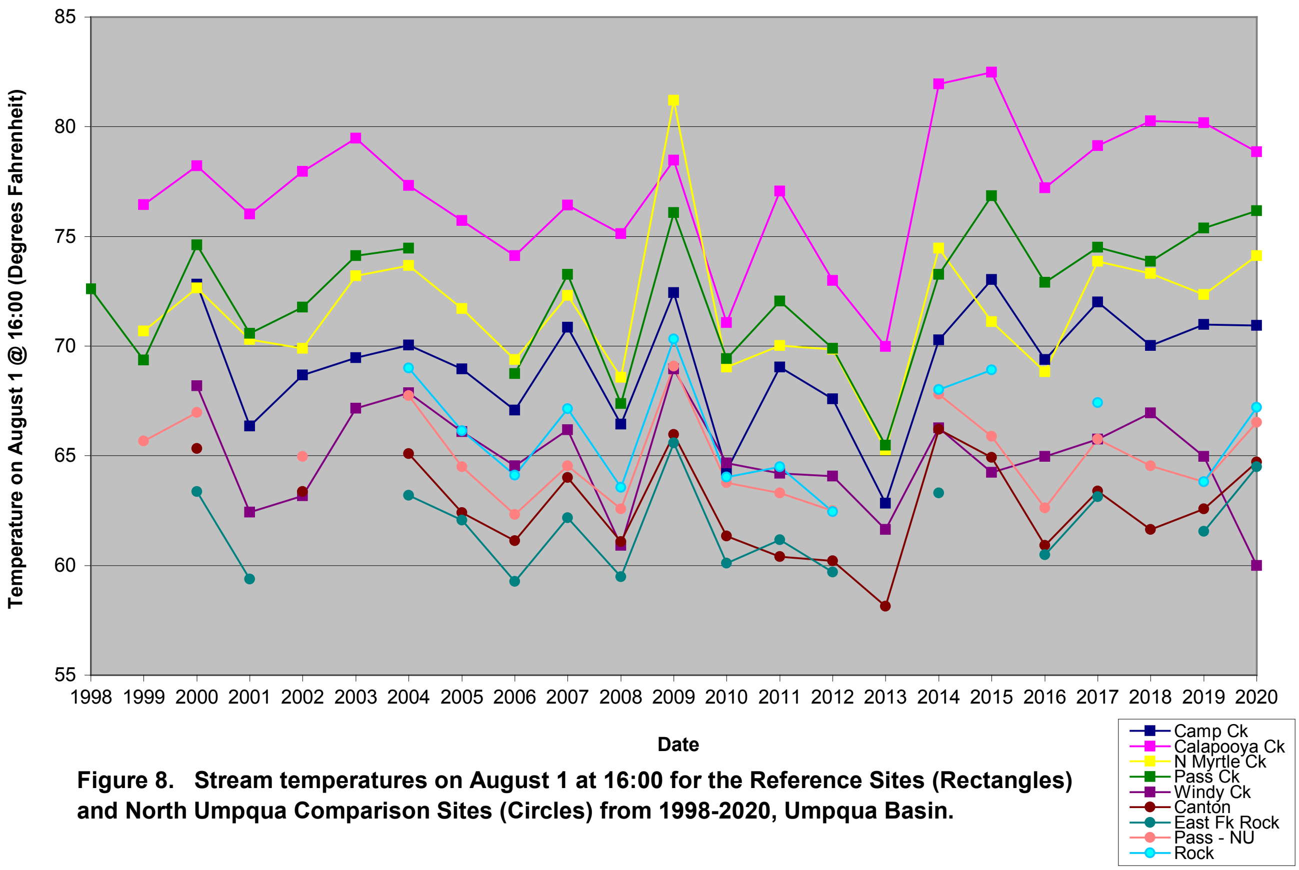


Figure 8. Stream temperatures on August 1 at 16:00 for the Reference Sites (Rectangles) and North Umpqua Comparison Sites (Circles) from 1998-2020, Umpqua Basin.

Trend Analysis of Reference Temperature 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 trends in the stream temperatures at the five sites for this project for the entire period of record for Dammann (2017). Since the 2017 Report, the DEQ has updated the trend analysis to include the 2018 data (Pritchard, 2018) and 2019 data (Pritchard and Doak, 2019) and now the 2020 data which also includes the North Umpqua comparison site analysis (Pritchard, 2020). The results of these trend analyses were included in the annual updates (Dammann, 2018 and 2019) and the 2020 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 seven 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) 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 using a seasonal Kendall trend analysis as described in Hirsch and Slack (1984). Specific results are in Figure 9. (Pritchard, 2020)

Site	Study	Years	Seasonal Kendall Trend Significance	p-value
Calapooya Ck.	ReferenceTemp	1999-2020	No Trend	0.59
Camp Ck.	ReferenceTemp	2000-2020	No Trend	0.30
North Myrtle Ck.	ReferenceTemp	1999-2020	No Trend	0.52
Pass Ck.	ReferenceTemp	1998-2020	Positive Trend – Sen. Slope (0.036)	0.08
Windy Ck.	ReferenceTemp	2000-2020	Negative Trend – Sen. Slope (-0.038)	0.01
Canton Ck.	NU-Comparison	2000-2019	No Trend	0.13
E. Fk. Rock Ck.	NU-Comparison	2000-2019	No Trend	1
Pass Ck. – NU	NU-Comparison	1999-2019	No Trend	0.66
Rock Ck.	NU-Comparison	2004-2019	No Trend	0.33

Note: There are some years with missing data (see Figure 9). The 2020 North Umpqua monitoring data was not included in the trend analysis and will be included in the 2021 trend analysis and report.

The only sites that had significant trends were Pass Creek with a positive trend and Windy Creek with a negative trend (Table 5, Figure 9, and Pritchard (2020)). 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. However, there is no known change at the site level that would warrant a change in stream temperature. The trend analysis of this data is integral start to potentially understanding the effects of climate change on streams in the basin.

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.

Stream Temperature Relative to Flows:

Flows have been collected during the summer at North Myrtle and Pass Creek reference sites by Oregon Water Resources Department (OWRD) and partners since 2004 and at Calapooya, Camp, and Windy Creeks since 2010 (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, 2020b.) 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). Note, that due to budget limitations, very few flow measurements were taken in 2019 and 2020; therefore, Figure 10 has not been updated 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 indicate 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 (Dammann, 2019: Appendix and Figure 11 t contains 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 - Appenidix). Note that very few flow measurements were collected by OWRD and partners at these sites in 2019 and 2020, therefore flow data were not included for these years.

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 periods
- 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 Canton, Pass, Rock and East Fork Rock sites will work well as comparison sites, as with the reference sites. The four North Umpqua sites also display the same pattern of interannual variability (though less pronounced) and overall 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.

Summer, 2020 PUR and BLM had several water temperature recorders in place in the Rock Creek drainage for baseline for a restoration project that burned over during the Archie Fire in September, 2020. Data from the four long-term sites analyzed with this project will be critical for evaluating the effects of the fires in relation to the other sites and to the restoration effects post fire.

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 60.8^{o}F (16.0^{o}C) and streams designated as salmon and trout rearing and migration areas may not exceed 64.4^{o}F (18.0^{o}C) (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 (64.4^{o}F threshold) and Windy Creek and the North Umpqua sites have been designated as core cold-water habitat (60.8^{o}F 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 (Figure 3).

Invasive Crayfish:

Beginning a few years ago, some of the field reference temperature sites, ringed crayfish (*Orconectes neglectus*) were found with the native signal crawfish (*Pacifastacus leniusculus*) or instead of signal crawfish where signals are typically present. Ringed crayfish are from the Great Plains and are identified by the orange tips on their claws with black bands (Oregon Department of Fish and Wildlife (ODFW), 2018). In 2018 and 2019, at the Camp Creek study site there were both signal crawfish and adult and juvenile ringed crayfish. However, in 2020, only ringed crayfish were found (though there were some crayfish too small to identify). Downstream from the Camp Creek study site below the confluence with Mill Creek, several juvenile ringed crayfish have also been found each year. At Calapooya Creek where there were previously typically signal crayfish, only ringed crayfish were present at all three visits each year, with the exception of June, 2020 when no crayfish were seen. In 2019, in North Myrtle Creek there were also several ringed crayfish along with the native signal crayfish and ringed crayfish were seen there in 2020 as well. As of 2020, we have had no sightings of ringed crayfish at the Pass Creek or Windy Creek reference temperature sites. Sightings have been reported to the local ODFW office as well as the Oregon Invasive Species Hotline.

Photo 2. Invasive Ringed crayfish (*Orconectes neglectus*) found at the Calapooya Creek site. (Photo courtesy of Katie Dammann)

Acknowledgments:

This analysis is funded by the SW Oregon Bureau of Land Management (BLM) Resource Advisory Committee (RAC), Roseburg BLM, 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 and Coos Bay BLM as part of the Umpqua Basin Stream Flow and Temperature Monitoring Project through PUR. 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. Data from the North Umpqua sites were from the Roseburg BLM monitoring and one BLM site was monitored by PUR last year.

Thanks to the DEQ for conducting the trend analysis, specifically, thanks to Steve Hanson, Nick Haxton-Evans, Travis Pritchard, and Sam Doak. 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.

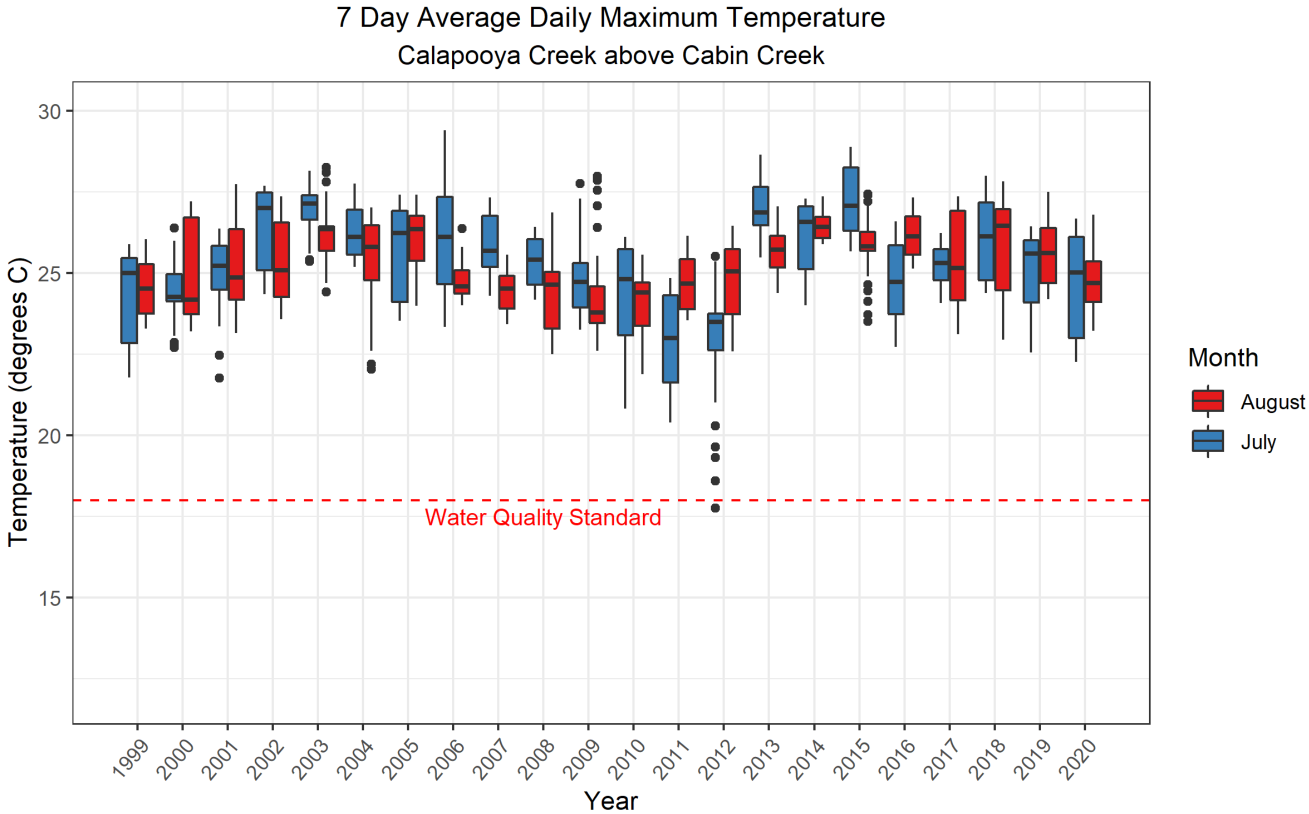
How to Obtain the 2020 Update or Previous Data and Reports:

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, 2020a) 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 on the Umpqua Basin Stream Temperature and North Umpqua Comparison Analysis 2020 Update CD. The annual updates provide more analysis of that year's data combined with a discussion of patterns over the period of record. In addition, the Getdata program, found on the CD, allows the user to retrieve several statistics and graphs from the temperature data files.

All reference temperature and North Umpqua comparison site data can be found in DEQ's AQWMS database. Additionally, all previous 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, 2020b) 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



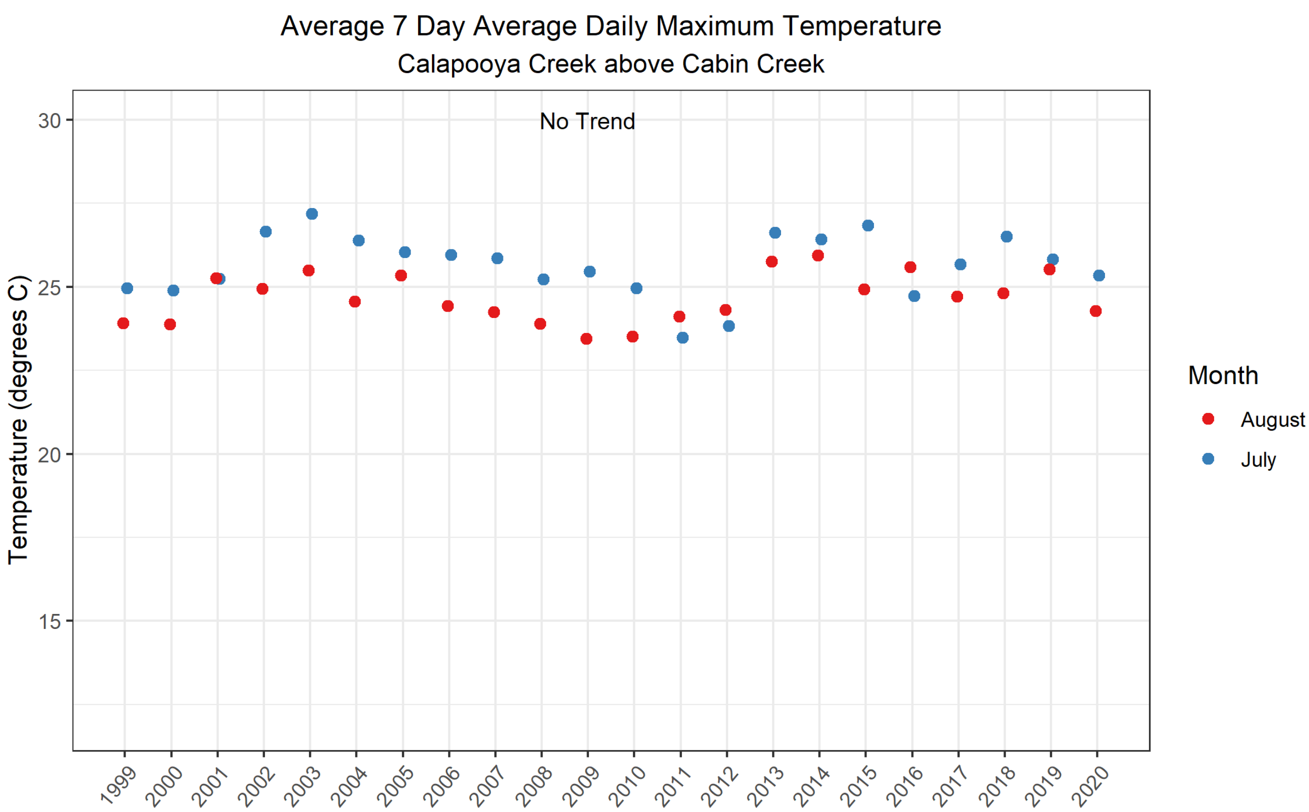
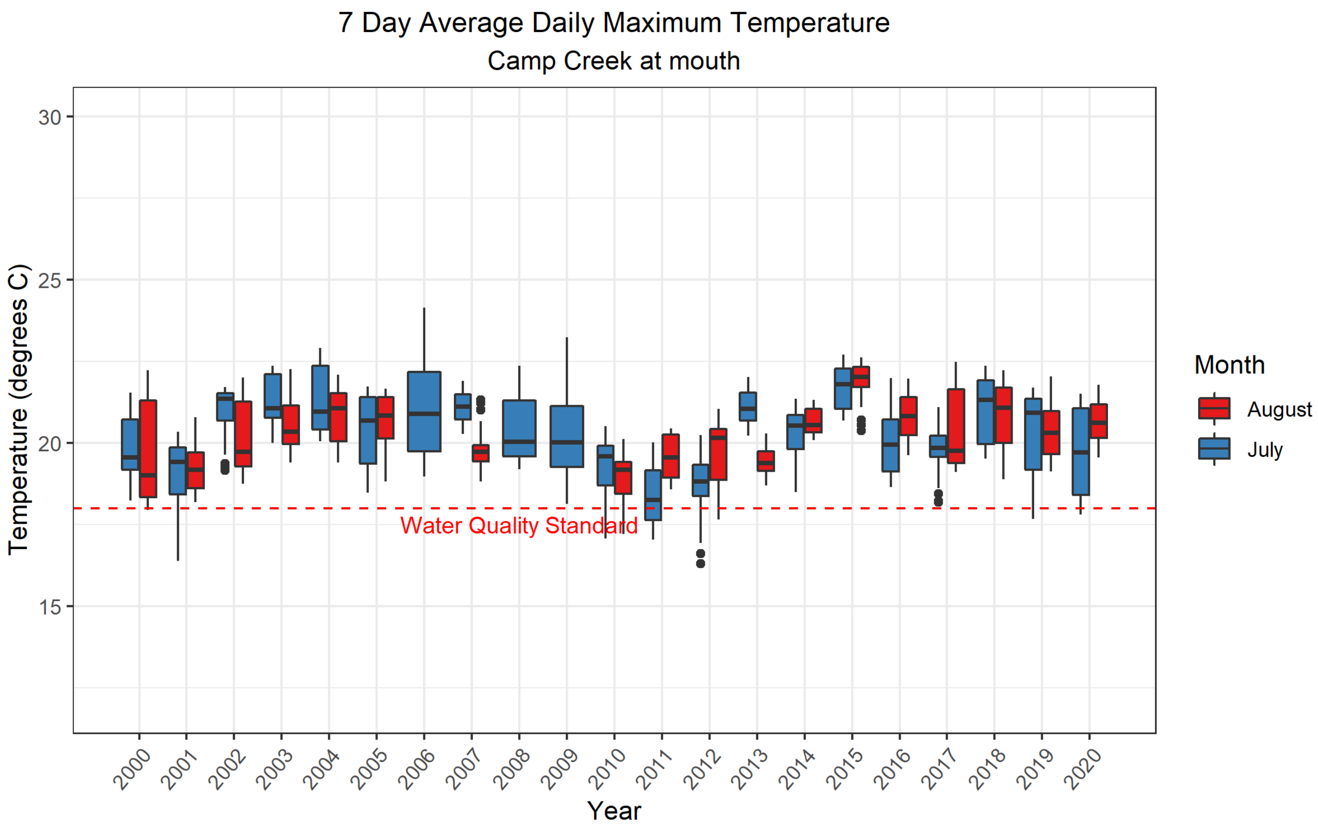


Figure 9. Pritchard (2020) DEQ trend analysis of reference stream temperature data using a Seasonal Kendall trend analysis (Hirsch and Slack, 1984). Since the dataset began on July 1 for many of the early years of project monitoring, the seven day average daily maximum stream temperature is described 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)



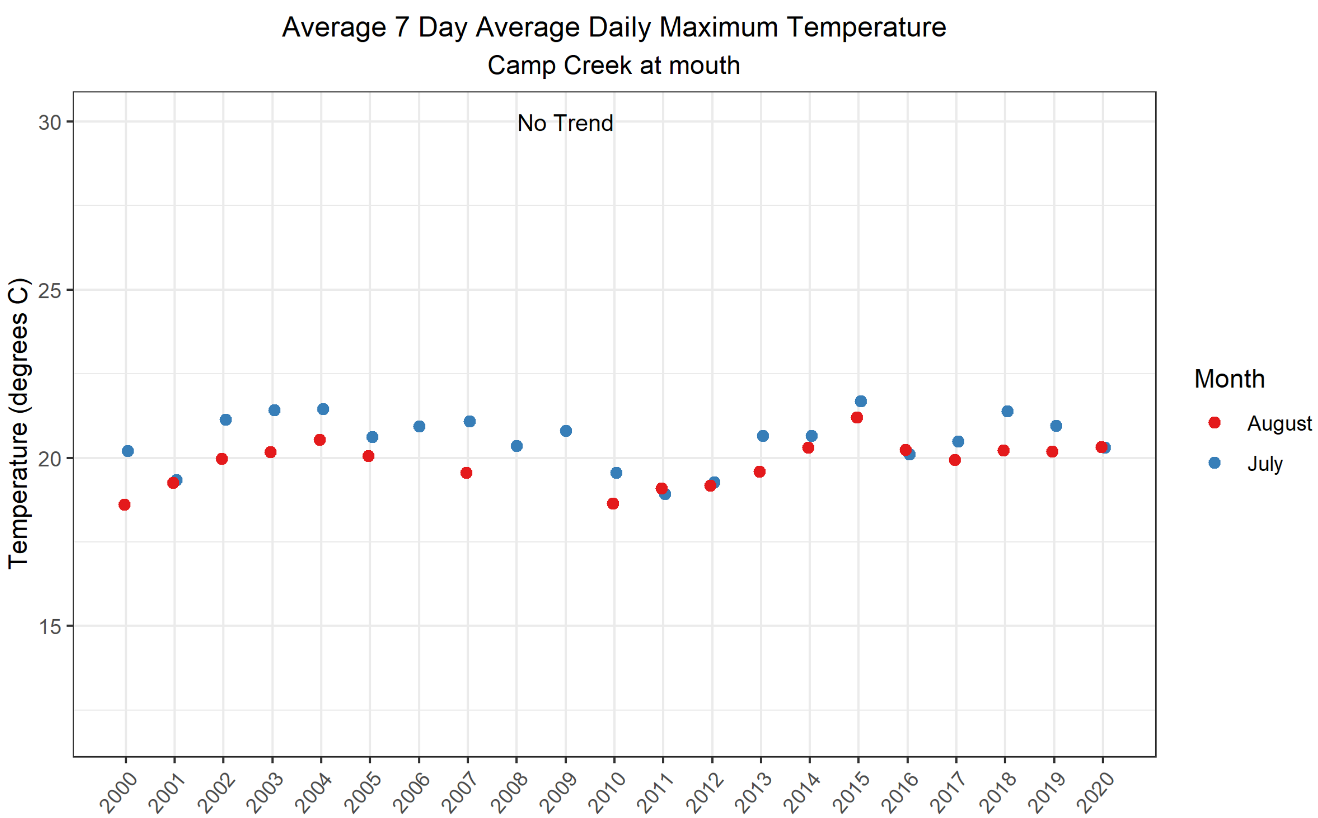
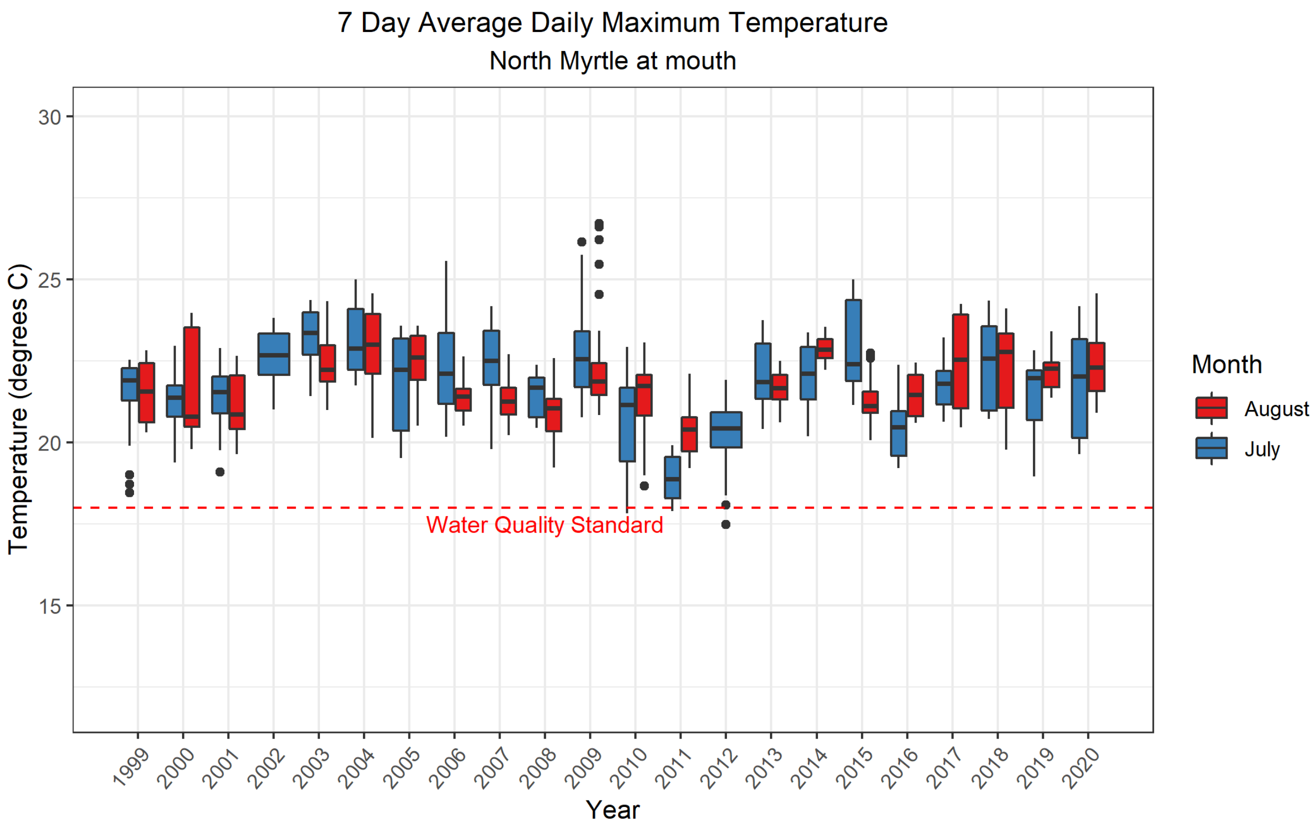


Figure 9. Continued. (Page 2 of 9)



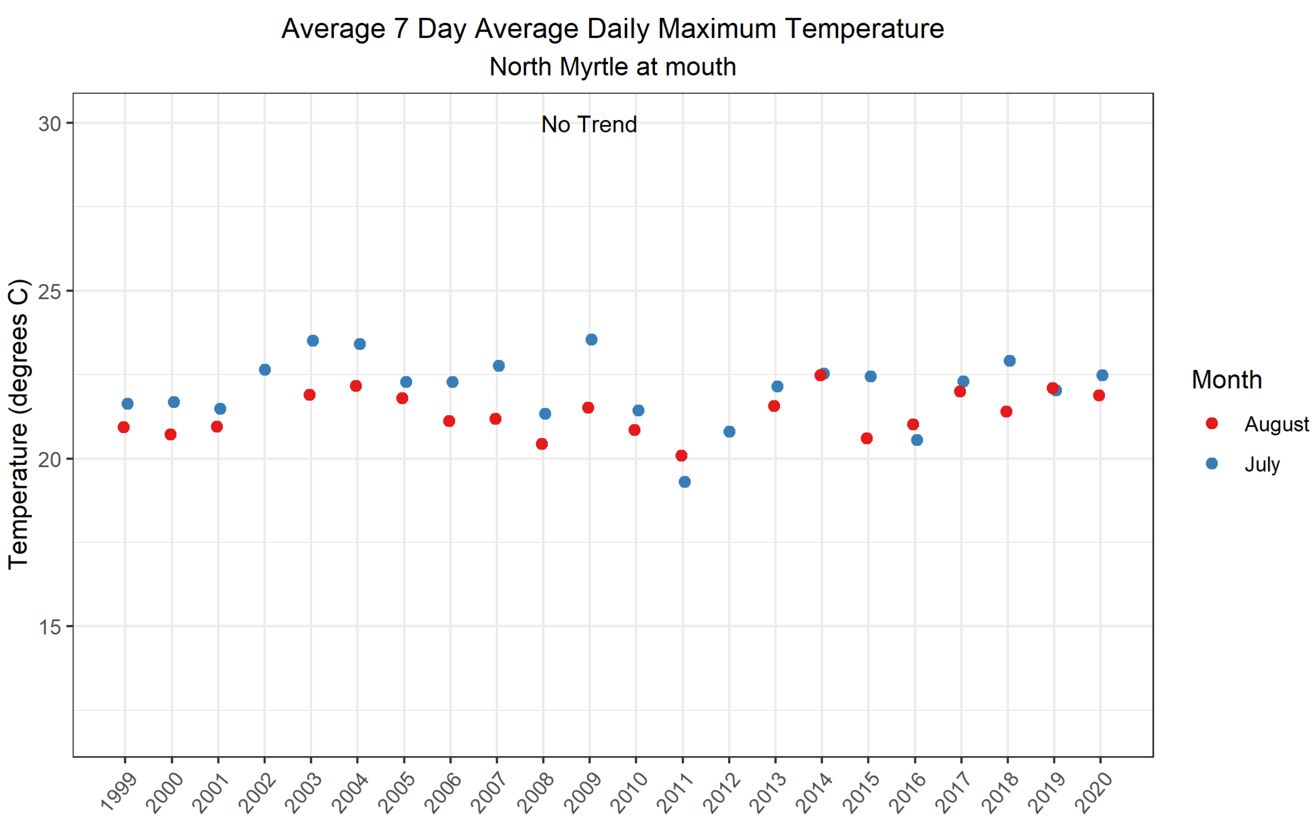
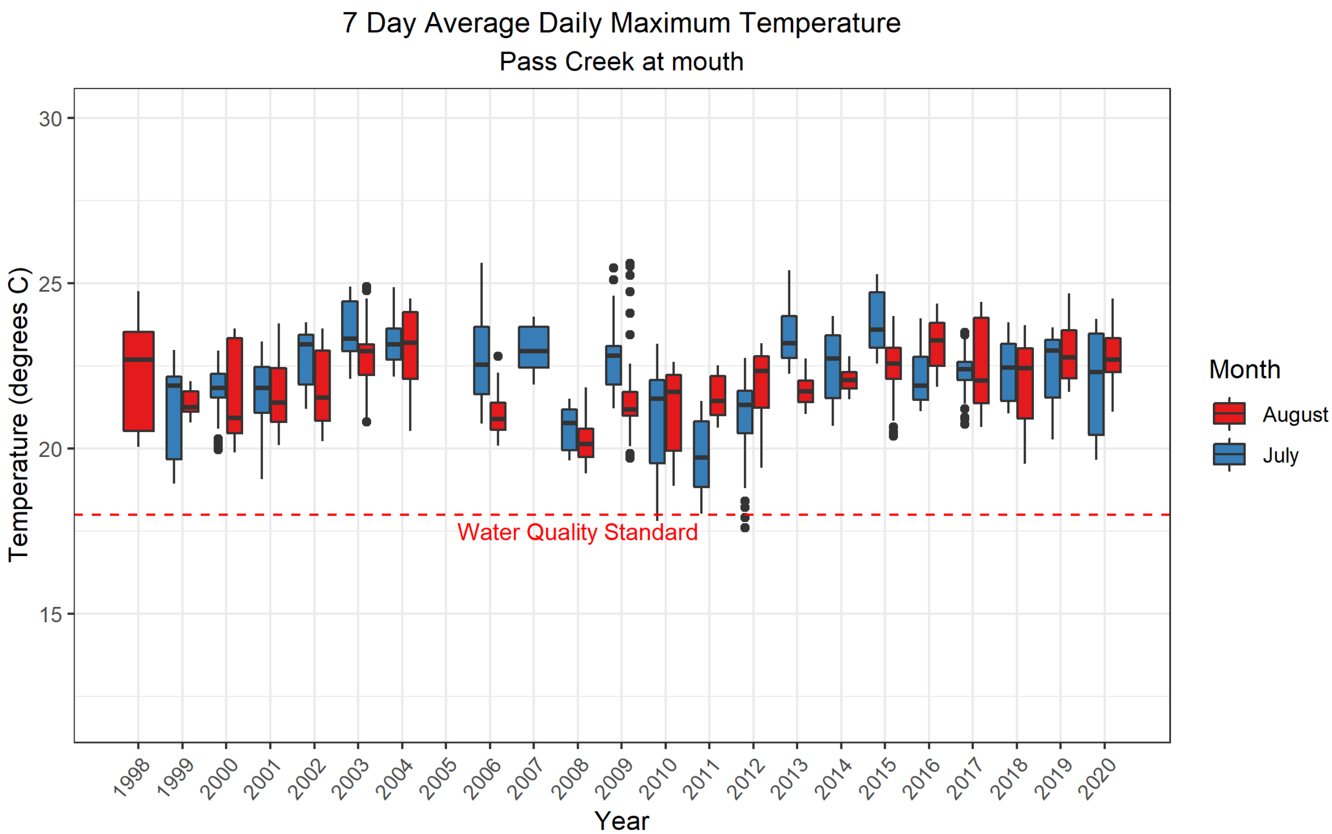


Figure 9. Continued. (Page 3 of 9)



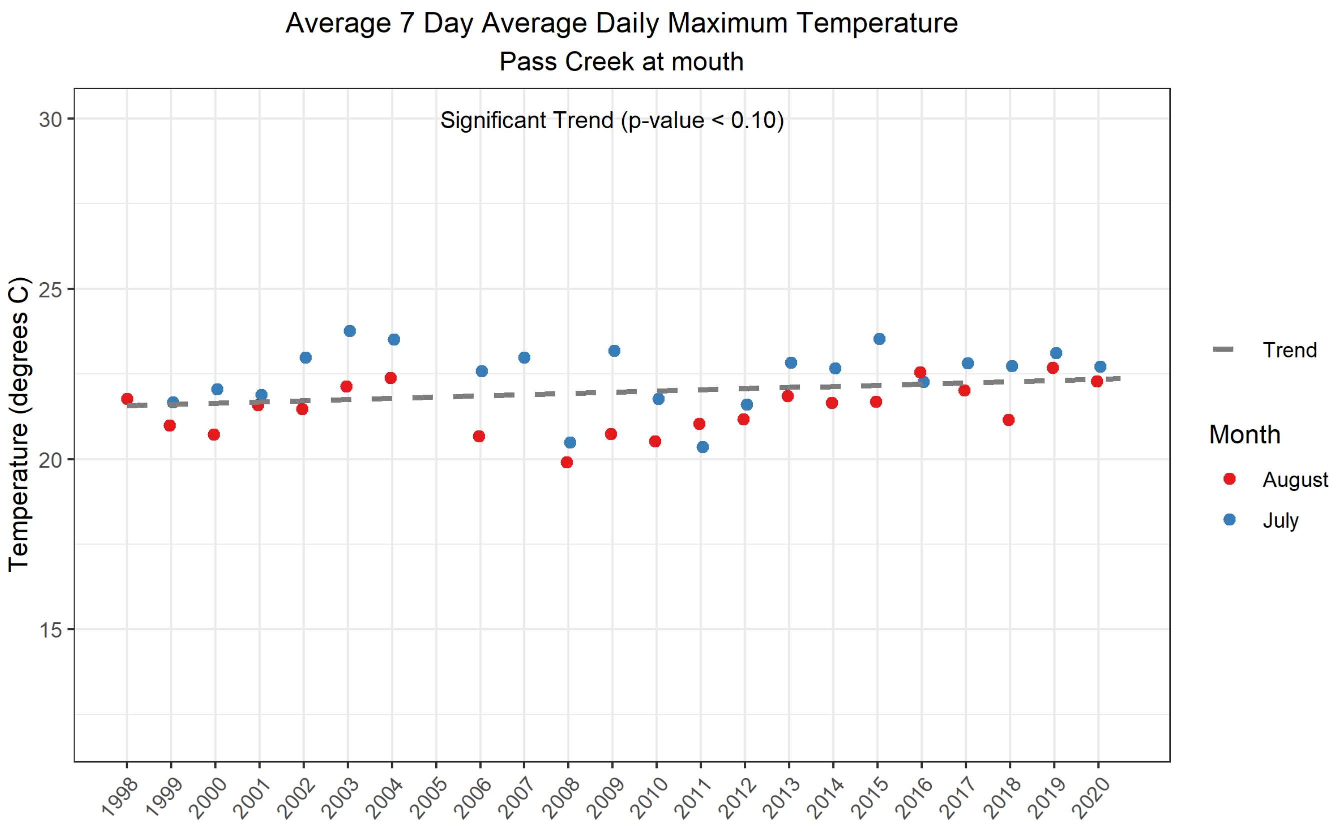
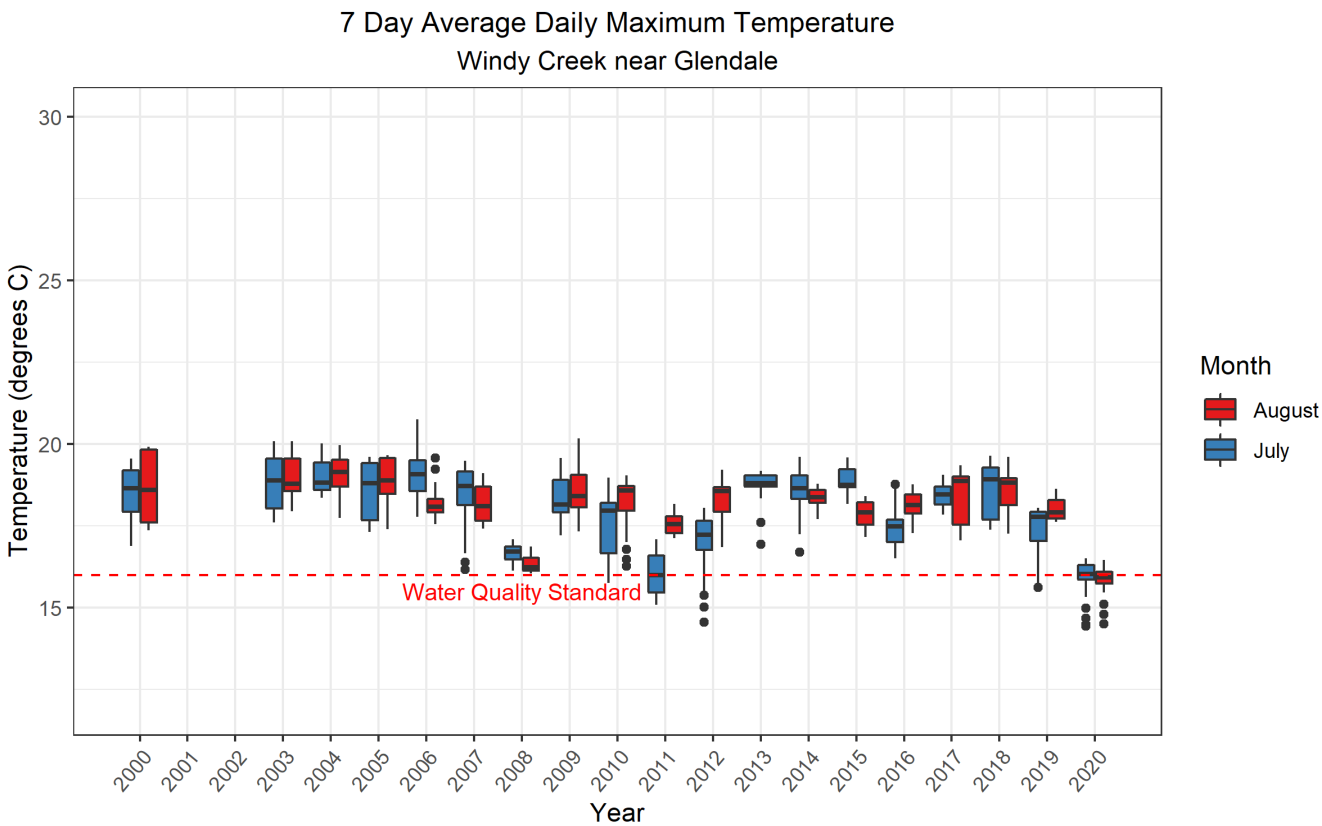


Figure 9. Continued. (Page 4 of 9)



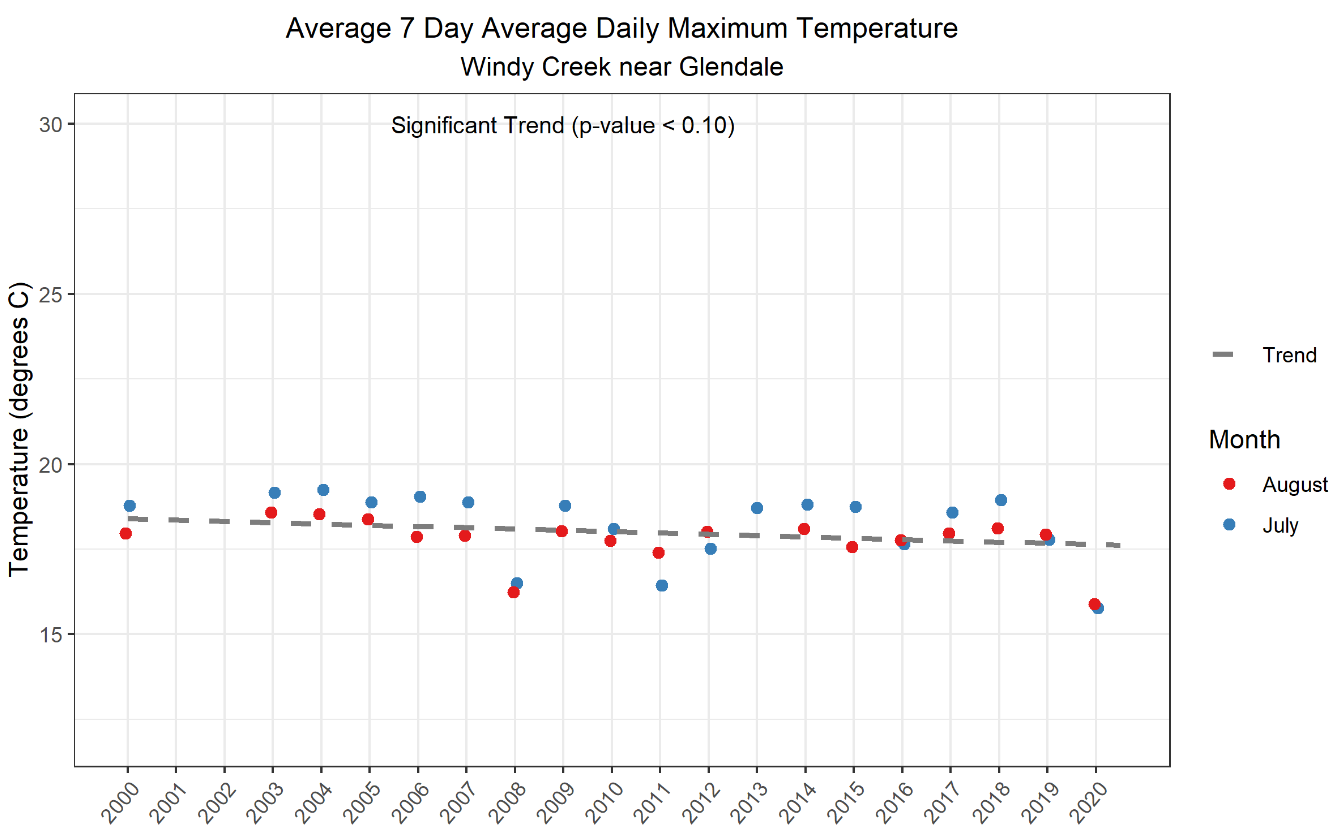
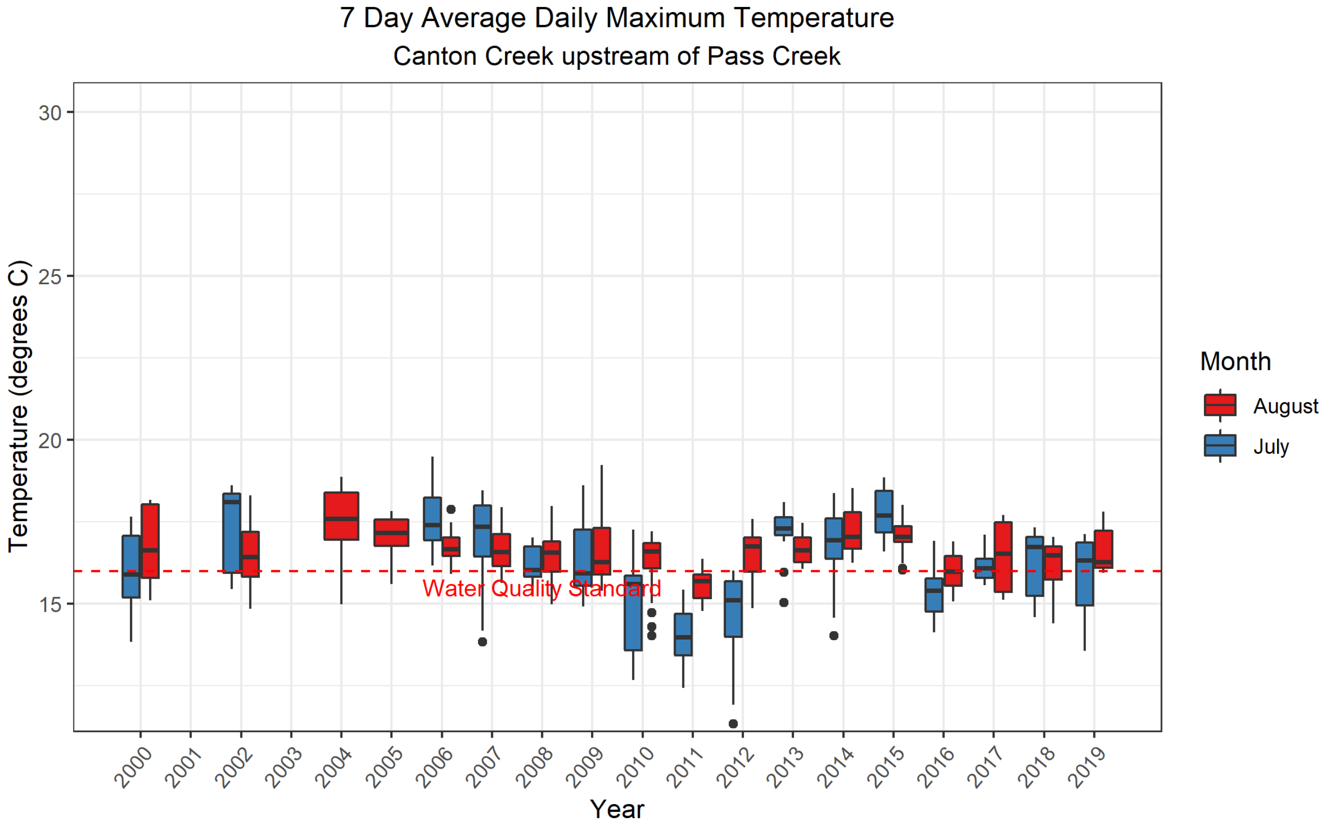


Figure 9. Continued. (Page 5 of 9)



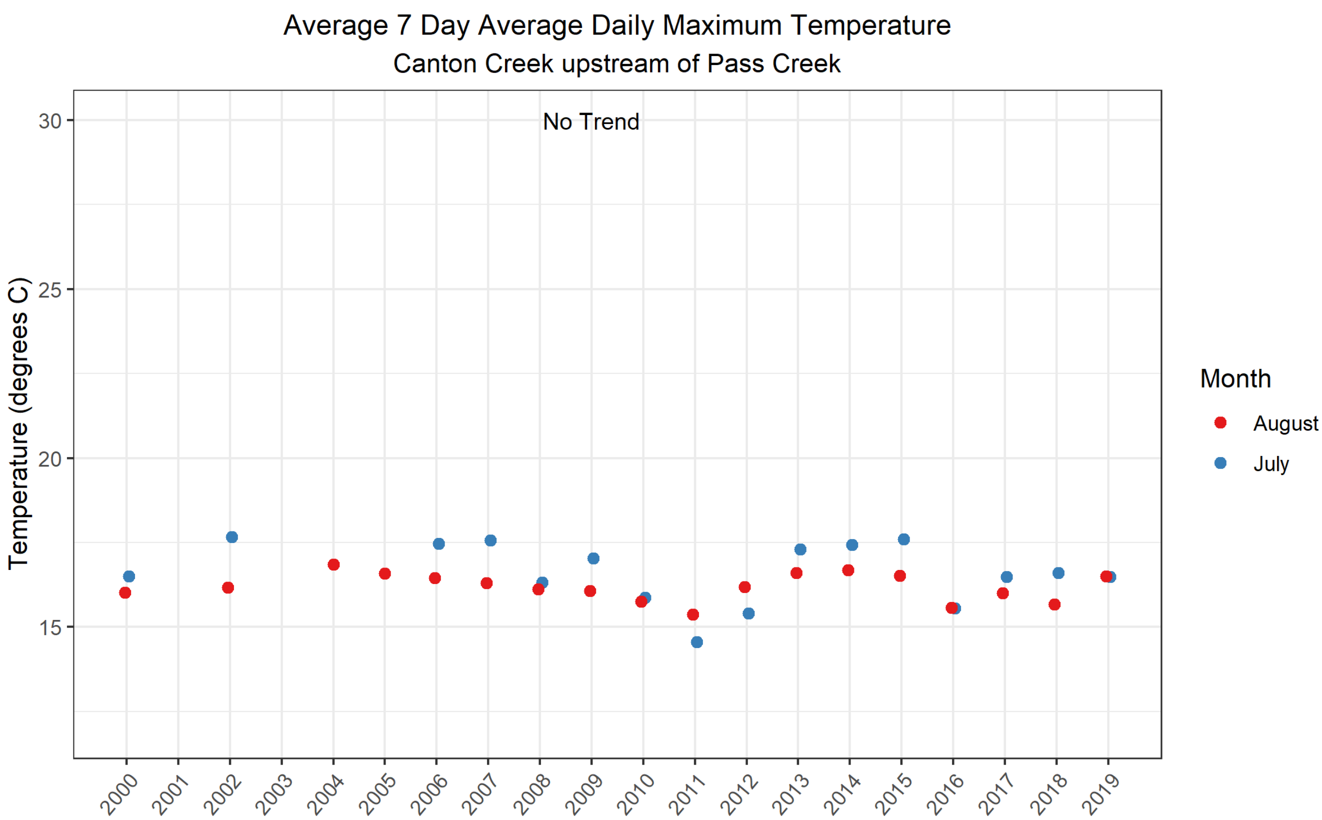
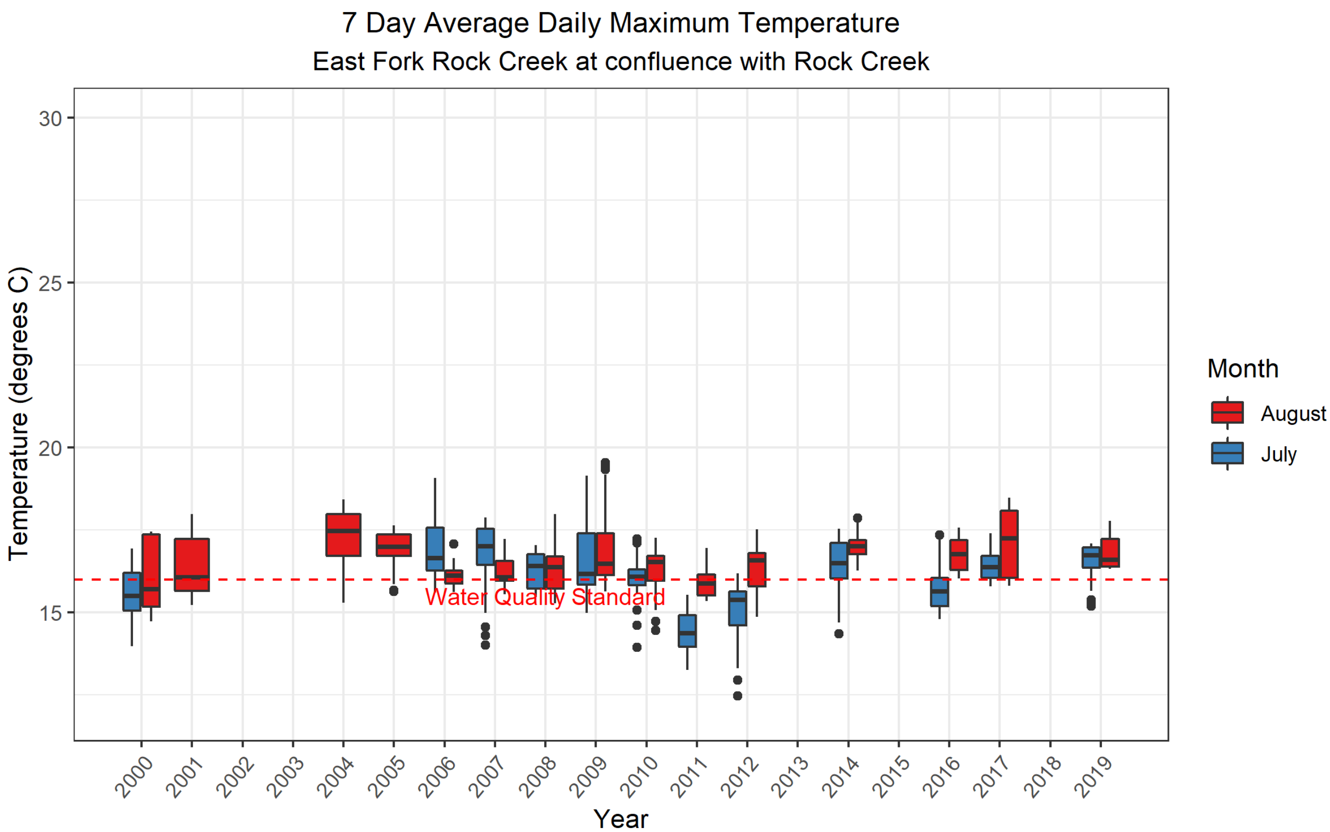


Figure 9. Continued. (Page 6 of 9)



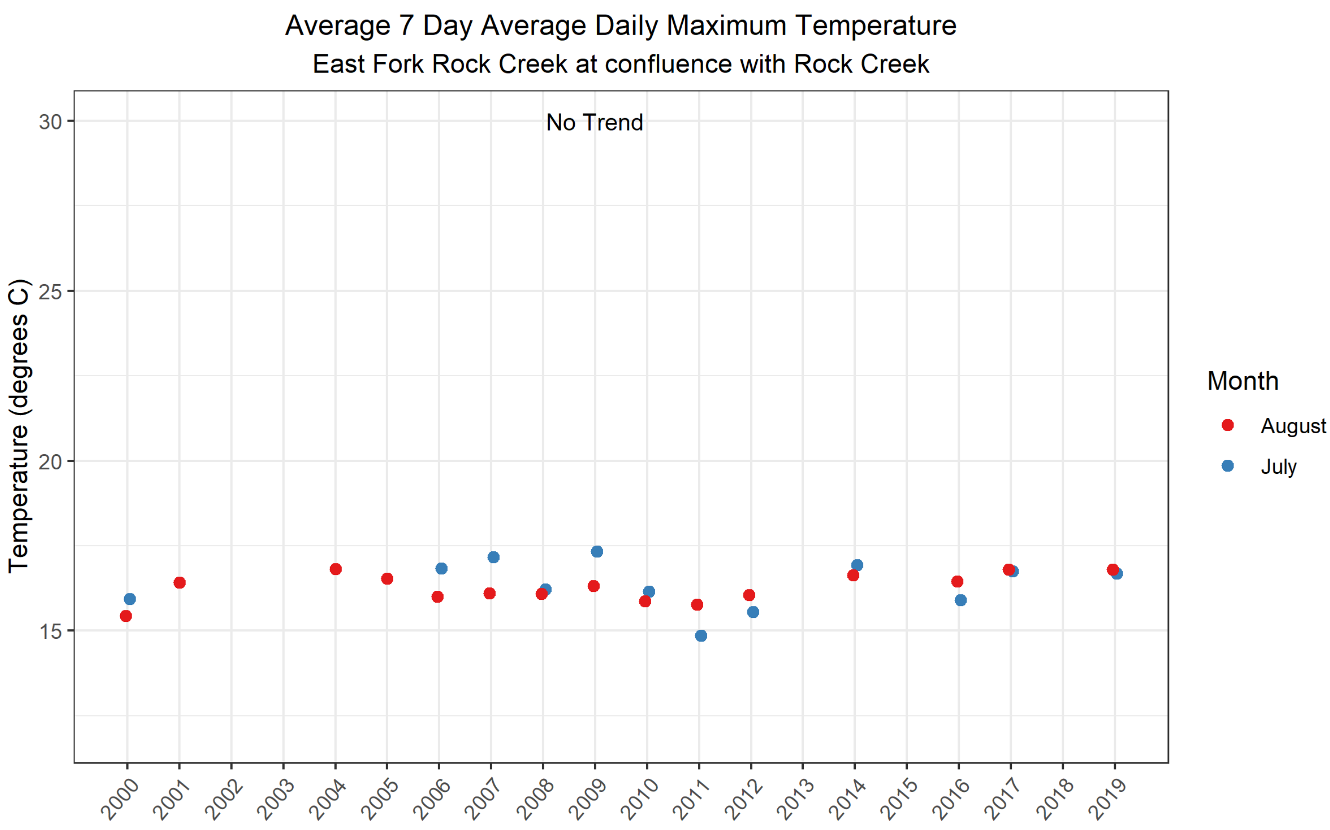
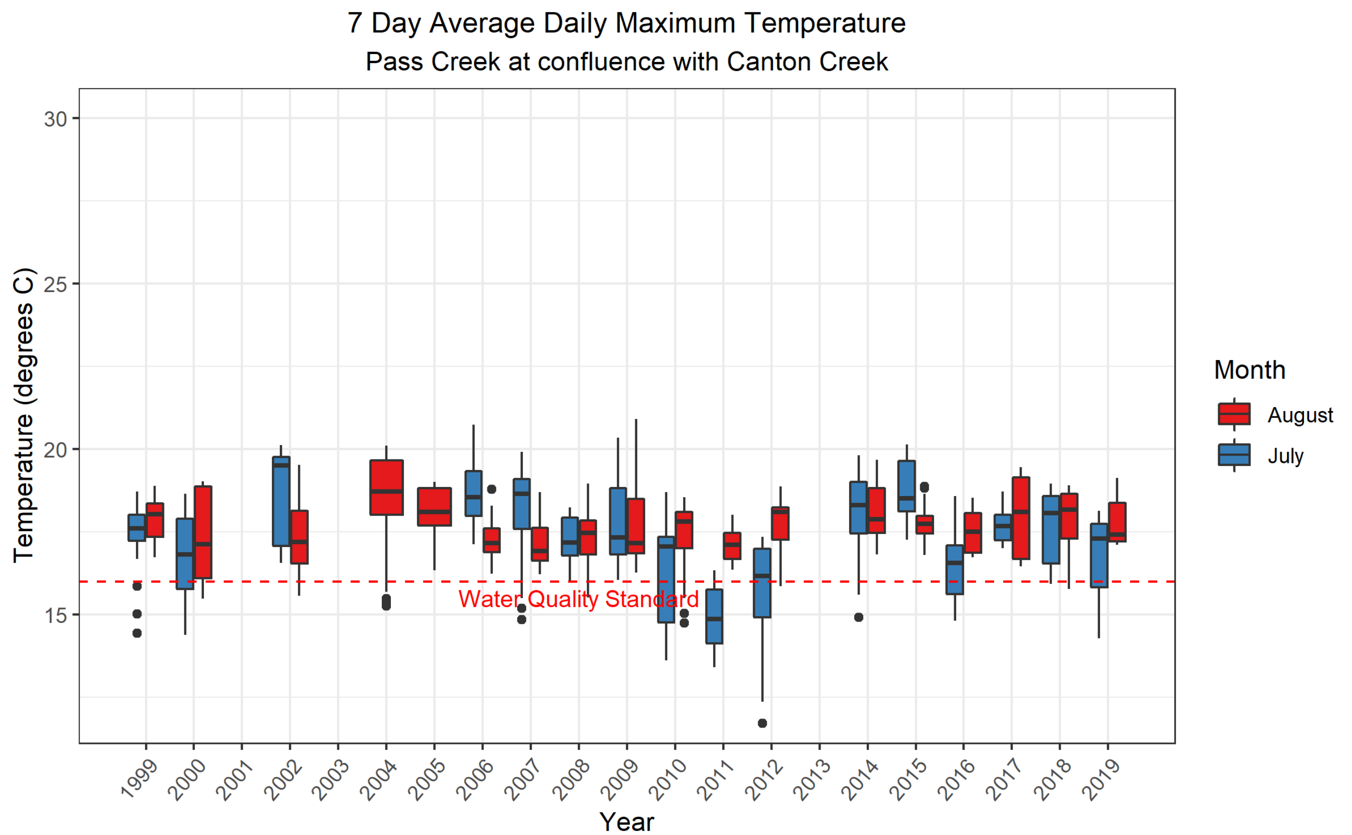


Figure 9. Continued. (Page 7 of 9)



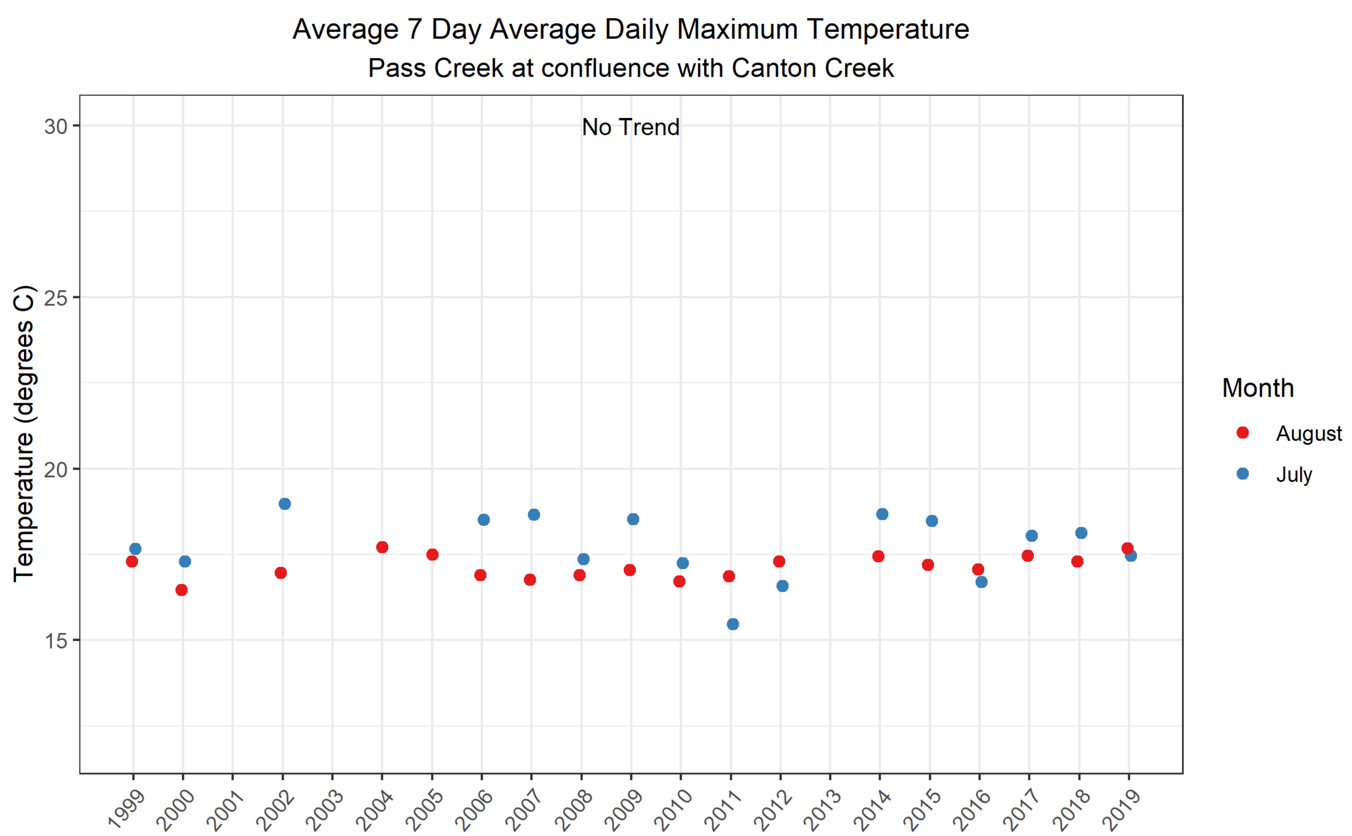
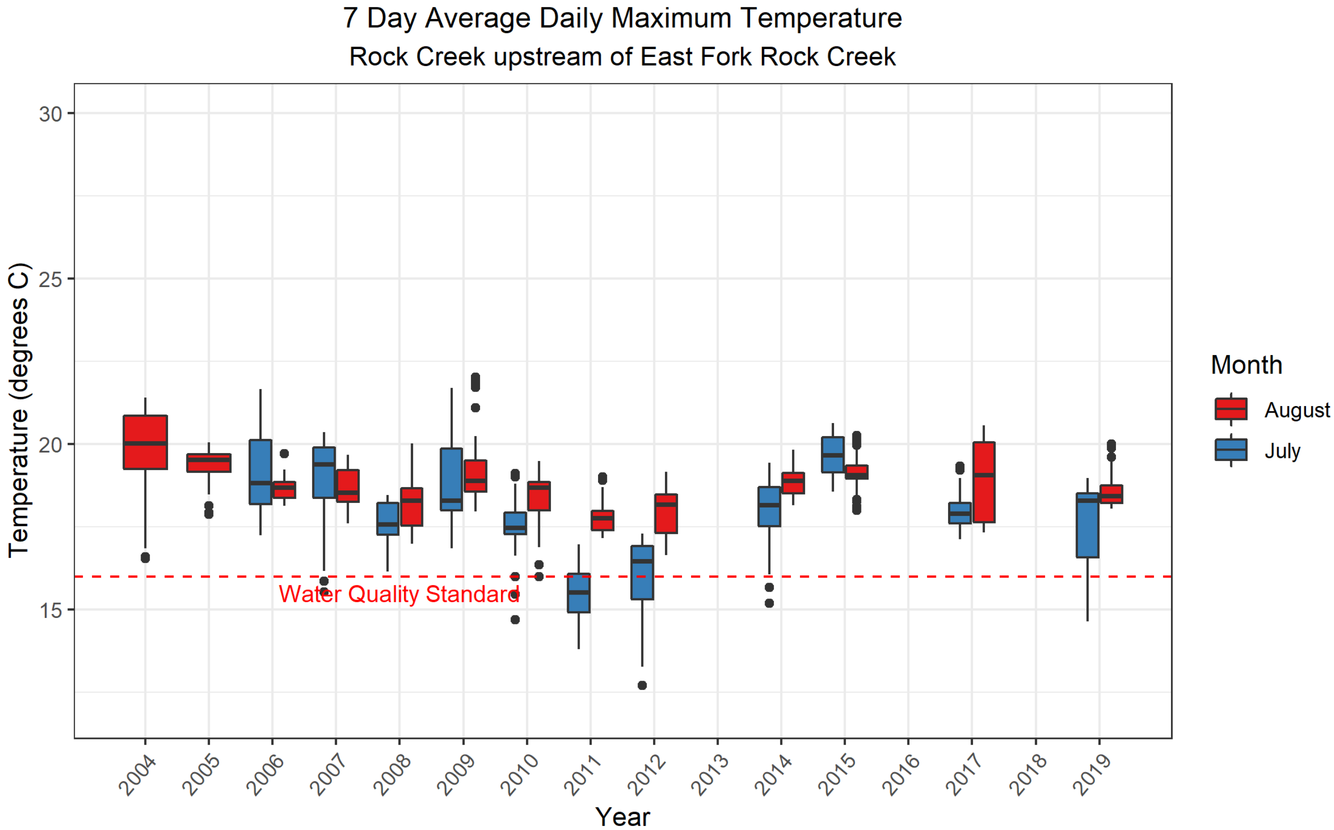


Figure 9. Continued. (Page 8 of 9)



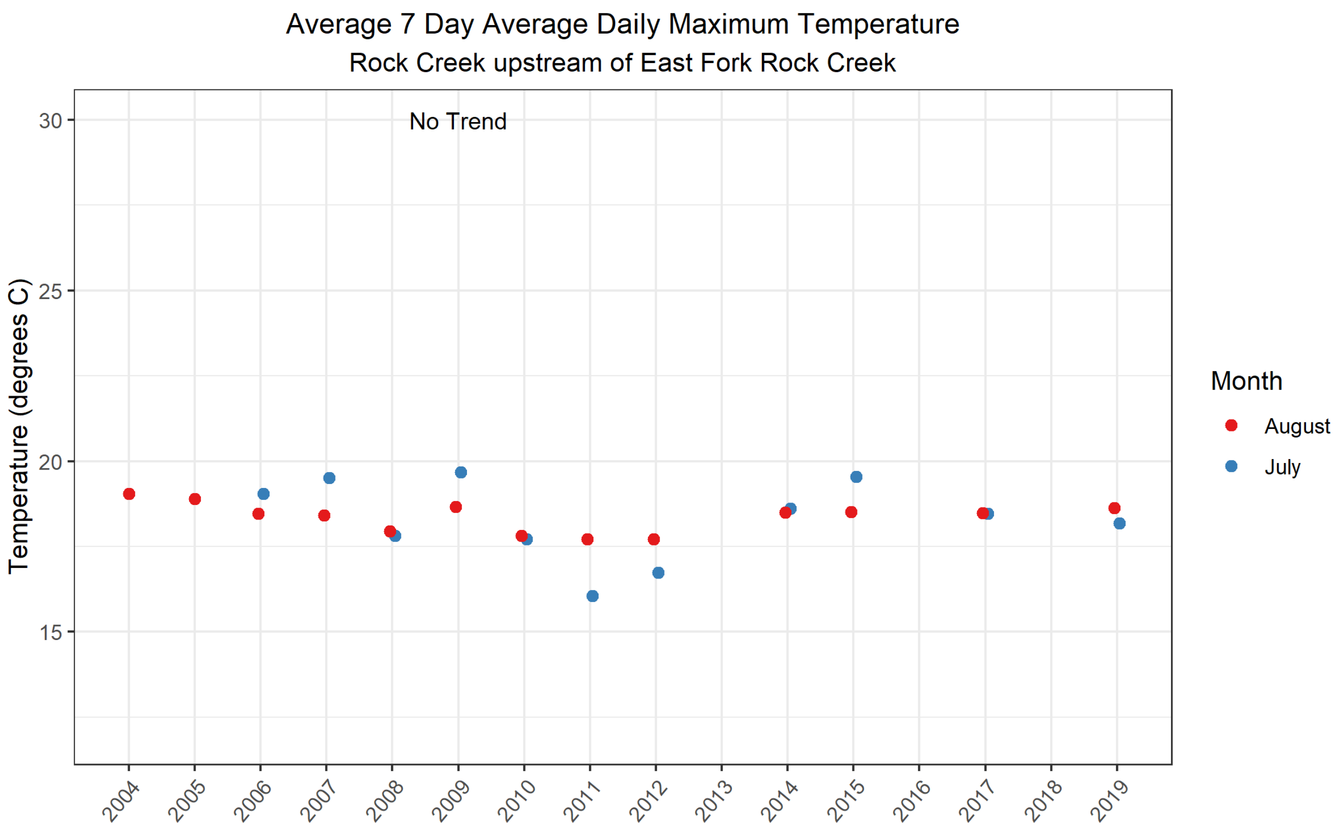
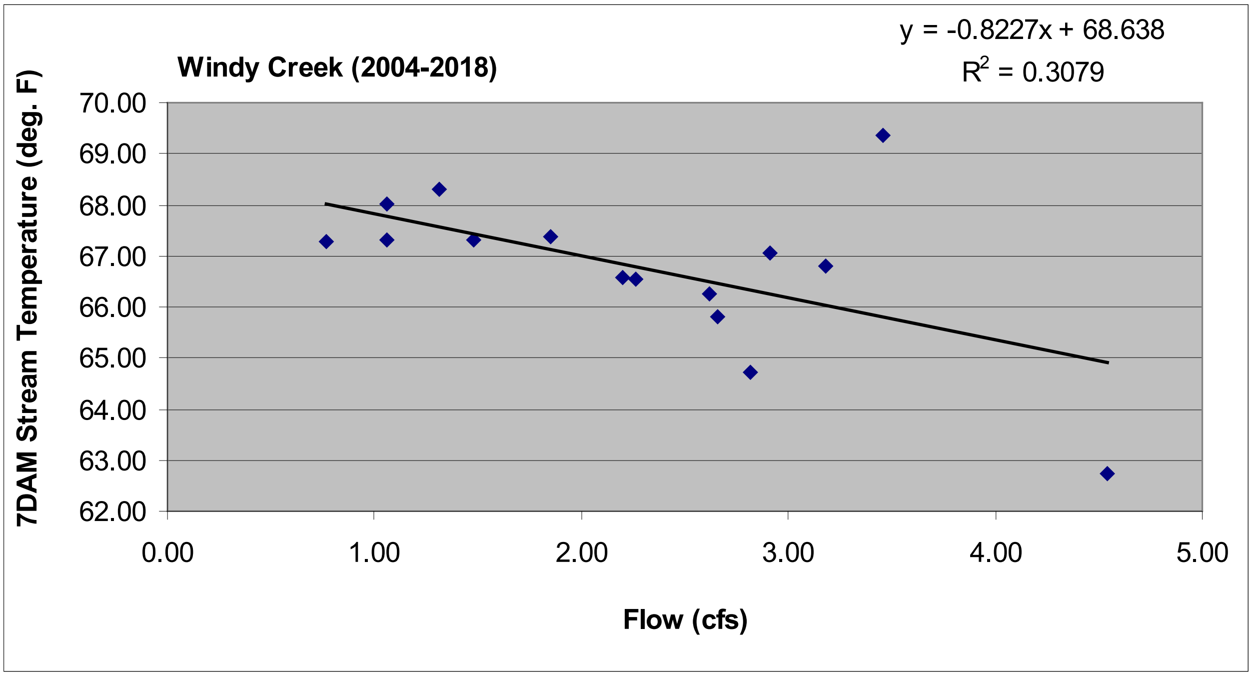


Figure 9. Continued. (Page 9 of 9)



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.

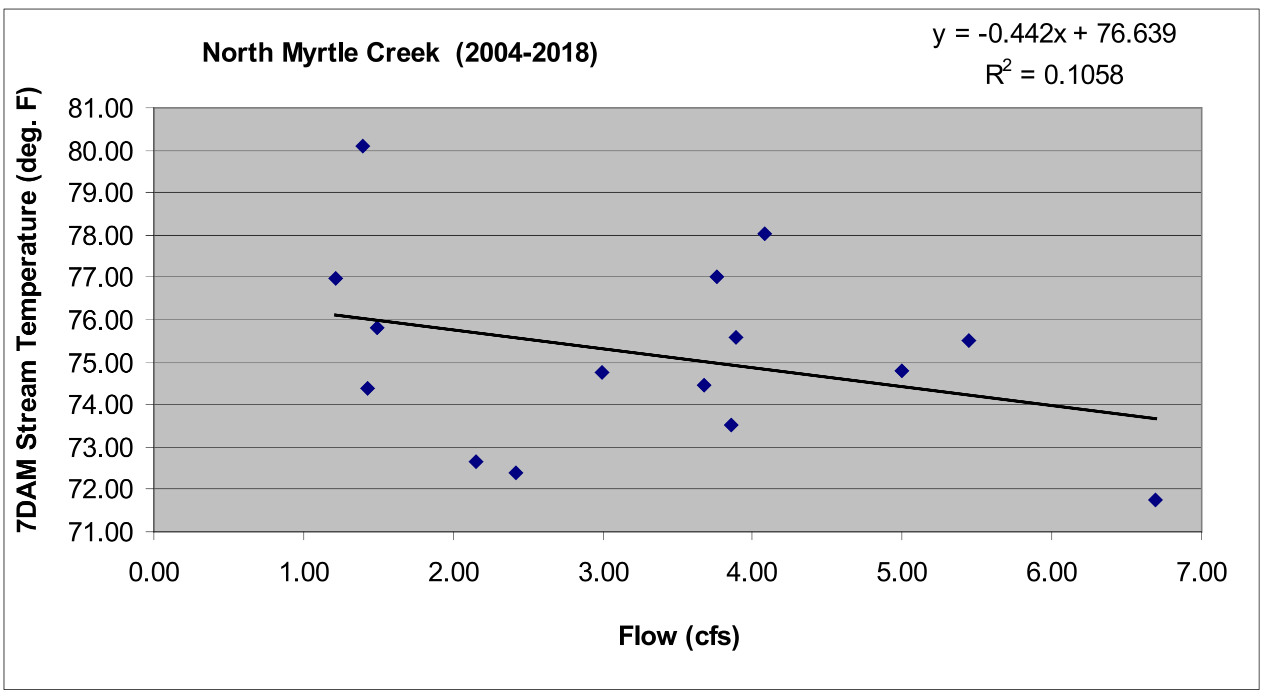
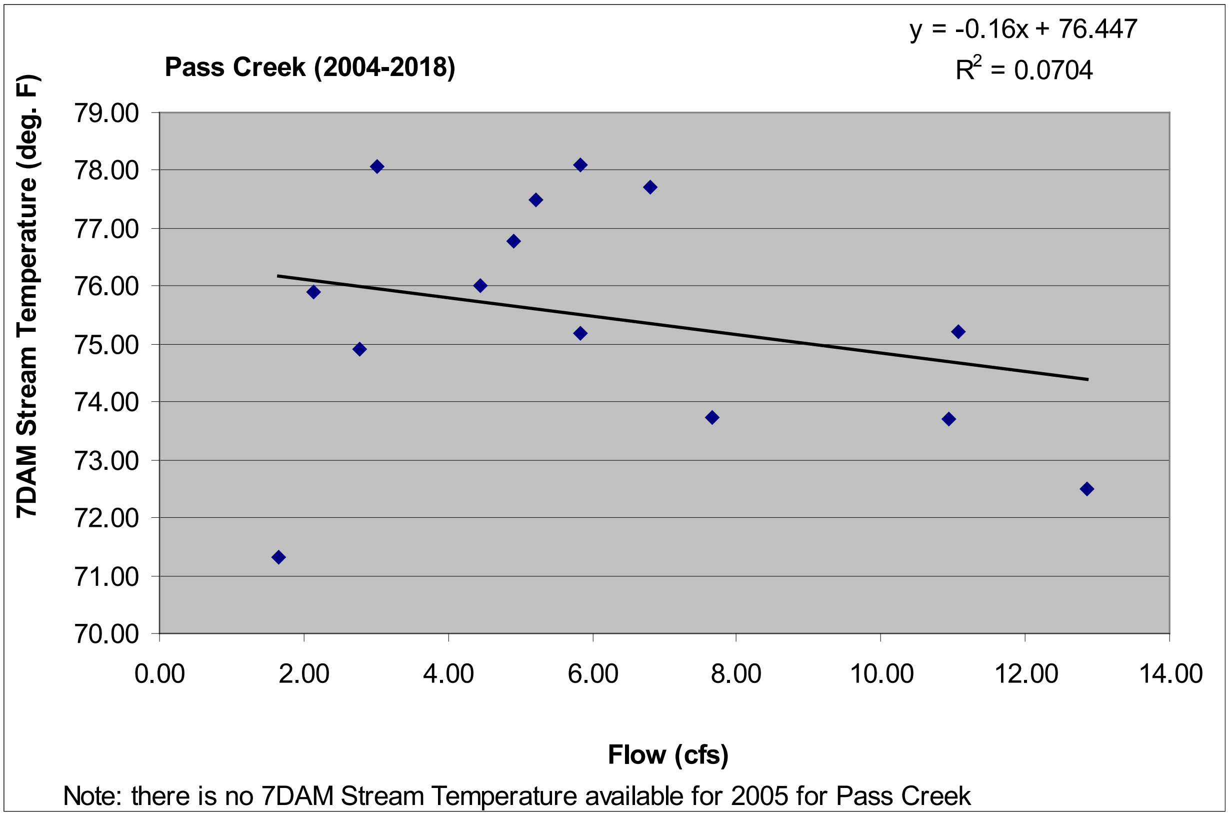


Figure 10. 2004-2018 Reference site 7DAM stream temperatures compared to flows on that day. Stream flows from OWRD and partners (Umpqua Basin Watershed Council {PUR}, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2013; PUR, 2014b, 2015, 2016b, 2017, and 2018). Note that flows were not taken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



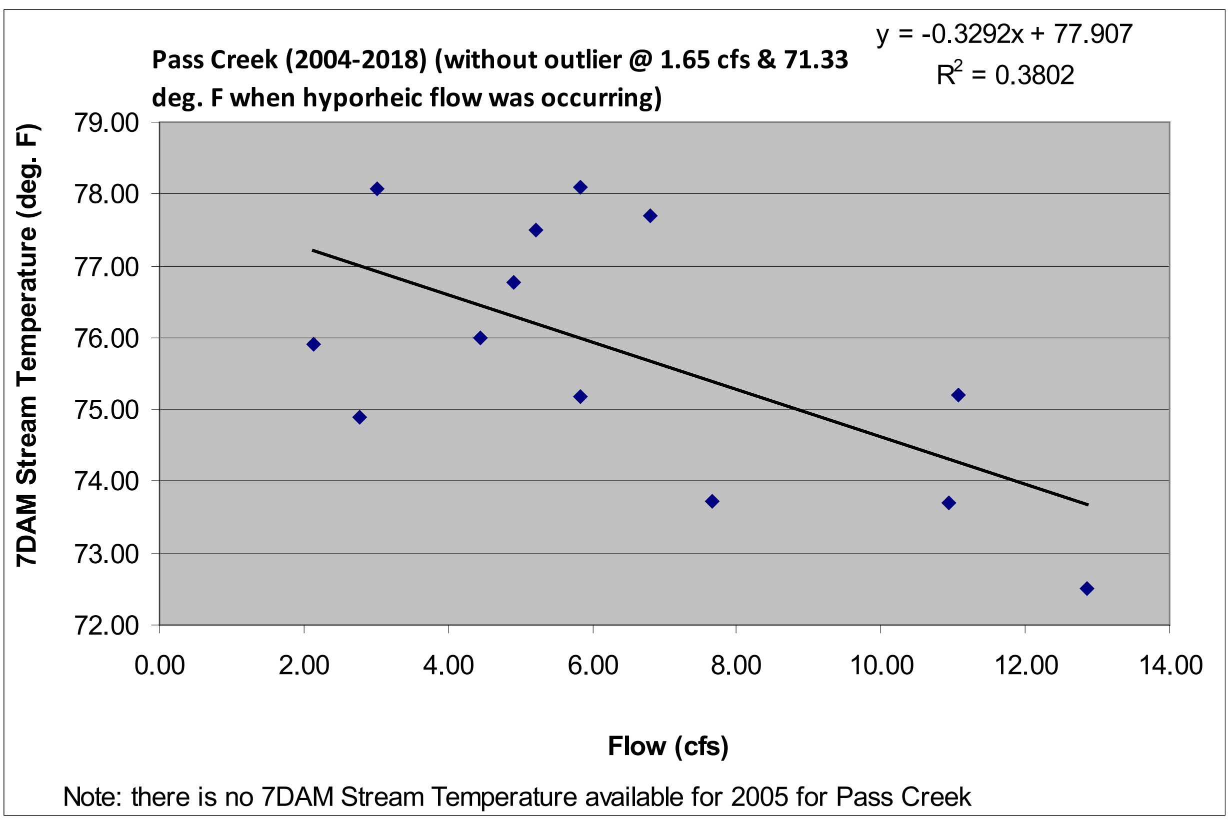
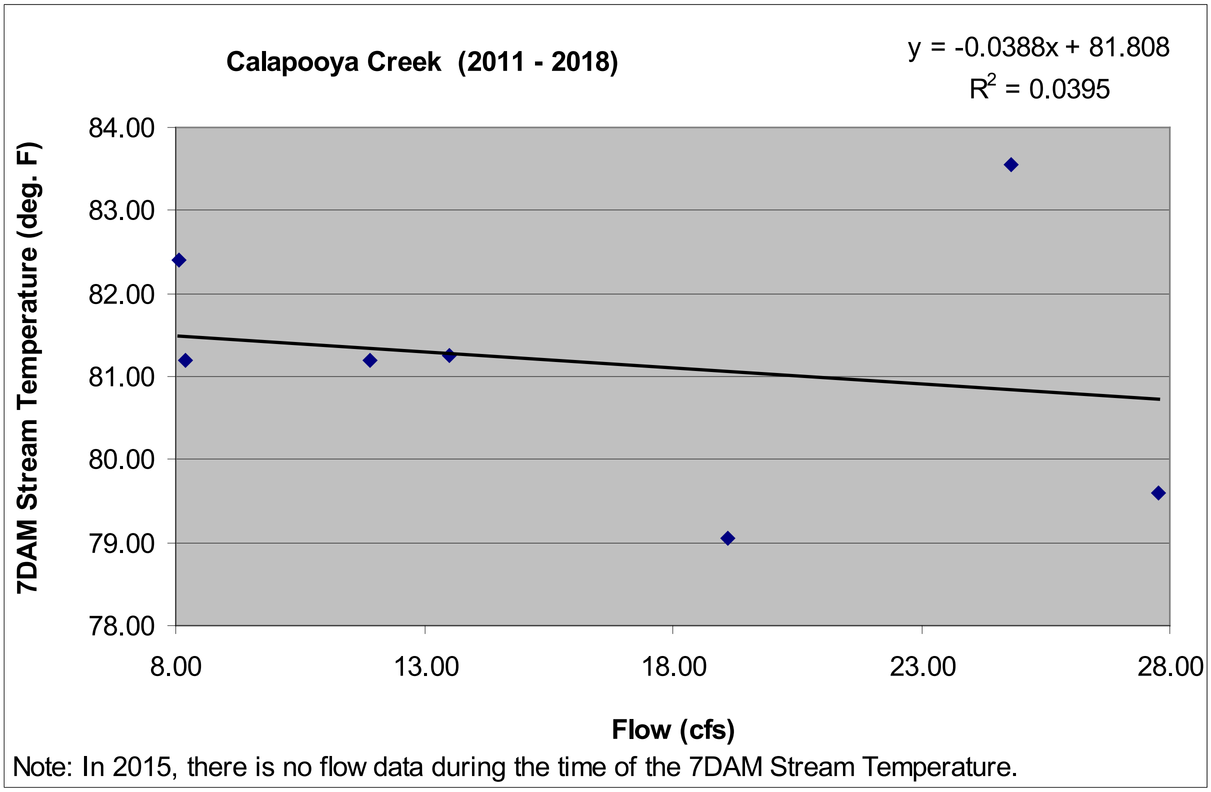


Figure 10. Continued. (Page 2 of 3)



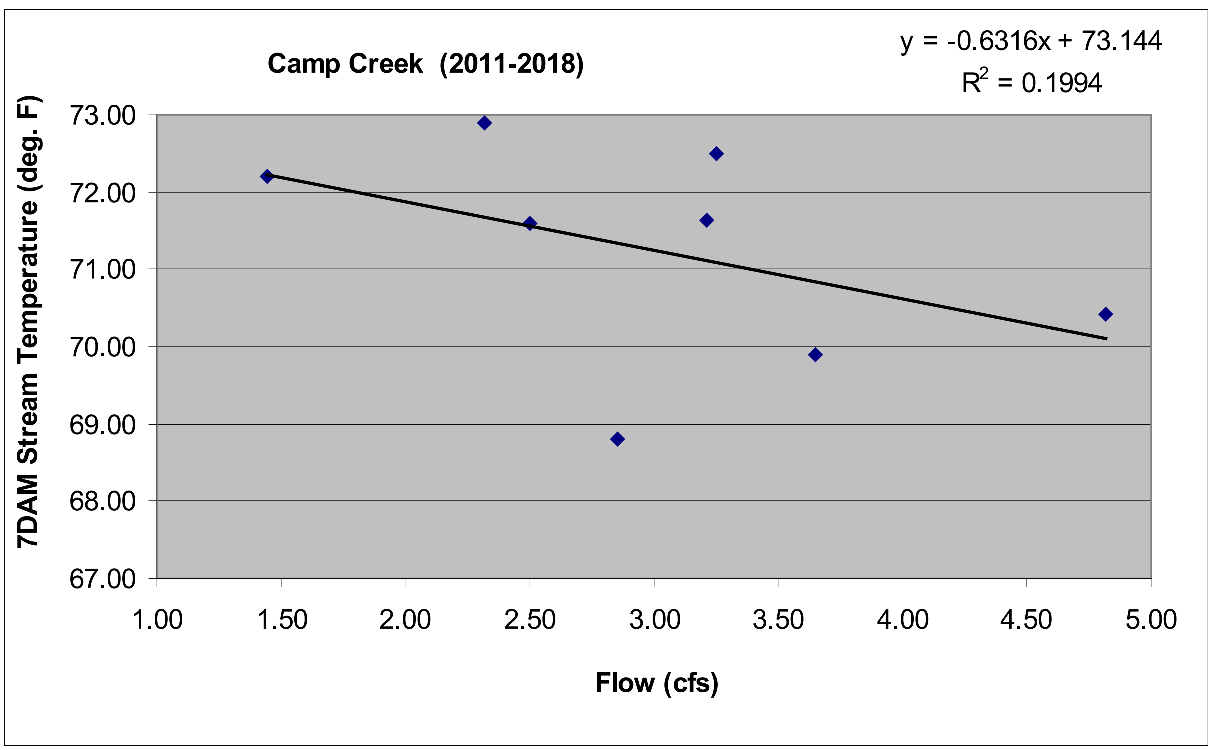
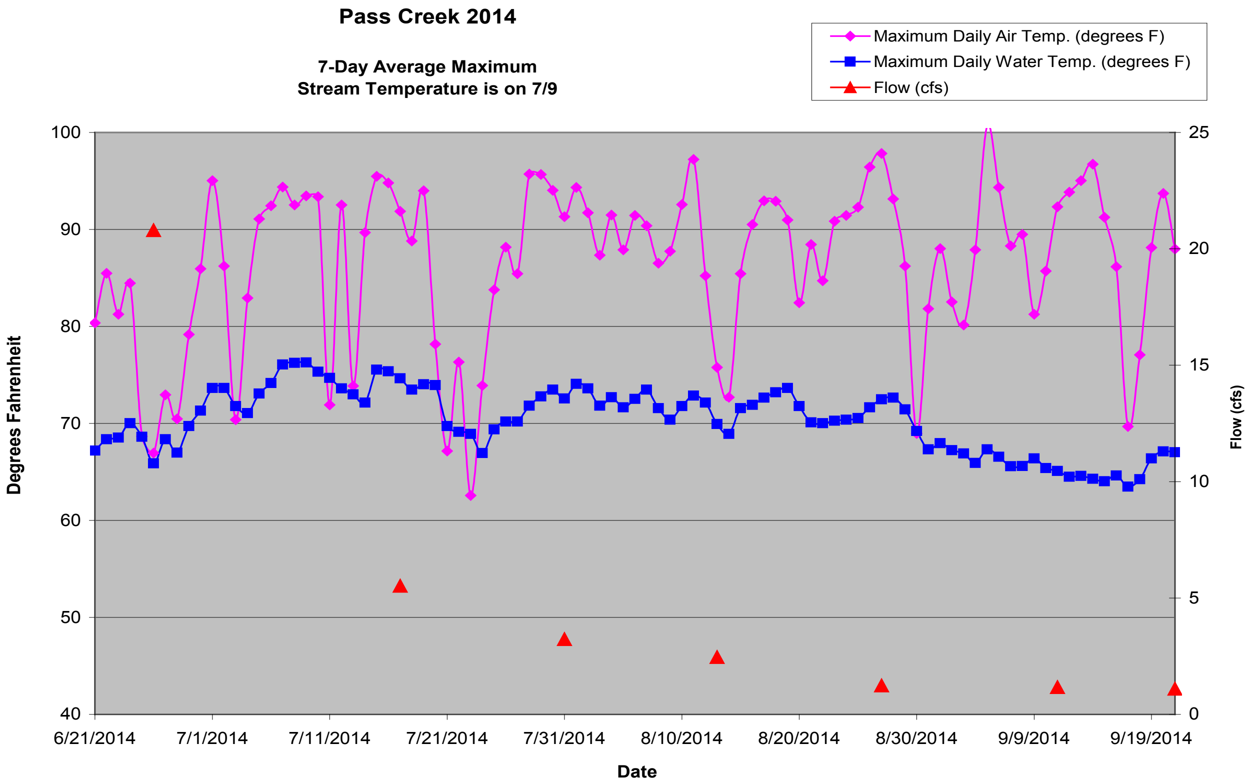


Figure 10. Continued. (Page 3 of 3)



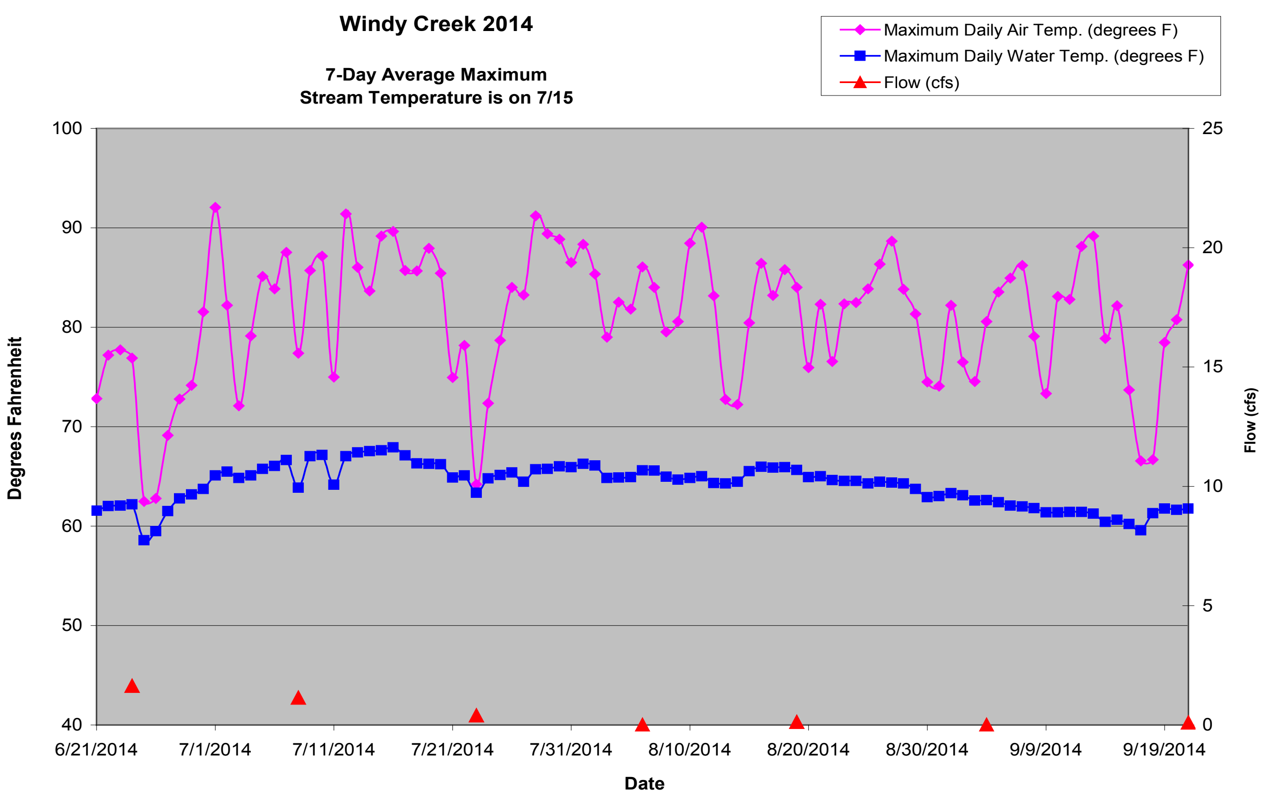


Figure 11. Pass and Windy Creek Maximum daily air temperature and flow compared to maximum daily stream temperature for 2014. These two site years were depicted because they had high air temperatures throughout the summer, but the stream temperatures decreased as flow and daylength decreased later in 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).

References:

Arismendi, I., M. Safeeq, S.L Johnson, J.B. Dunham, R. Haggerty. 2013. Increasing synchrony of high temperature and low flow in western North American streams: double trouble for coldwater biota? Hydrobiologia 712(1): 61-70.

Bell, M.C. 1986. Fisheries Handbook of Engineering Requirements and Biological Criteria. U.S. Army Corps of Engineers, Office of the Chief of Engineers, Fish Passage Development and Evaluation Program, Portland, Oregon.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. in: Salo, E.O. and T.W. Cundy (eds.). Streamside Management: Forestry and Fishery Interactions. College of Forest Resources, University of Washington, Seattle, Washington. Pages 191-232.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. Journal of the Fisheries Board of Canada 9(6): 265-323.

Brown, G.W. 1969. Predicting temperatures of small streams. Water Resources Research 5(1): 68-75.

Brown, G.W. and J.T. Krygier. 1970. Effects of clear-cutting on stream temperature. Water Resources Research 6(4): 1133-1139.

Clews, E., I Durance, I.P. Vaughan, and S.J. Ormerod. 2010. Juvenile salmonid populations in a temperate river system track synoptic trends in climate Global Change Biology. 16(12): 3271-3283.

Dammann, D.M. 2007. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2007. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2008. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2008. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2009. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2009. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2010. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2010. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2011. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2011. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2012. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2012. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2013. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2013. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2014. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2014. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2015. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2015. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2016. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2016. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2017. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2016. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2018. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2016. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2019. Umpqua Basin Stream Temperature Characterization – Reference Site Update 2016. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2020a. The Effects of Minimum Air Temperature and Maximum Air Temperature on Summer Stream Temperature at Reference Temperature Sites, Umpqua Basin. Partnership for the Umpqua Rivers (PUR), Roseburg, Oregon.

Dammann, D.M. 2020b. Umpqua Basin Low Flow Monitoring Report of 1998-2018 data. Partnership for the Umpqua Rivers, Roseburg, Oregon.

Dammann, D.M. and K. Smith. 2006. PUR Umpqua Basin Stream Temperature Characterization – Reference Site Update – 2006 Data. Partnership for the Umpqua Rivers, Roseburg, Oregon.

Hokanson, K.E.F., Kleiner, C.F., and T. W. Thorslund. 1977. Effects of constant temperatures and diel temperature fluctuations on specific growth and mortality rates and yield of juvenile Rainbow Trout, *Salmo gairdneri*. Journal of the Fisheries Research Board of Canada 34(5): 639-648.

Hirsch, R.M., and J.R. Slack. 1984. A nonparametric trend test for seasonal data with serial dependence. Water Resources Research 20(6): 727-732.

HydroGeoLogic, Inc. 2005. Final 2004 Annual Groundwater Monitoring Report and Quarterly Groundwater Monitoring Report, Quarter 4, 2004, Operable Unit 1, Fritzsche Army Airfield Fire Drill Area Former Ford Ord, California. Developed for U.S. Army Corps of Engineers' Sacramento District Office. Sacramento, California.

Iowa State University of Science and Technology. 2020. Iowa Environmental Mesonet. http://mesonet.agron.iastate.edu/wx/afos/.

Isaak, D., S. Wenger, E. Peterson, J. Ver Hoef, D. Nagel, C. Luce, S. Hostetler, J. Dunham, B. Roper, S. Wollrab, G. Chandler, D. Horan, S. Parkes-Payne. 2017. The NorWeST summer stream temperature model and scenarios for the western U.S.: A crowd-sourced database and new geospatial tools foster a user community and predict broad climate warming of rivers and streams. Water Resources Research, 53: 9181-9205.

Isaak, D.J., S.P. Woolrab, D.L. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980-2990. Climate Change 113: 499-524.

Jassby, A.D. and J.E. Cloern. 2017. Wq: Some tools for exploring water quality monitoring data. R package version 0.4.9. https://cran.r-project.org/package=wql.

Jefferson, A. G.E. Grant, S.L. Lewis, and S.T. Lancaster. 2010. Coevolution of hydrology and topography on a basalt landscape in the Oregon Cascade Range, USA. Earth Surface Processes and Landforms 35(7): 803-816.

Mail Tribune. September 1, 2015. Medford's summer is one for the record books – again. Medford, Oregon.

Meals, D.W., J. Spooner, S.A. Dressing, and J.B. Harcum. 2011. Statistical Analysis for Monotonic Trends. Tech. Notes 6, November 2011. Developed for U.S. Environmental Protection Agency by Tetra Tech, Inc., Fairfax, VA, 23 p.

Michie and Bryant. 2015. Stream Temperature Status and Trends within the Coastal Coho ESU. DEQ.

National Weather Service. November, 2015a. National Weather Service – Local Climate: NOWData, Medford, Oregon. http://nowdata.rcc-acis.org/mfr.

National Weather Service. November, 2015b. National Weather Service – Local Climate: NOWData, Portland, Oregon. http://nowdata.rcc-acis.org/pqr.

National Weather Service. December, 2016a. National Weather Service – Local Climate: NOWData, Medford, Oregon. http://w2.weather.gov/climate/xmacis.php?wfo=mfr.

National Weather Service. December, 2016b. National Weather Service – Local Climate: NOWData, Portland, Oregon. http://w2.weather.gov/climate/xmacis.php?wfo=pqr.

National Weather Service. December, 2017a. National Weather Service – Local Climate: NOWData, Medford, Oregon. http://w2.weather.gov/climate/xmacis.php?wfo=mfr.

National Weather Service. December, 2017b. National Weather Service – Local Climate: NOWData, Portland, Oregon. http://w2.weather.gov/climate/xmacis.php?wfo=pqr.

National Weather Service. December, 2018a. National Weather Service – Local Climate: NOWData, Medford, Oregon. http://w2.weather.gov/climate/xmacis.php?wfo=mfr.

National Weather Service. December, 2018b. National Weather Service – Local Climate: NOWData, Portland, Oregon. http://w2.weather.gov/climate/xmacis.php?wfo=pqr.

National Weather Service. December, 2019a. National Weather Service – Local Climate: NOWData, Medford, Oregon. http://w2.weather.gov/climate/xmacis.php?wfo=mfr.

National Weather Service. 2019b. August 2019 Climate Summary. Medford, Oregon. https://www.wrh.noaa.gov/mfr/fcst/index.php

National Weather Service. December, 2020a. National Weather Service – Local Climate: NOWData, Medford, Oregon. http://w2.weather.gov/climate/xmacis.php?wfo=mfr.

National Weather Service. December, 2020b. National Weather Service – Local Climate: NOWData, Portland, Oregon. http://w2.weather.gov/climate/xmacis.php?wfo=pqr.

National Weather Service. 2020c. May 2020 Climate Summary. Medford, Oregon. https://www.wrh.noaa.gov/mfr/fcst/index.php

National Weather Service. 2020d. June 2020 Climate Summary. Medford, Oregon. https://www.wrh.noaa.gov/mfr/fcst/index.php

National Weather Service. 2020e. July 2020 Climate Summary. Medford, Oregon. https://www.wrh.noaa.gov/mfr/fcst/index.php

National Weather Service. 2020f. August 2020 Climate Summary. Medford, Oregon. https://www.wrh.noaa.gov/mfr/fcst/index.php

National Weather Service. 2020g. September 2020 Climate Summary. Medford, Oregon. https://www.wrh.noaa.gov/mfr/fcst/index.php

The News-Review. July 29, 2009. Record heat slaps Roseburg. Roseburg, Oregon.

The News-Review. July 30, 2009. Whew! Another heat record established. Roseburg, Oregon.

The News-Review. September 2, 2015. Was it hot enough for you?: Roseburg this summer was hottest on record. Roseburg, Oregon.

Oregon Department of Environmental Quality (ODEQ). 2003. Figure 320A: Fish Use Designations Umpqua Basin, Oregon. https://www.oregon.gov/deq/Rulemaking%20Docs/figure320a.pdf.

ODEQ. 2006. Assessment Methodology for Oregon's 2004/2006 Integrated Report on Water Quality Status.

ODEQ. 2009. Water Monitoring and Assessment Mode of Operations Manual, Version 3.2. Portland: ODEQ.

ODEQ. 2011. Methodology for Oregon's 2010 Water Quality Report and List of Water Quality Limited Waters. Portland: ODEQ.

ODEQ. 2014. Methodology for Oregon's 2012 Water Quality Report and List of Water Quality Limited Waters. Portland: ODEQ.

ODEQ. 2018. Methodology for Oregon's 2018 Water Quality Report and List of Water Quality Limited Waters. Portland: ODEQ.

Oregon Department of Fish and Wildlife (ODFW). 2018. Crayfish Found in Oregon. https://www.dfw.state.or.us/conservationstrategy/invasive_species/docs/Crayfish_Comparison.pdf.

The Oregonian. July 29, 2009. Health concerns heat up. Portland, Oregon.

The Oregonian. July 30, 2009. Not the record, but whew! Portland, Oregon.

Partnership for the Umpqua Rivers (PUR). 2014a. Quality Assurance Project Plan for the Partnership for the Umpqua Rivers. Roseburg, Oregon.

PUR. 2014b. Streamwalker – Summer 2014 Final Report. Roseburg, Oregon.

PUR. 2015. Streamwalker – Summer 2015 Final Report. Roseburg, Oregon.

PUR. 2016a. Quality Assurance Project Plan for the Partnership for the Umpqua Rivers - Amendment. Revision 1. Roseburg, Oregon.

PUR. 2016b. Streamwalker – Summer 2016 Final Report. Roseburg, Oregon.

PUR. 2017. Streamwalker – Summer 2017 Final Report. Roseburg, Oregon.

PUR. 2018. Streamwalker – Summer 2018 Final Report. Roseburg, Oregon.

PUR. 2020. OWEB Completion Report for the Umpqua Basin Stream Flow and Temperature Monitoring Project: 2017-18 (Grant #217-2054).

Pritchard, T. 2017. (Unpublished) DEQ Trend Analysis of Umpqua Basin Reference Temperature Data – 1998-2017. Hillsboro, Oregon.

Pritchard, T. 2018. (Unpublished) DEQ Trend Analysis of Umpqua Basin Reference Temperature Data – 1998-2018. Hillsboro, Oregon.

Pritchard, T. and S. Doak 2019. (Unpublished) DEQ Trend Analysis of Umpqua Basin Reference Temperature Data – 1998-2019. Hillsboro, Oregon.

Pritchard, T. 2020. (Unpublished) DEQ Trend Analysis of Umpqua Basin Reference Temperature Data 1998-2020 and North Umpqua Comparison Sites – 1998-2019. Hillsboro, Oregon.

The Register-Guard. September 2, 2015. Eugene summer was hottest on record, National Weather Service says. Eugene, Oregon.

Smith, K. 2001a. Umpqua Basin Stream Temperature Reports: 1999-2001. Umpqua Basin Watershed Council, Roseburg, Oregon.

Smith, K. 2001b. Use of a Control Site to Reduce Inter-Year Variability in Stream Temperature Data in the Umpqua Basin. Umpqua Basin Watershed Council, Roseburg, Oregon.

Smith, K. 2003. Stream Temperature in the Umpqua Basin Characteristics and Management Implications. Umpqua Basin Watershed Council, Roseburg, OR.

Smith, K. 2004. Umpqua Basin Stream Temperature 2004 Update. Umpqua Basin Watershed Council, Roseburg, OR.

Smith, K. 2005. UBWC Stream Temperature Characterization Project Reference Site Update 2005 Data. Umpqua Basin Watershed Council, Roseburg, OR.

Smith, K. 2010. Use of Synoptic Temperature Data to Reduce Inter-year Stream Temperature Variability within the Umpqua Basin. Partnership for the Umpqua Rivers, Roseburg, OR.

Tague, C. and G.E. Grant. 2004. A geological framework for interpreting the low-flow regimes of Cascade streams, Willamette River Basin, Oregon. Water Resource Research 40: W04303: doi:10.1029/2003WR002629.

Taylor, G.H. and C. Hale. July 24, 2006. July Heat Wave Temperatures / Records. Oregon Climate Service. Oregon State University, Corvallis, OR.

Umpqua Basin Watershed Council. 2004. Streamwalker – Summer 2004 Final Report. Roseburg, Oregon.

Umpqua Basin Watershed Council. 2005. Streamwalker – Summer 2005 Final Report. Roseburg, Oregon.

Umpqua Basin Watershed Council {PUR}. 2006. Streamwalker – Summer 2006 Final Report. Roseburg, Oregon.

Umpqua Basin Watershed Council {PUR}. 2007. Streamwalker – Summer 2007 Final Report. Roseburg, Oregon.

Umpqua Basin Watershed Council {PUR}. 2008. Streamwalker – Summer 2008 Final Report. Roseburg, Oregon.

Umpqua Basin Watershed Council {PUR}. 2009. Streamwalker – Summer 2009 Final Report. Roseburg, Oregon.

Umpqua Basin Watershed Council {PUR}. 2010. Streamwalker – Summer 2010 Final Report. Roseburg, Oregon.

Umpqua Basin Watershed Council {PUR}. 2011. Streamwalker – Summer 2011 Final Report. Roseburg, Oregon.

Umpqua Basin Watershed Council {PUR}. 2012. Streamwalker – Summer 2012 Final Report. Roseburg, Oregon.

Umpqua Basin Watershed Council {PUR}. 2013. Streamwalker – Summer 2013 Final Report. Roseburg, Oregon.