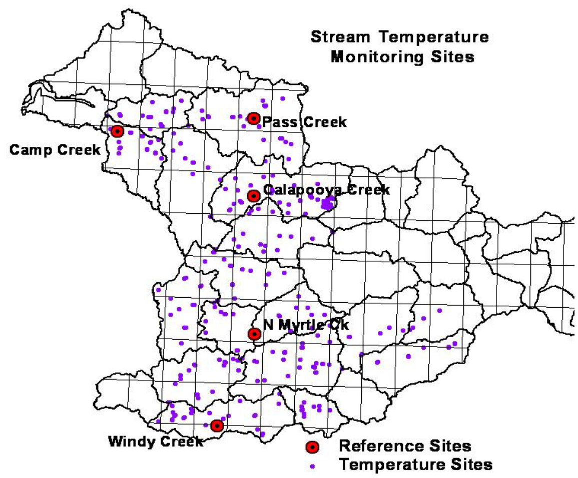
Umpqua Basin Stream Temperature Characterization – Reference Site 2018 Update

(Covering Project Duration 1998-2018)

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

This is the annual update of the Umpqua Basin Reference Stream Temperature Project, a long term temperature study. This report presents stream temperature conditions for 2018 and compares that to the air and stream temperature data collected since 1998 as well as flow data since 2004. 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 (Smith, 2003, 2004, and 2005; Dammann and Smith, 2006; Dammann, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, and 2017). The data from these five sites (Calapooya, Camp, North Myrtle, Pass, and Windy Creeks) can be used as models to normalize for annual variability in other stream locations lacking long-term data, especially those with a short record of data such as restoration project monitoring sites. This normalization is achieved either by making an adjustment or comparison from the data by using the ratio method (Smith, 2001b), the use of synoptic temperature data (Smith, 2010), or other methods described below.



This report will (1) analyze stream temperature patterns at the Umpqua basin reference temperature sites for this year as well as the period of record (2) look at effects of air temperature, flow, and day length on stream temperature at these sites, particularly flow using flow data collected at the sites (since 2004) by Oregon Water Resources Department (OWRD) for PUR and (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.

Photo 1. Salmonberries (*Rubus spectabilis*) at Camp Creek site.

2018 Regional and Reference Site Summer Flows and Air and Stream Temperature:

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 1, 2, and 3 and NWS, 2018a and 2018b, and Iowa State University of Science and Technology, 2018). Also, while the study sites do not have headwaters in the snow zone, they do in the transient snow zone and flows are not typically impacted by the snowpack.

By the peak of the snow season, most of Oregon's snowpack was 70% of normal (NRCS, 2018), Then, May 2018 was warmer and dryer than normal (NWS, 2018c) which resulted in significant snowmelt with rates of snowmelt at some sites 150-250% of typical spring melt rates (NRCS, 2018). June, 2018 had a mix of spring and summer weather but overall was warmer and dryer (Table 1 and NWS, 2017d). The second week of July, warmed up and there were thunderstorms in the area that caused several fires; the remainder of July was very smoky (NWS, 2018e). August and early September could also be characterized as hot, dry, and smoky (NWS, 2018f and 2018g). Temperatures began cooling down around the second week of September (NWS, 2018g).

Overall, Summer 2018 was characterized as warmer and dryer than normal (Table 1), with fewer days with extreme temperatures (Table 3) than there have been in several years. There were several heat waves in the region throughout the summer but the longest stretch of maximum daily air temperatures above 85°F in Roseburg was late July through early August (Table 2). However, with the exception of a few days of cooler weather on August 2, 11 and 16, this heat wave actually extended from July 21-August 22 (Table 2). July 24-26 maximum air temperatures were 100°F, 101°F, and 101°F respectively (Table 2).

While the past three summers have been relatively cooler, 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). August 2017 had the highest record. 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).

Table 1. Monthly Average Maximum Temperatures and Monthly Precipitation for Roseburg, Oregon (NWS, May, June, July, August, and September 2018)

Month	**Average Maximum Temperature**	**Departure from Normal**	**Monthly Precipitation**	**Departure from Normal**
May, 2018	73.8°F	+3.9°F	0.27"	-2.00"
June, 2018	79.5°F	+3.5°F	0.62"	-0.51"
July, 2018	90.6°F	+6.3°F	0.00"	-0.42"
August, 2018	87.3°F	+2.6°F	0.03"	-0.44"
September, 2018	79.0°F	+0.4°F	0.26"	-0.70"

Table 2. Heat waves with at least three consecutive high maximum daily air temperatures above 85°F in Roseburg, Oregon from May to September, 2018. All National Weather Service (NWS) data are preliminary and have not undergone final quality control. (Iowa State University of Science and Technology, 2018 and NWS, 2018a)

Date Range	Location	Daily Maximum Air Temperatures
June 17-19	Roseburg	87-95°F
July 10-18	Roseburg	85-101°F
July 21-August 1	Roseburg	87-101°F; the temperatures July 24-26 were 100°F, 101°F, and 101°F respectively
August 3-10	Roseburg	85-98°F
August 12-15	Roseburg	87-94°F
August 17-22	Roseburg	86-94°F
September 4-7	Roseburg	85-91°F
September 26-28	Roseburg	88-89°F

Table 3. Record weather events for Roseburg, Medford, and Eugene, Oregon from May to September, 2018. All National Weather Service (NWS) data are preliminary and have not undergone final quality control. (Iowa State University of Science and Technology, 2018 and NWS, 2018a and 2018b)

Date	Location	Record Broken
June 20, 2018	Roseburg	Highest maximum temperature for this date (95°F)
July 3, 2018	Eugene	Lowest minimum temperature for any date in July (38°F)
July 25, 2018	Roseburg	Highest maximum temperature for this date (101°F)
September 25, 2018	Eugene	Highest maximum temperature for this date (88°F)

Note: The NWS office in Medford covers Medford and Roseburg. The NWS office in Portland covers Eugene. Sometimes they report different statistics. Medford did not have any record weather events during this time period.

Radiant energy, specifically, solar radiation, is a very important factor in heating streams (Brown, 1969 and Beschta, *et al.*, 1987). Solar radiation reaching streams is reduced by canopy cover, but can change daily from changes in surface area due to changes in flow, changes in day length, changes in cloud cover, and changes in solar output (which is often expressed by air temperature changes). Another important factor affecting changes in stream temperature at a site is flow which will be discussed in detail later in this report.

Beginning in 1998-2000, summer air and stream temperature data were collected with continuous temperature recorders set for 30 minute intervals at the five reference sites. Since 2009, the period of record has been from at least June 21 to September 21; prior to 2009, it was collected from at least July 1 to mid-September. In 2018, air and stream temperature data was collected beginning June 7 (at Calapooya Creek), June 9 (at North Myrtle Creek), June 10 (at Camp and Pass Creeks), and June 11 (at Windy Creek) (Figures 1 and 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). The heat waves in air temperature at the reference sites corresponded with those in the surrounding cities (Table 2 and Figure 1). Just like the highest air temperatures in the surrounding cities were in mid-late July in 2018 (Table 2), they were for the reference temperature sites as well (Figure 1). This corresponded to the maximum stream temperatures for all of the reference sites being in late July (Figure 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 2018, the 7DAM stream temperature for Calapooya and North Myrtle Creeks was July 27 and for Camp, Pass and Windy Creeks was July 28.

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

In 2018, the 7DAM stream temperatures for the reference sites exhibited similar patterns to previous years in the 19-20 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). In 2018, no sites had the highest or lowest 7DAM stream temperatures compared to the period of record, but most ranked somewhere in the middle (Figure 3 and Table 4). Interestingly, in 2015, which was the hottest year on record, the 7DAM stream temperatures were not the highest, but between the 2nd and 7th highest for the period of record (Dammann, 2015)

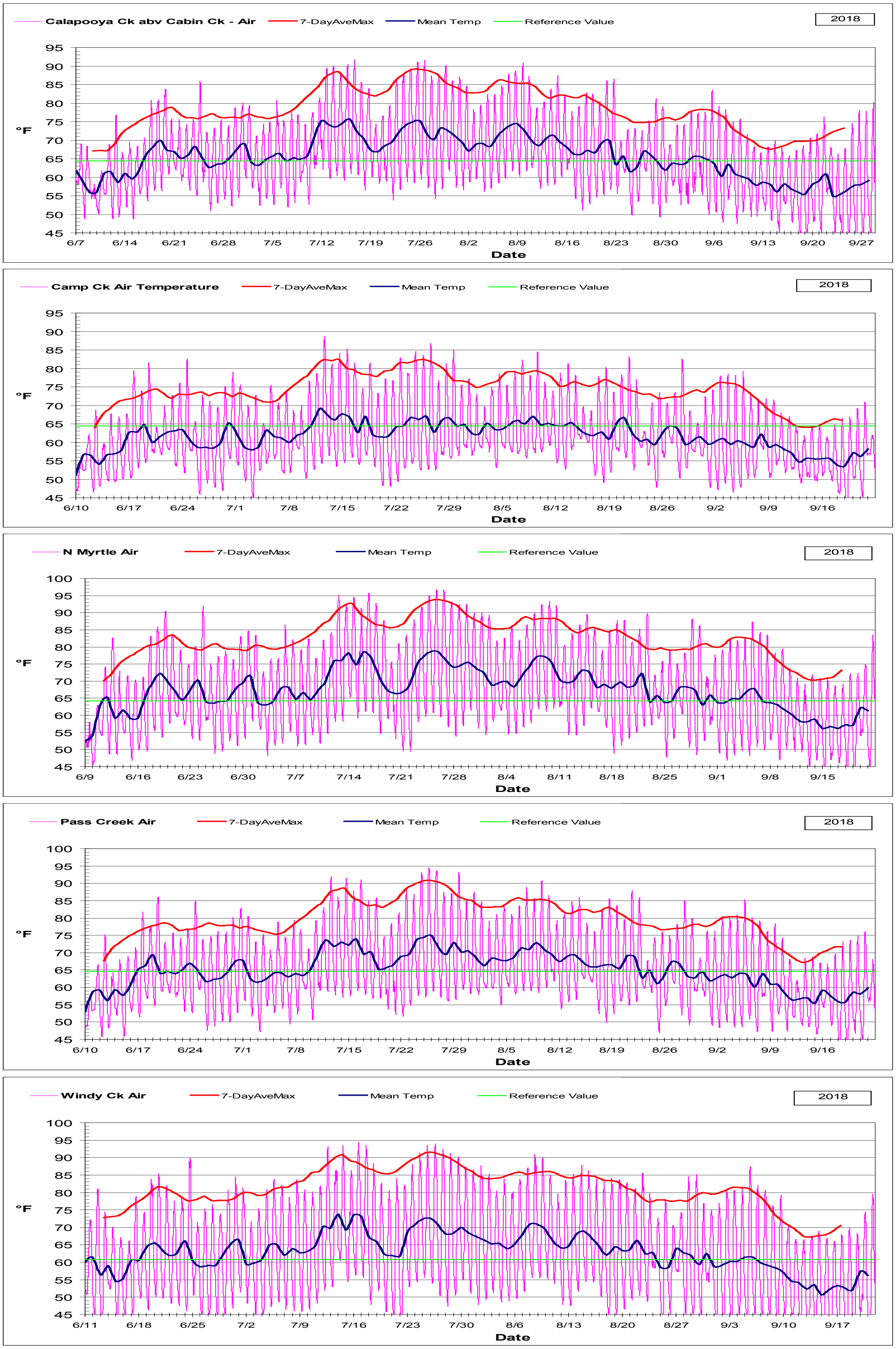


Figure 1. 2018 Umpqua Basin reference site air temperature data measured at 30-minute intervals. The reference value is set at the Oregon Department of Environmental Quality (ODEQ) temperature standard for stream temperature (64.4°F for all streams except Windy Creek which is 60.8°F (ODEQ 2003 & 2018)).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

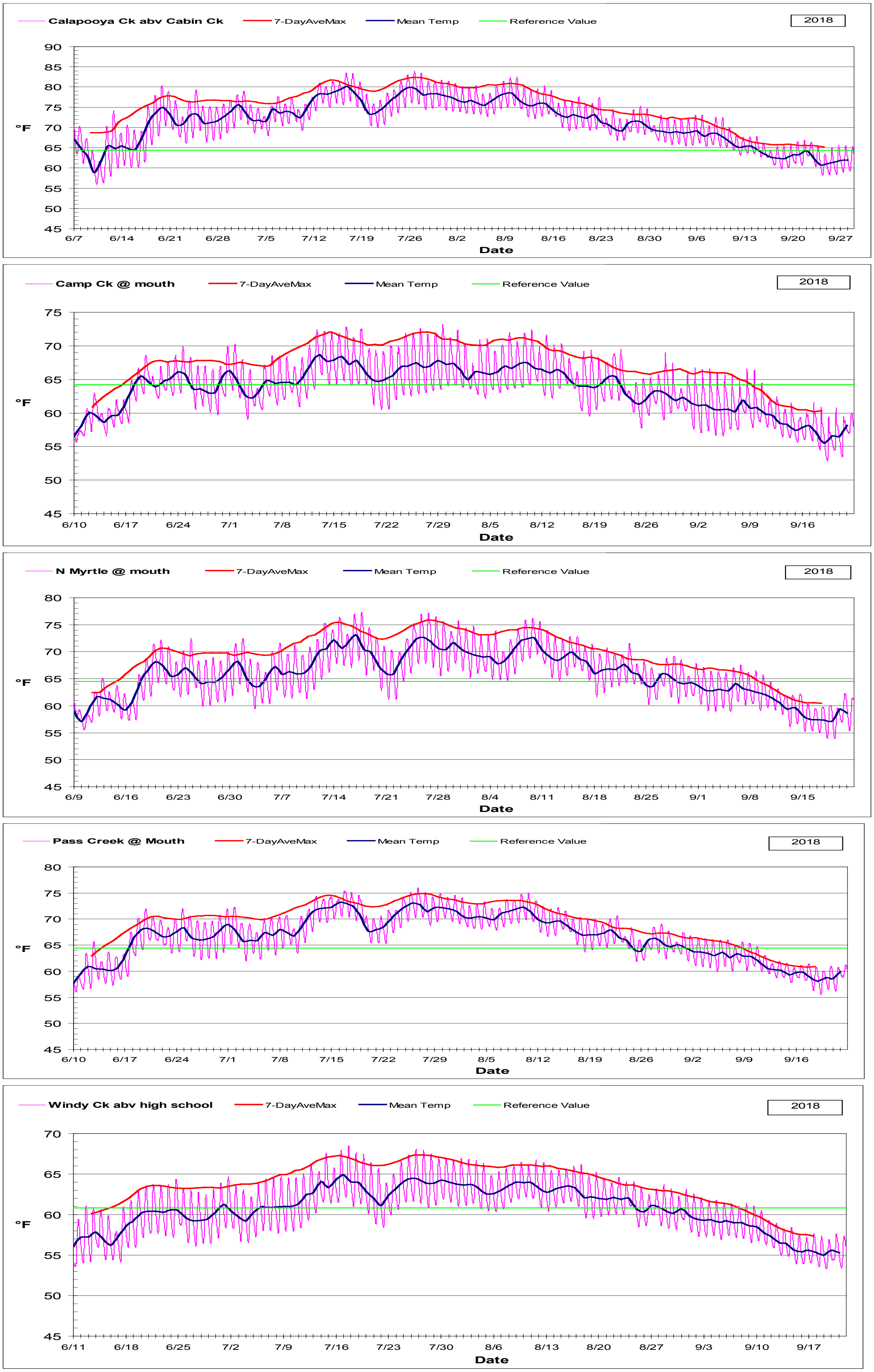


Figure 2. 2018 Umpqua Basin reference site stream temperature data measured at 30-minute intervals. The reference value is 64.4°F for all sites except Windy Creek which is 60.8°F (ODEQ 2003 & 2018). The 7 day average maximum (7DAM) stream temperature is centered on the date.

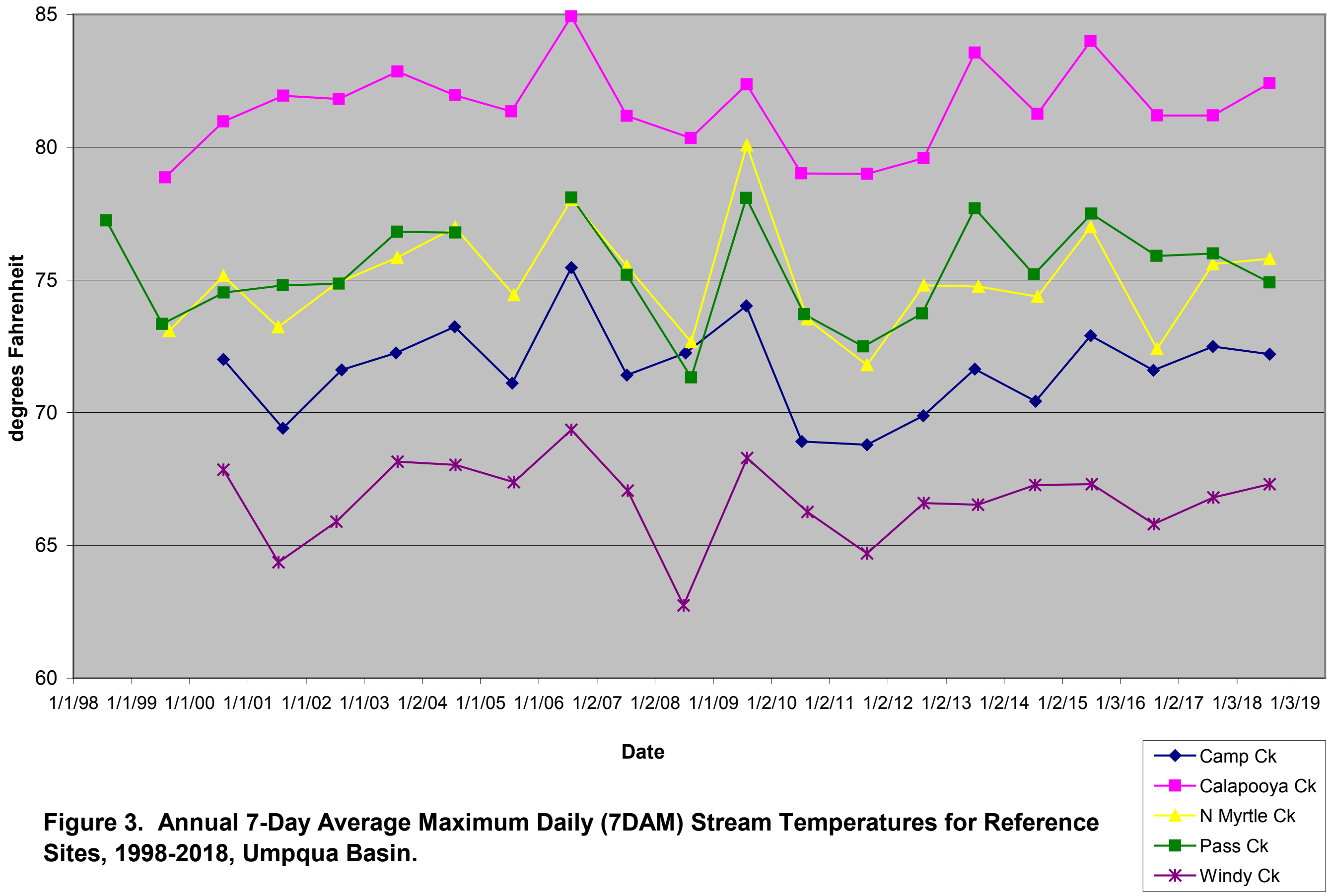


Figure 3. Annual 7-Day Average Maximum Daily (7DAM) Stream Temperatures for Reference Sites, 1998-2018, Umpqua Basin.

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 and Table 4).

Table 4. Umpqua Basin reference site highest, lowest, and difference in 7-day average maximum (7DAM) stream temperatures from 1998-2017 and distance from sites to ridgetop.

	Calapooya Ck	Camp Ck	N Myrtle Ck	Pass Ck	Windy Ck
Highest 7DAM temperature (^{o}F)	84.92	75.46	80.08	78.10	69.36
Lowest 7DAM temperature (^{o}F)	78.86	68.80	71.80	71.33	62.75
Difference in 7DAM temperatures (^{o}F) (ΔT)	6.06	6.66	8.28	6.77	6.61
Distance from site to ridgetop divide (miles)	28.47	21.41	18.26	13.30	9.63
Drainage area (acres)	103,500	22,550	37,190	40,090	15,660
Ranking of 2018 Data	5th Highest	8th Highest	6th Highest	12th Highest	7th Highest (Tie)
Years of survey	20	19	20	20	19

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 has varied annually as much as 6.06 to 8.28ºF depending on the site during the 19-20 year period of record (Figure 3 and Table 4).

The approximately 6-8ºF temperature difference in 7DAM stream temperature for the reference 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.

As previously mentioned, Summer 2015 was the hottest summer on record for the three cities that surround the study sites; however, though they were among the hottest, they did not result in the hottest stream temperatures. The years 2014 and 2013 had the 2nd and 3rd hottest summers on record, 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 18 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. (Dammann, 2015)

Timing of 7DAM Stream Temperatures:

For the 19-20 year period of record, the dates of the 7DAM stream temperatures 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 8-18 and August 9-18 and an increase from June 30 – July 1 as well. With more years of data, we will learn if a typical bell curve be established or if another pattern will emerge.

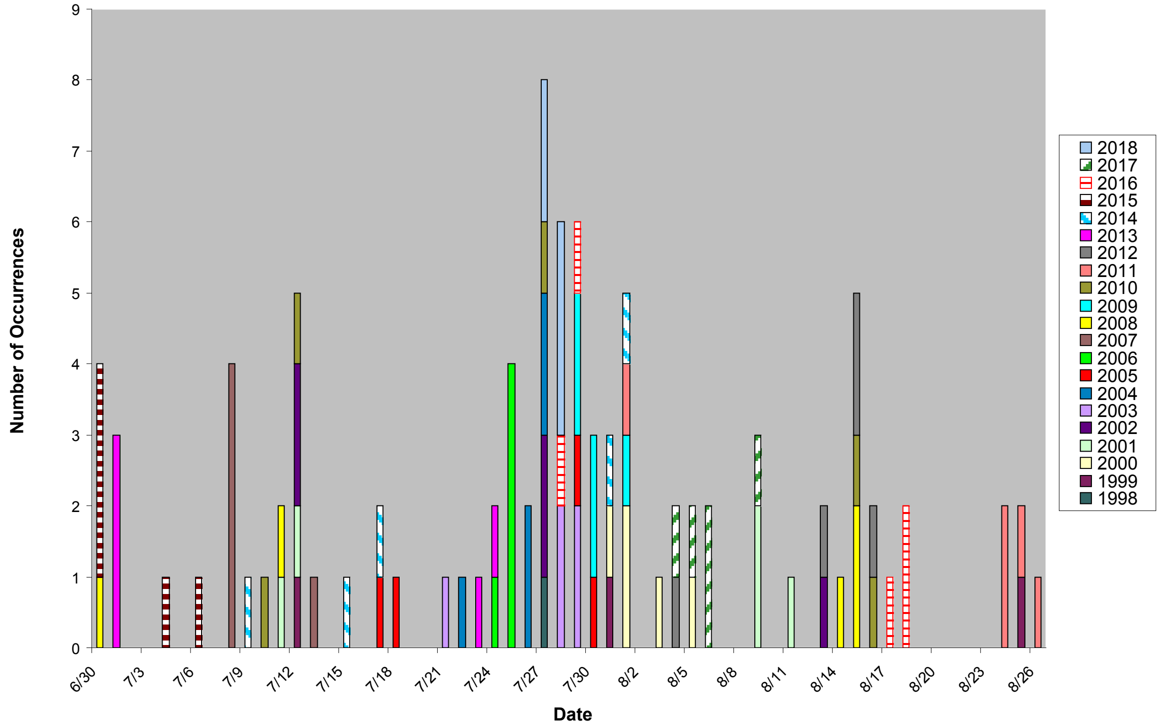


Figure 4: Dates of 7-day average maximum stream temperatures for the Umpqua Basin reference sites from 1998-2018 (center date of rolling 7 day period).

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). In 2018, the 7DAM stream temperatures occurred on July 27 or 28 for all 5 sites, during the three-day period of air temperatures equal to or exceeding 100°F. 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 (Dammann, 2009) and in 2006 when there were record breaking high minimum temperatures in late July (Taylor and Hale, 2006 and Dammann and Smith, 2006). In contrast, some years, such as 2014 had no defining hot period that drove the maximum stream temperatures resulting in 7DAM stream temperatures to be spread throughout several weeks (Figure 4).

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).

In 2016, PUR had one water temperature site (North Fork Deer near the Mouth) that had the 7DAM stream temperature during the early June heat wave (on June 5th). The reference temperature sites had summer stream temperature data beginning between June 5 and June 12. That same year, Roseburg District BLM, Umpqua National Forest, and PUR combined had a 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 the one mentioned above had the 7DAM stream temperature early in the season (in early June). While the BLM and USFS sites were year-round, the PUR sites data set began on June 2. Since the PUR sites are lacking the early part of the heat wave (May 31-June 1), the possibility still exists that these data sets may have missed the 7DAM stream temperature, however, since the maximum stream temperatures for the PUR sites were not in early June (unlike with North Fork Deer), it is less likely than if the maximum did occur in early June. 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 (Figure 2). 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 5). August 1, 4pm temperatures (Figure 5) show a similar pattern as the 7DAM stream temperatures (Figure 3), with Calapooya Creek being the highest each year and Windy Creek the lowest (with one exception for each) (Figure 5). 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 5). 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).

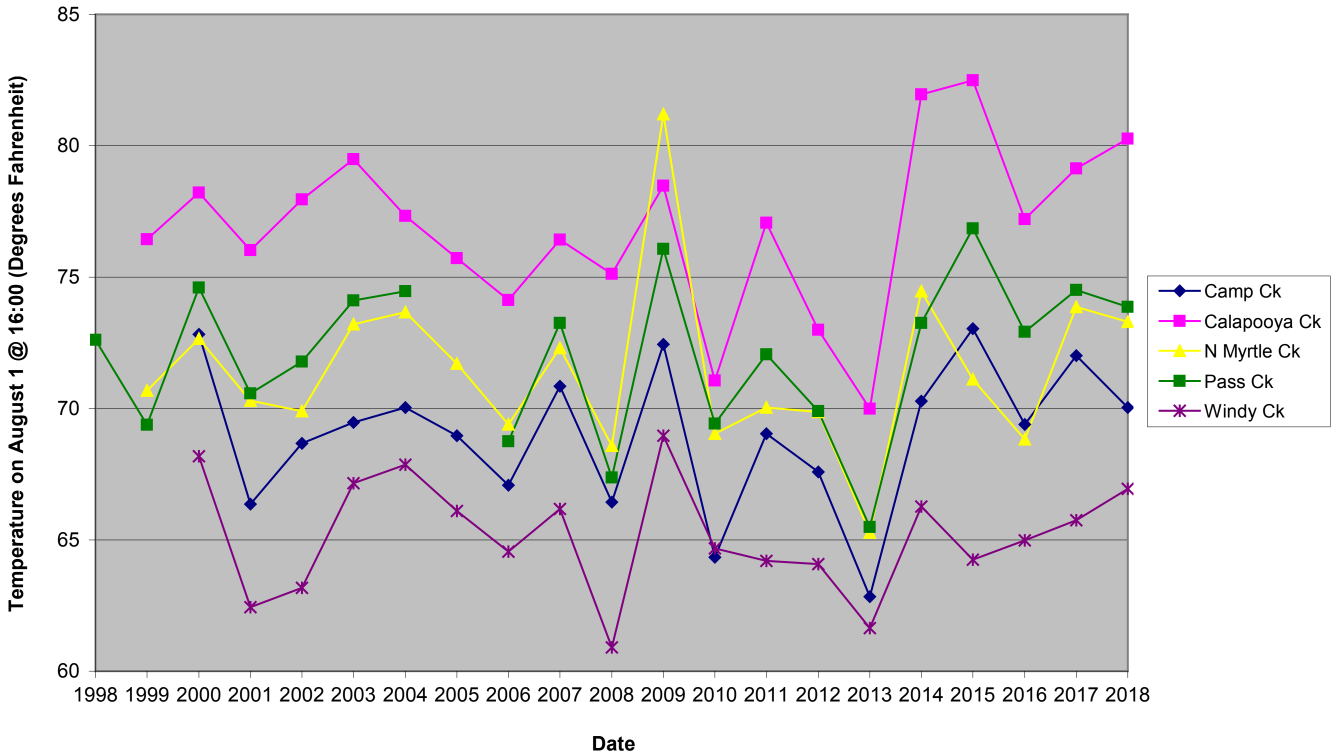


Figure 5. Umpqua Basin reference site stream temperatures on August 1 at 16:00 from 1998-2018.

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 (2018) modified this analysis to look at trends in the stream temperatures at the five sites for this project for the entire period of record (19-20 years) (Table 5 and Figure 6). 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 (2018) 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). More specific results are in Figure 6. (Pritchard, 2018)

Site	Years	Significant Seasonal Kendall Trend	p-value
Calapooya Creek	1999-2018	No Trend	0.57
Camp Creek	2000-2018	No Trend	0.38
North Myrtle Creek	1999-2018	No Trend	0.92
Pass Creek	1998-2018	No Trend	0.39
Windy Creek	2000-2018	Yes (Negative Trend)	0.08

The only site that had a significant trend was Windy Creek with a negative trend (p=0.08) and a Sen's slope of -.0.03 (Table 5, Figure 6, and Pritchard (2018)). While this analysis does not sort out the cause of the significant decrease in 7DAM stream temperatures from 2000-2018, it could be due to any number of factors including climate change, changes in flow conditions, natural disturbances, and/or anthropogenic actions.

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) 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 2014, 2015, 2016, 2017, and 2018). (In 2011, flows at Calapooya Creek were taken approximately ¼ mile downstream due to access issues, there is a very small stream entering between the two sites, but it should have a minimal effect on the flow.) 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.

Data indicates a strong negative correlation between flow and 7DAM stream temperature at Windy Creek (r^2= 0.3079) (Figure 7) which indicates that as flow increases, 7DAM stream temperature decreases. This is the strongest correlation of any of the sites in this study (Figure 7). 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 7). 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 7). 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 7).

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. More data in future years will indicate if there is a correlation at these sites and provide more insight into all five sites. (Figure 7)

The Effect of Air Temperature and Flows on Stream Temperature:

Since 2010, the summer flows at the five reference sites have been compared with maximum daily air temperatures and maximum daily stream temperatures. Figure 8 shows the 2018 comparisons and the 2010-2017 can be found in the Appendix (located on the Reference Temperature CD). In each stream, the trends in the water temperature reflect those in the air temperature (Figure 8), 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 (Figure 8 and Appendix 1). 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 8 and Appenidix 1).

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 will 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 to Enhance Other Project Level Stream Temperature Site Data:

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.

Aquatic resource specialists working in the Umpqua Basin (from PUR, USFS, three BLM Districts, Oregon Department of Fish and Wildlife, South Umpqua Rural & Community Partnership, and PacifiCorp) have used the reference temperature data to compare and confirm regional timing and trends in stream temperatures with their limited data sets. One way the data can and has been used, mentioned above, 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. Other methods of comparison that have been used include using ratios of 7DAM stream temperatures and various visual comparisons, such as those described below, could be used as well.

Figure 9, from Lyon, Smith and Dammann (2012), shows an example of a way to use the data. In this instance, the North Myrtle Creek (at the mouth) reference temperature site, is one of only three data sets in North Myrtle Creek with a complete record and given that it is at the confluence, it is very useful for comparison to the other sites.

Figure 10 shows another method of visual comparison to utilize that data. At the Wolf Creek Restoration Site #10, a weir was constructed and gravel was added to the site. Three water temperature recorders were placed upstream of the weir and three were placed downstream of the weir. During the period of maximum stream temperature, most of the locations had diurnal peaks, like the reference temperature data (Figure 10). However, during the period of low flows, the trend differed; all of the Wolf Creek #10 sites had diminished mid-day stream temperature peaks compared with the reference temperature sites possibly due to hyporheic flow through the gravels (Figure 10).

At the Wolf Creek Restoration Site #9, a weir was constructed, but no gravel was added. Trends are similar to that of Site #10 with the exception that there's no differentiation in the upstream and downstream temperature data since there's no gravels cooling the water upstream of the weir (Figure 10). Having the reference temperature data for comparison gives the ability to better describe the trends in the Wolf Creek project data since the reference sites do not show the same diminished diurnal peaks during the low flows.

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 has 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 streams exceeded the ODEQ criteria for every year at every site (Figure 3).

Invasive Crayfish:

In 2018, at some of the field 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). At the Camp Creek study site there were both signal crawfish and adult and juvenile ringed crayfish. Downstream from the Camp Creek study site, below the confluence with Mill Creek, several juvenile ringed crayfish were found. At Calapooya Creek where there are typically signal crayfish, only ringed crayfish were present on all three field visits. These sightings have been reported to the local ODFW office as well as the Oregon Invasive Species Hotline.

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

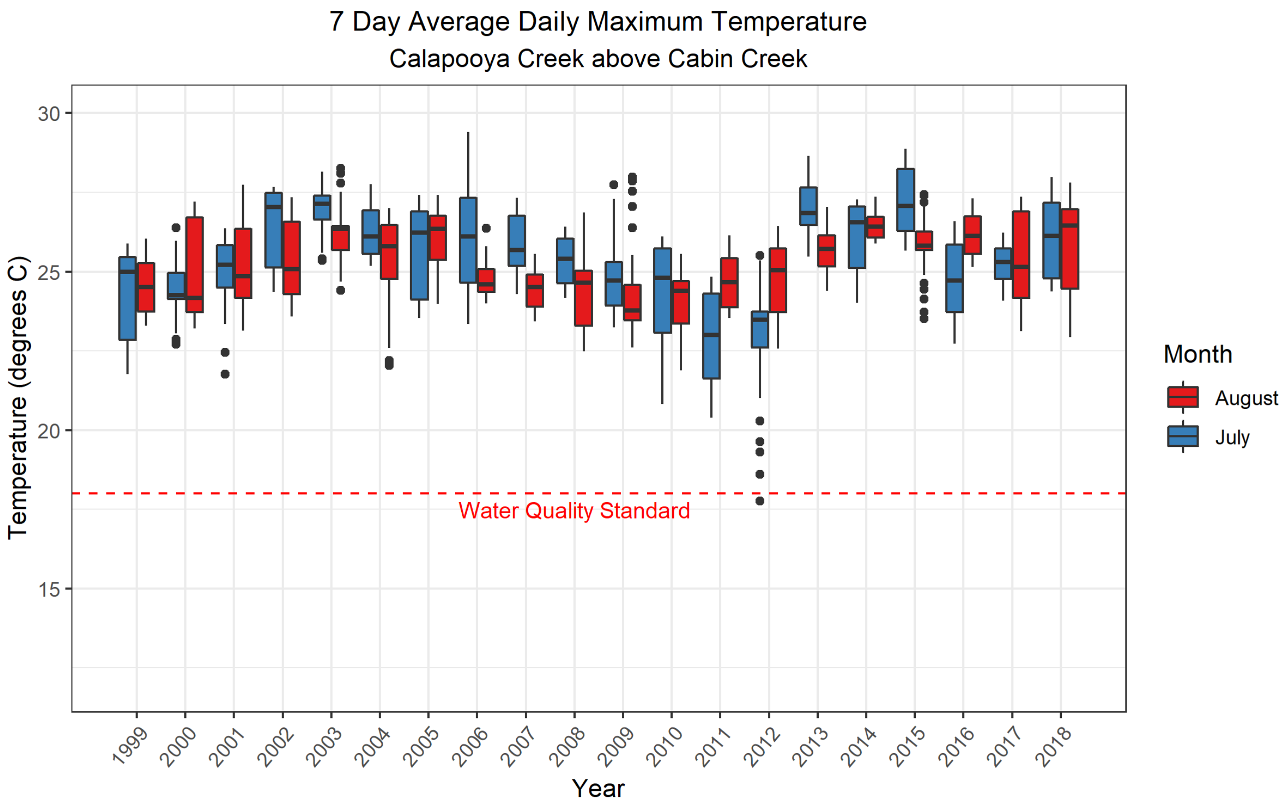
Acknowledgments:

This project is in cooperation with the stream flow monitoring conducted by the Oregon Water Resources Department and was funded by a grant from the Oregon Watershed Enhancement Board (OWEB) through PUR (Grant # 217-2054). Other components of the Umpqua Basin Stream Flow and Temperature Monitoring Project were funded by OWEB and the Southwestern Oregon Bureau of Land Management Resource Advisory Committee through PUR. Thanks to Roseburg Resources 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 2018 Update CD:

All previous reports, data, and photos for the length of this project are located on the Umpqua Basin Stream Temperature 2018 Update CD. In addition, the Getdata program, found on the CD, allows the user to retrieve several statistics and graphs from the temperature data files. The Umpqua Basin Stream Temperature Update 2018 CD can be obtained from Denise Dammann Consulting or PUR.

Denise Dammann Consulting
ddammann@jeffnet.org



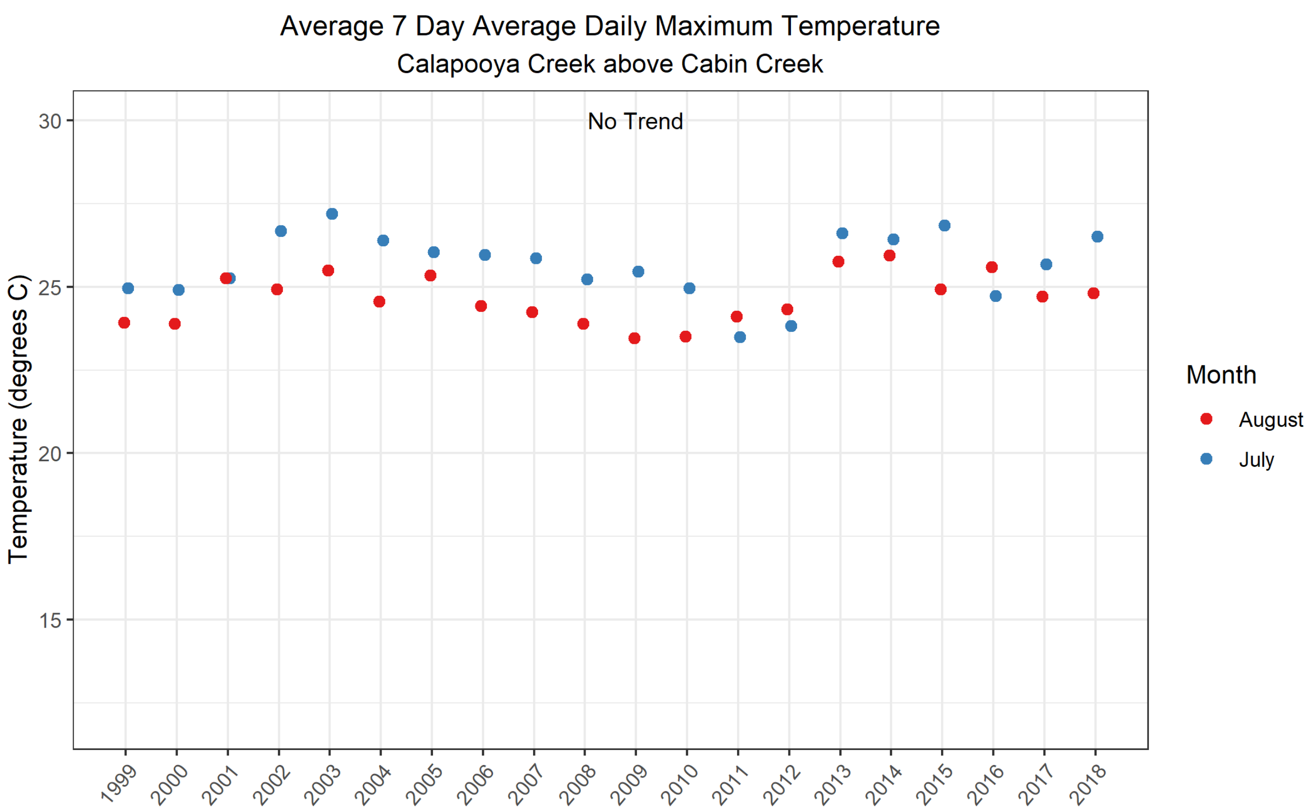
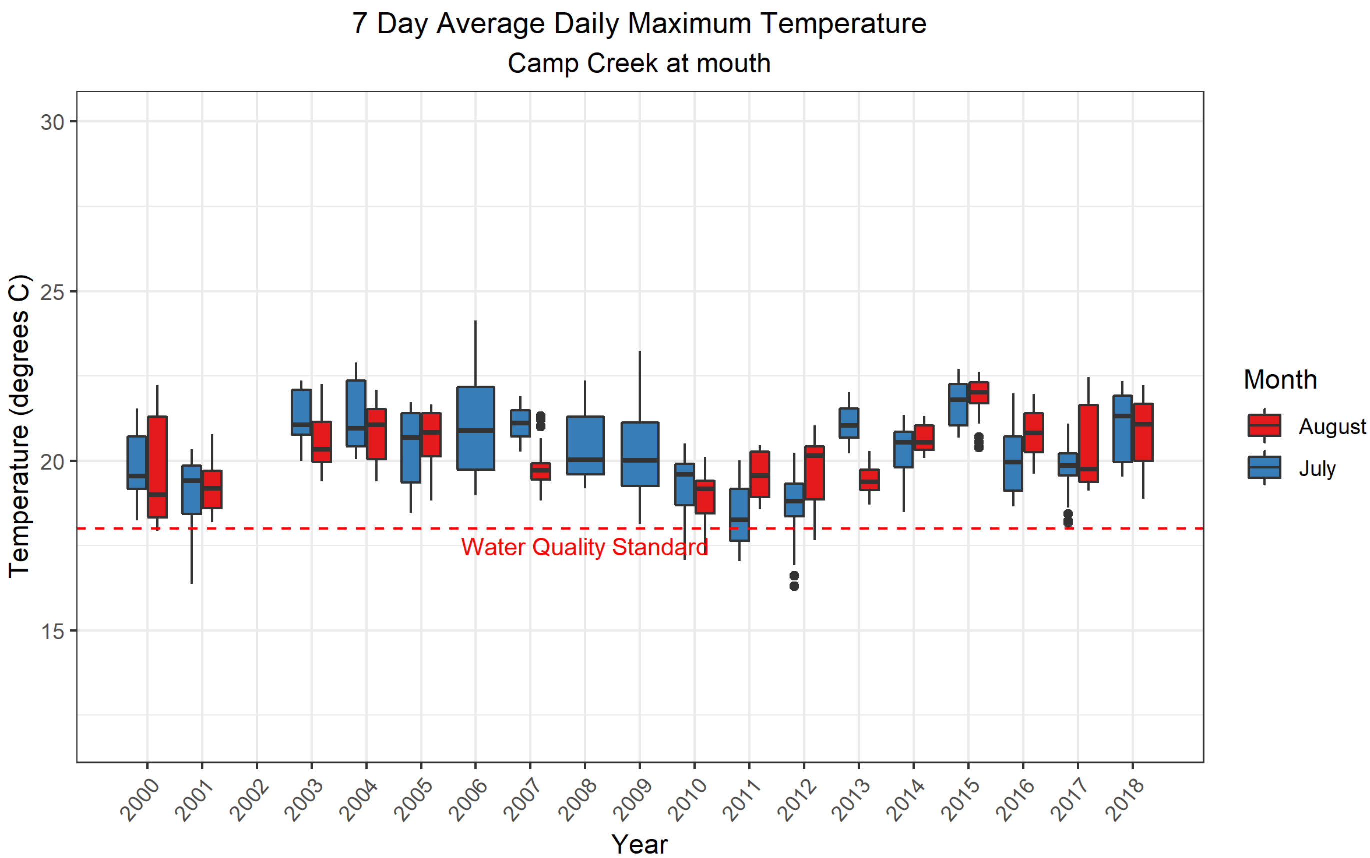


Figure 6. Pritchard (2018) DEQ trend analysis of reference stream temperature data using a Seasonal Kendall trend analysis (Hirsch and Slack, 1984). Since the dataset began on July 1 for many of the earlier years of survey, for this project, the seven day average daily maximum stream temperature is described as the first date in the rolling period (Note: If more than one day of data is missing or did not meet DEQ criteria, the entire month was removed from the analysis (however, that did not affect the analysis for the 7DAM stream temperature used in this paper). (Page 1 of 5)



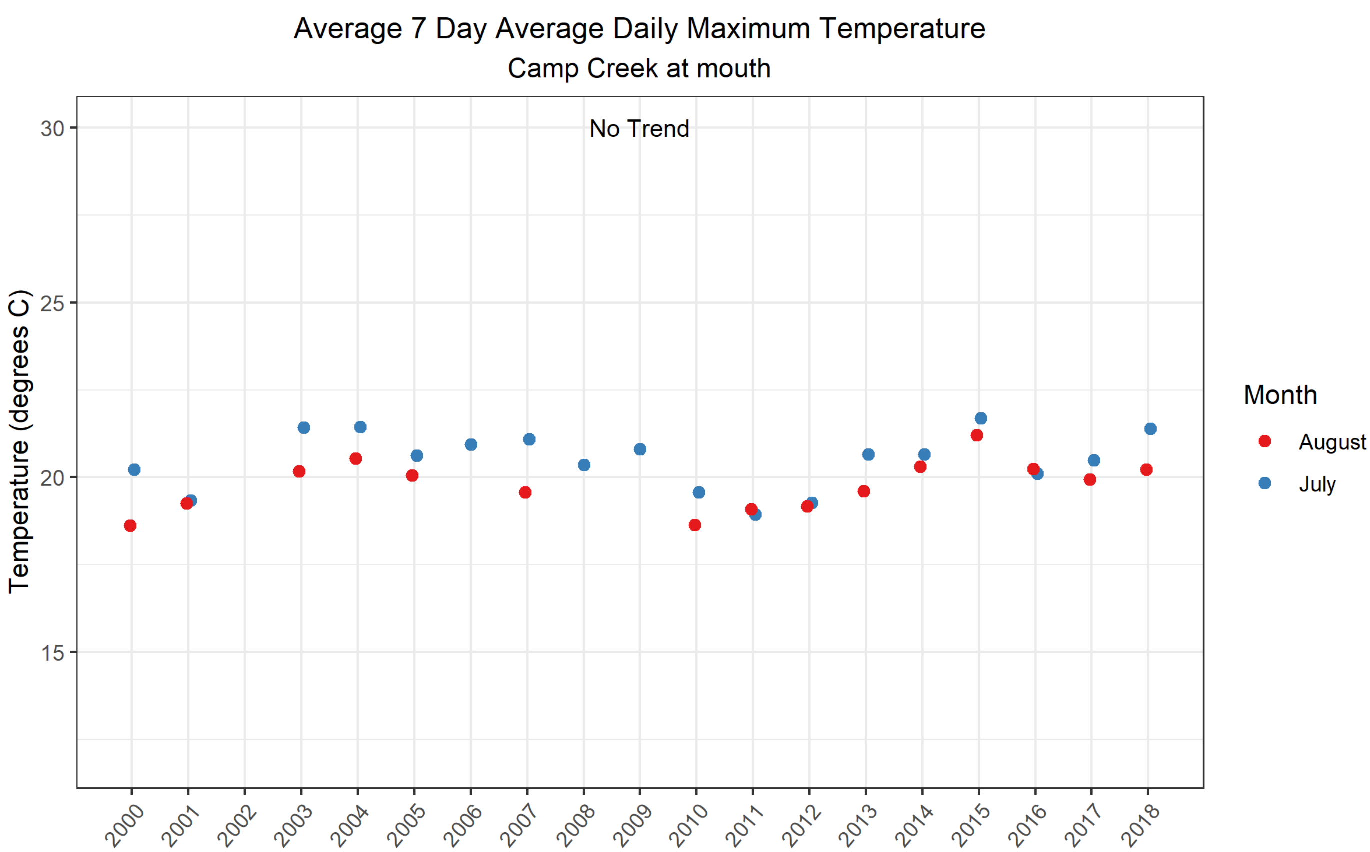
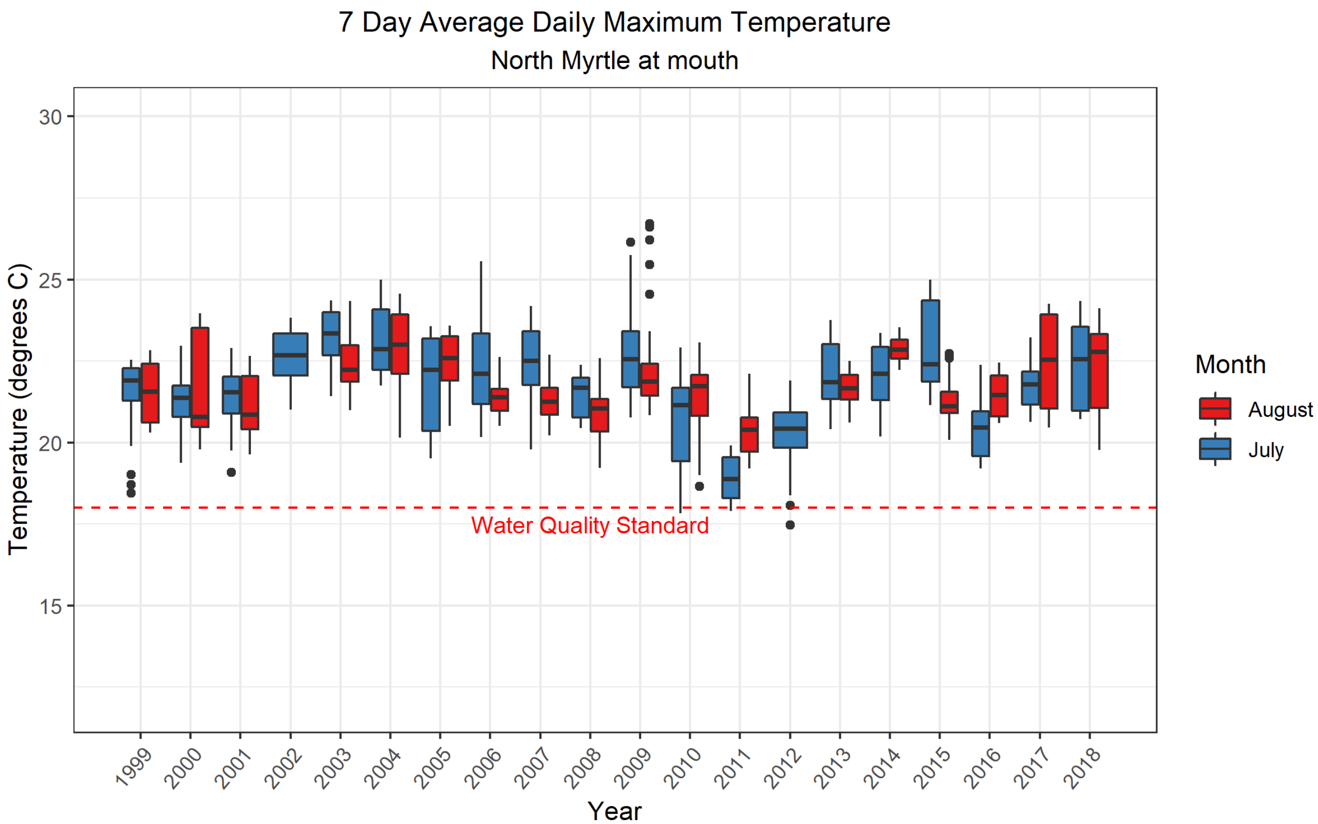


Figure 6. Continued. (Page 2 of 5)



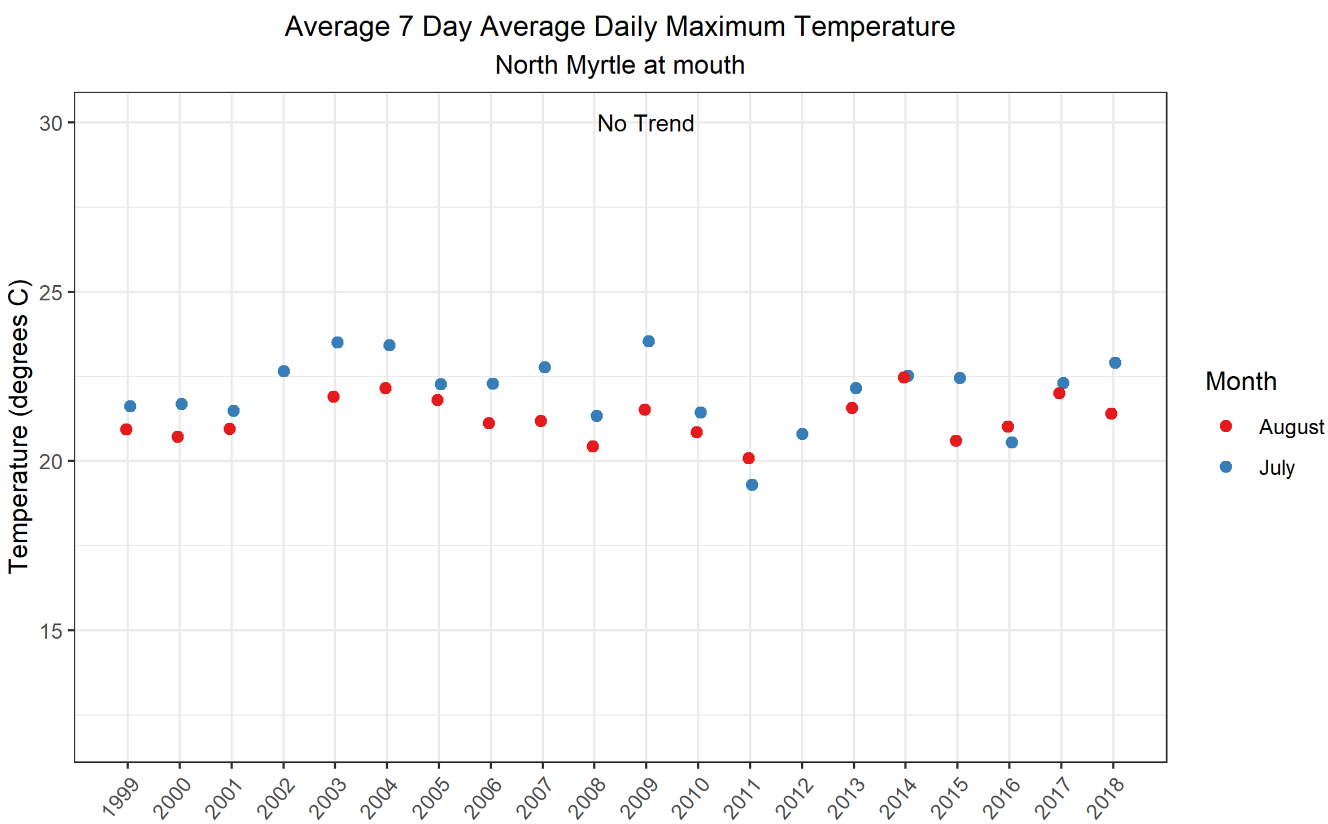
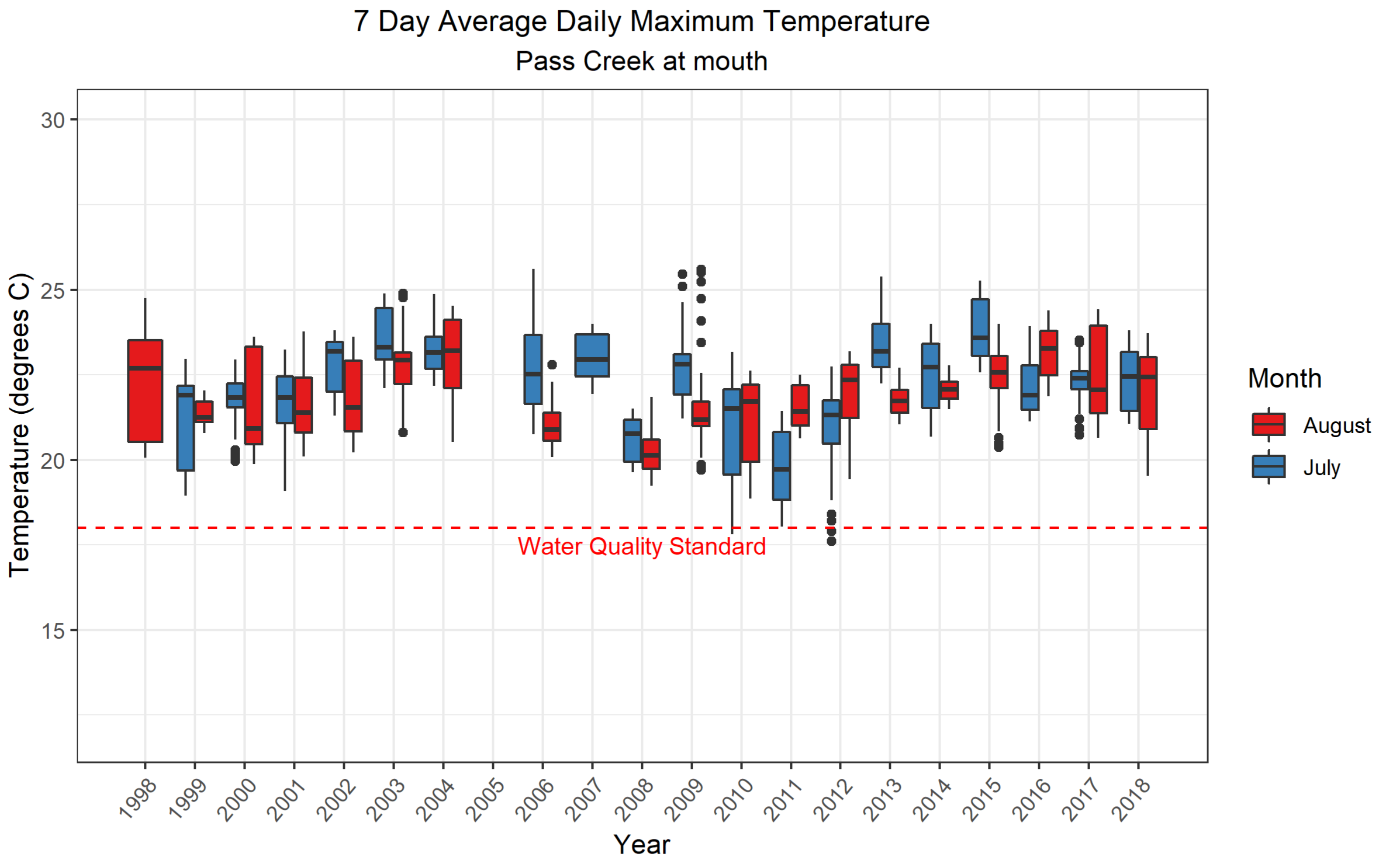


Figure 6. Continued. (Page 3 of 5)



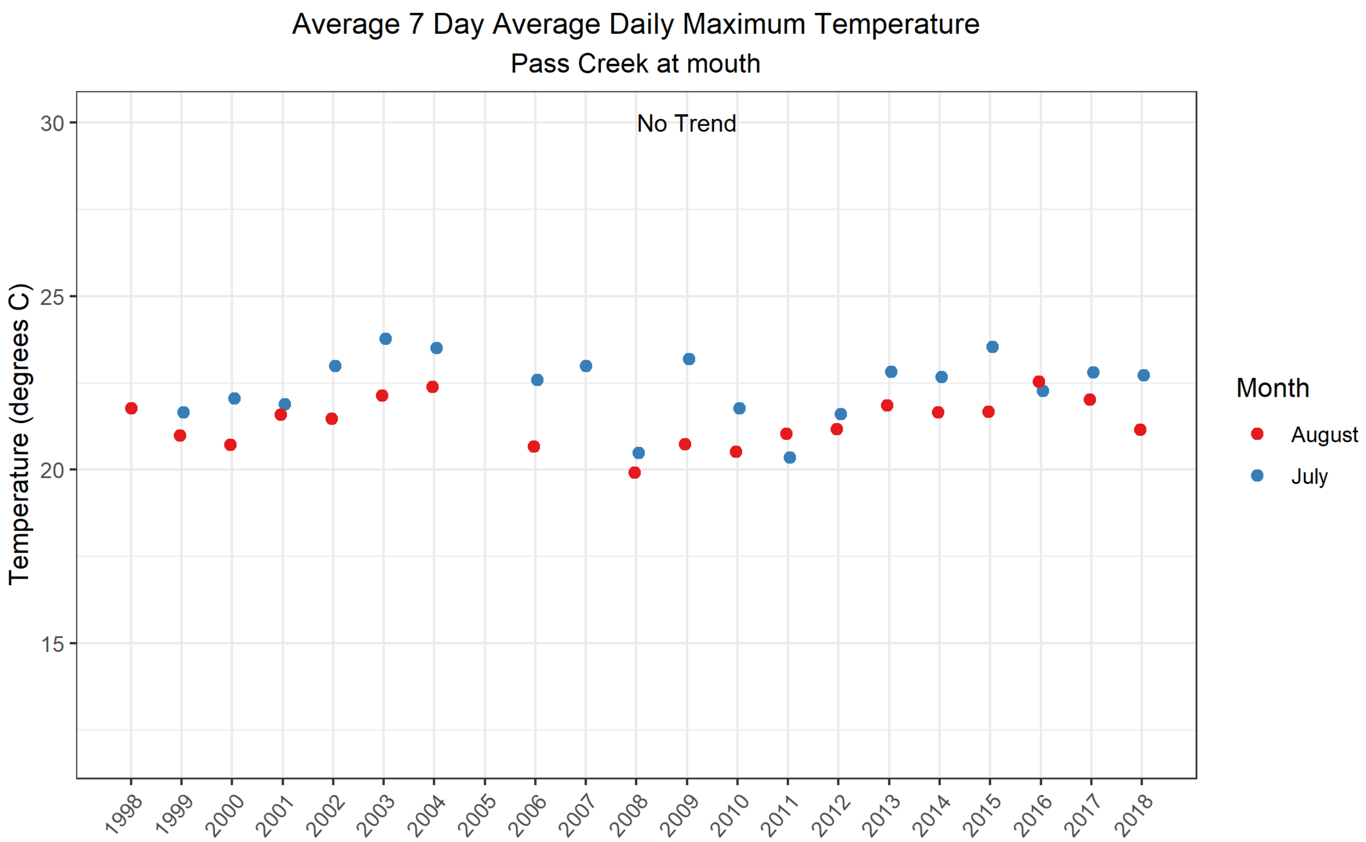
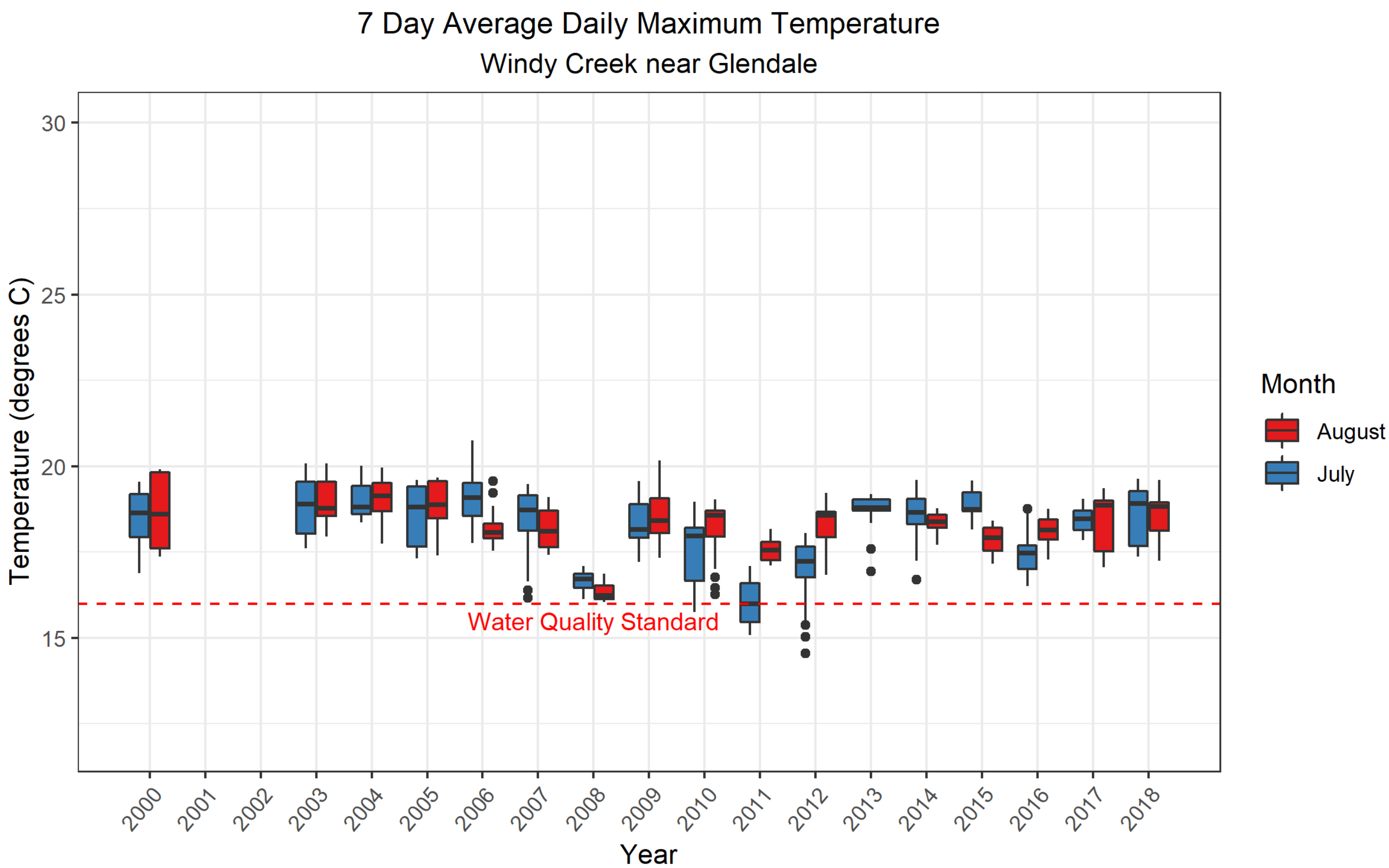


Figure 6. Continued. (Page 4 of 5)



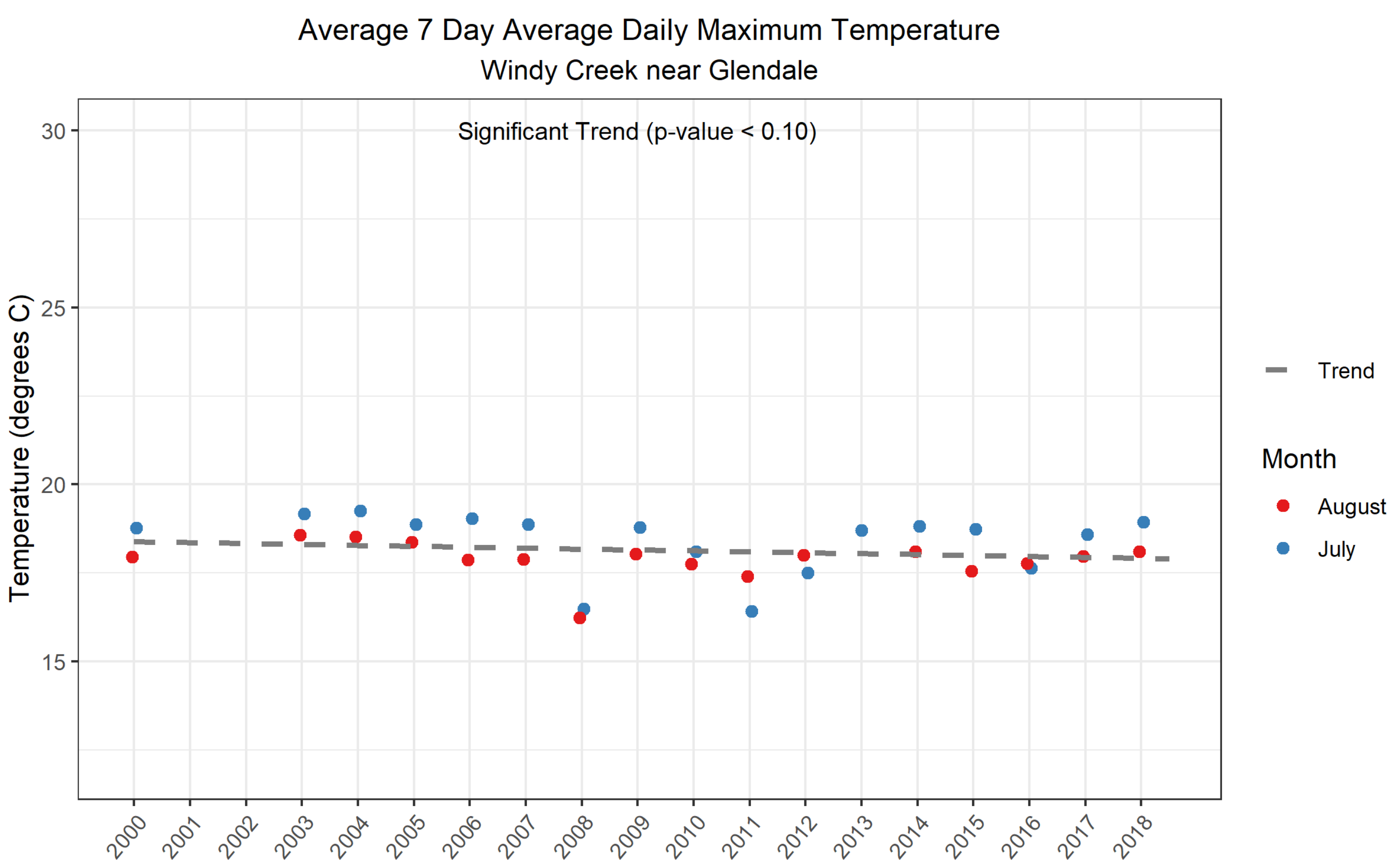
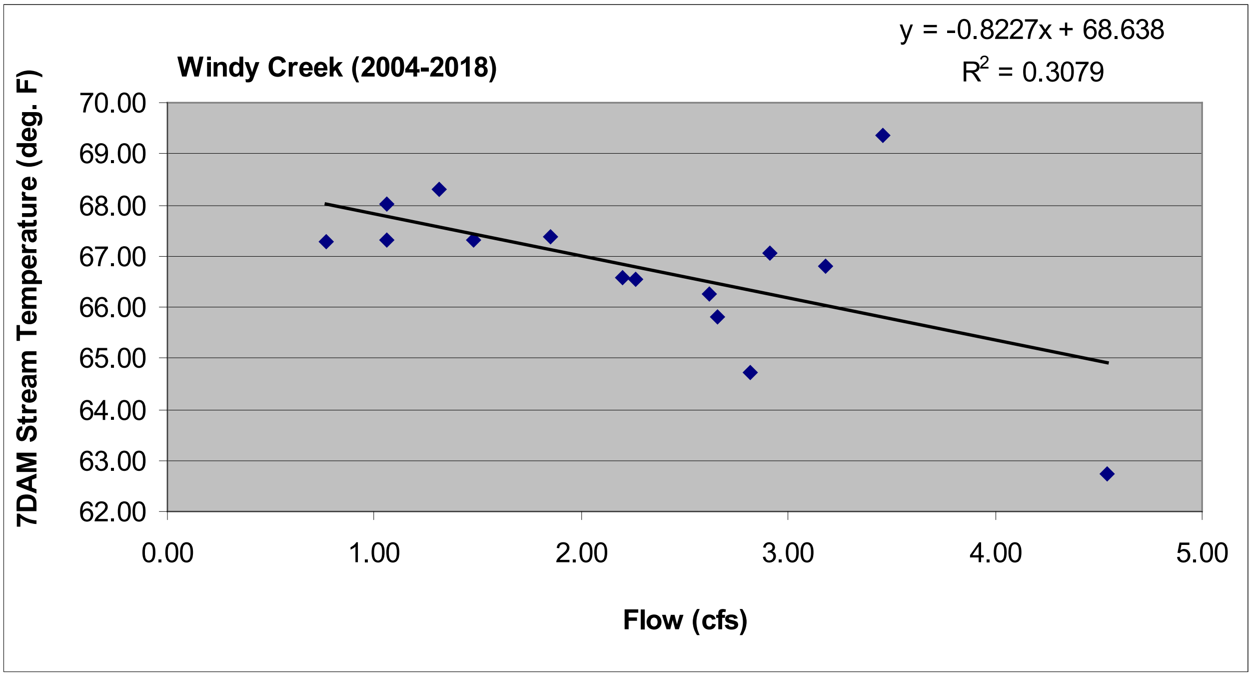


Figure 6. Continued. (Page 5 of 5)



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.

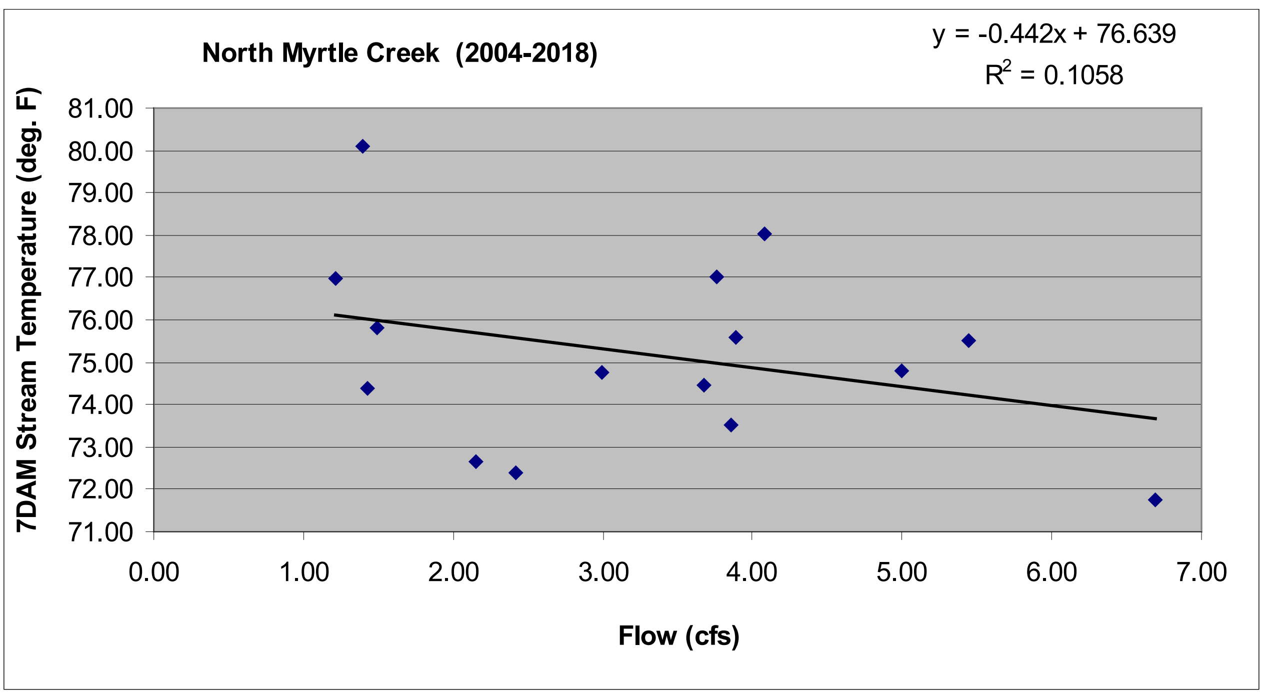
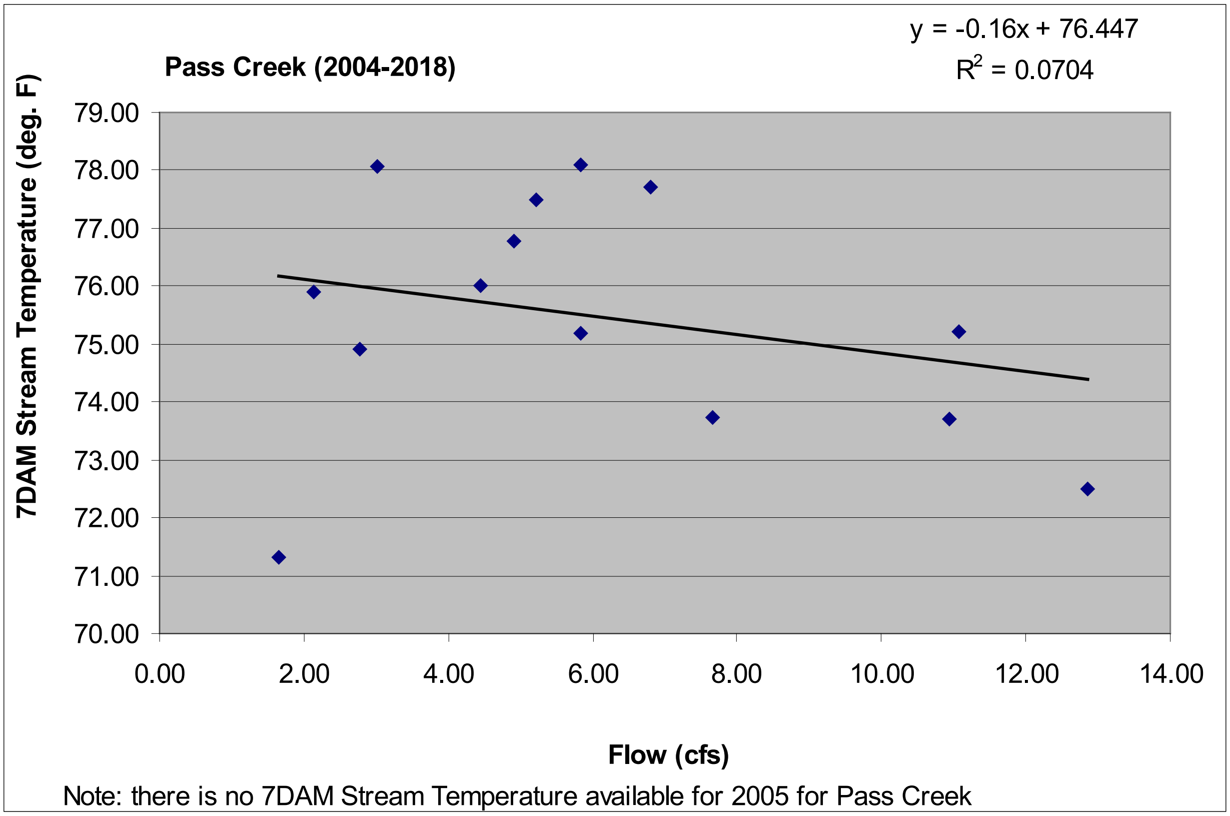


Figure 7. 2004-2018 Reference site 7DAM stream temperatures compared to flows on that day. Stream flows from OWRD (Umpqua Basin Watershed Council {PUR}, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2013; PUR, 2014, 2015, 2016, 2017, and 2018). (Page 1 of 3)



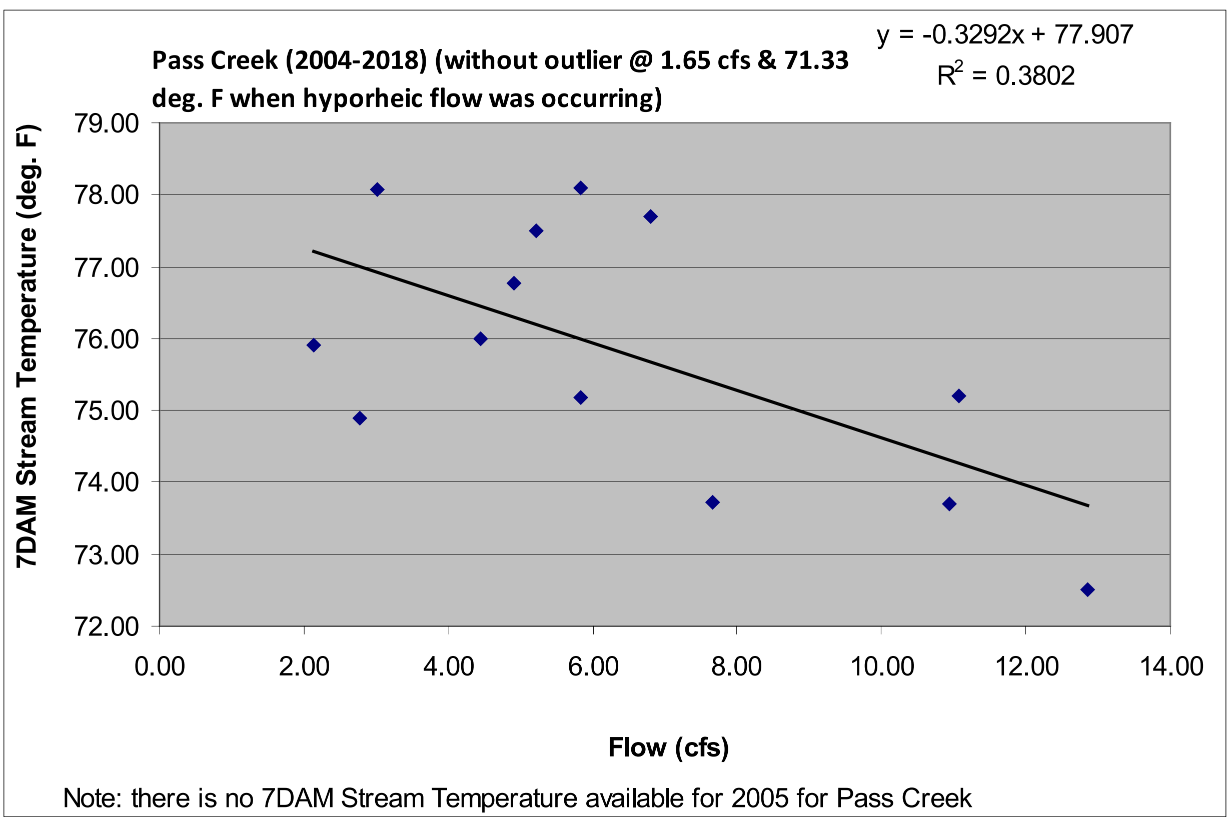
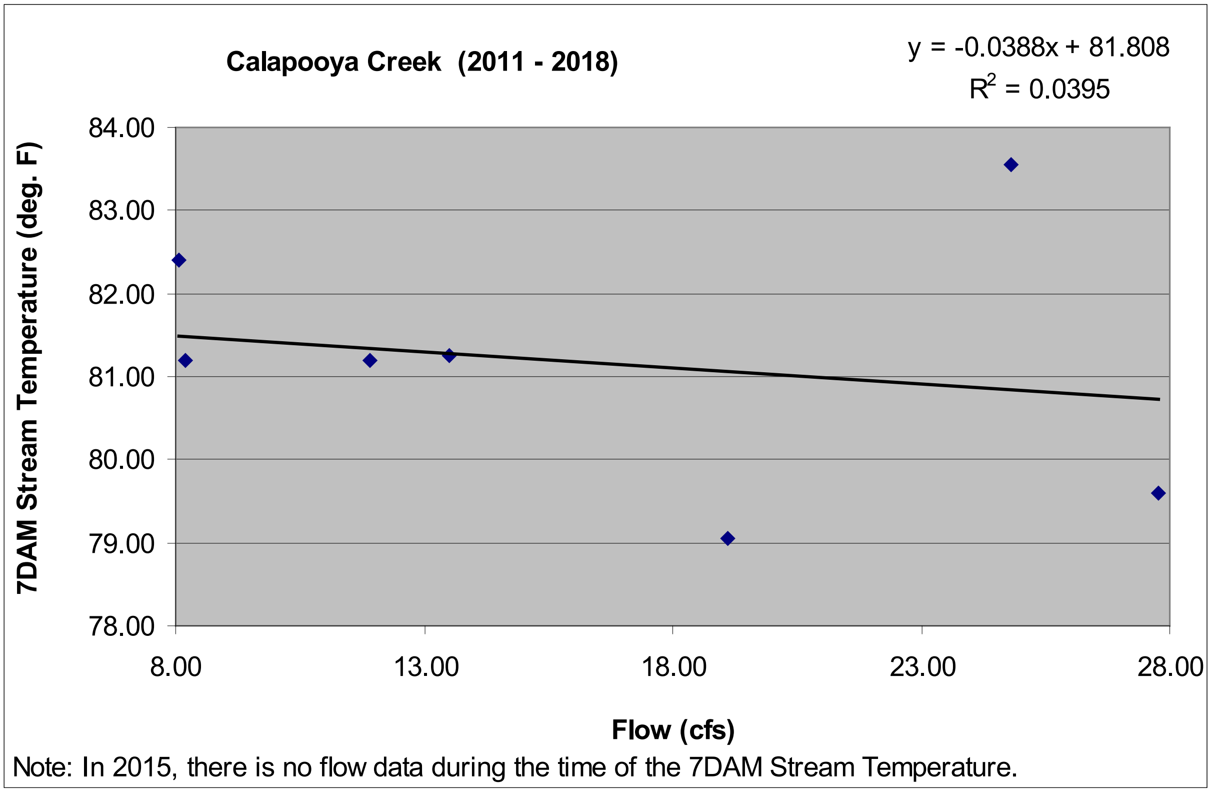


Figure 7. Continued. (Page 2 of 3)



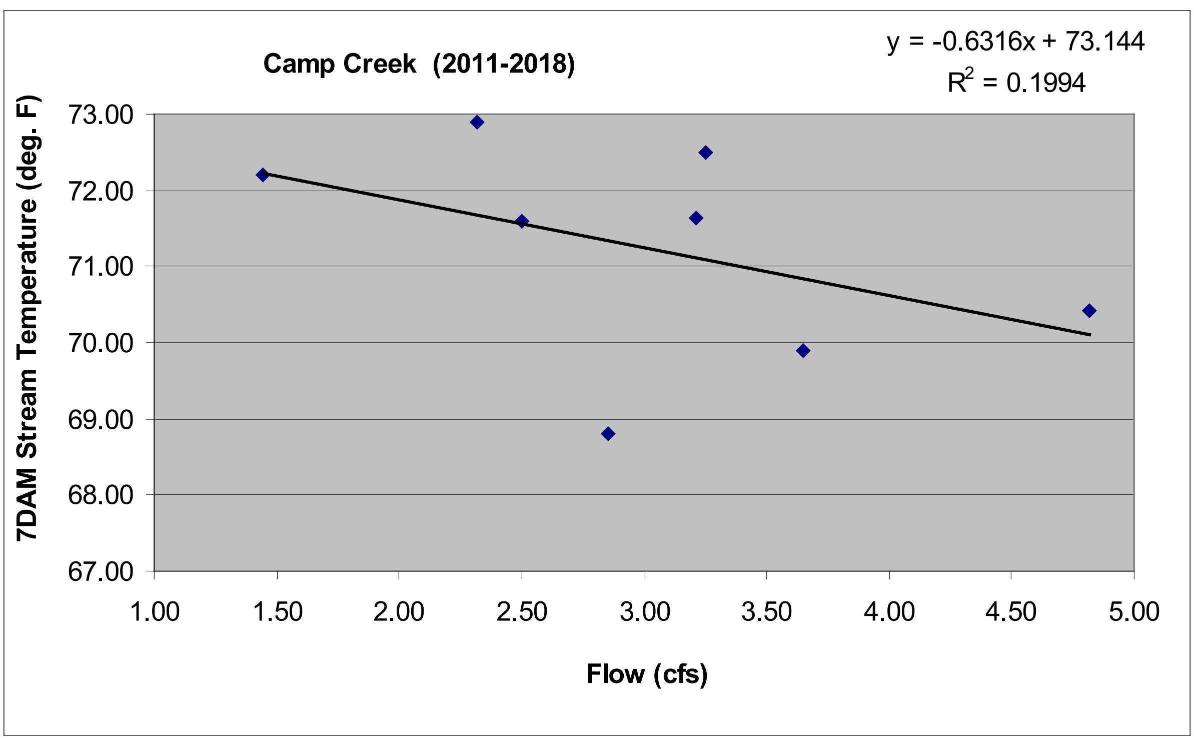
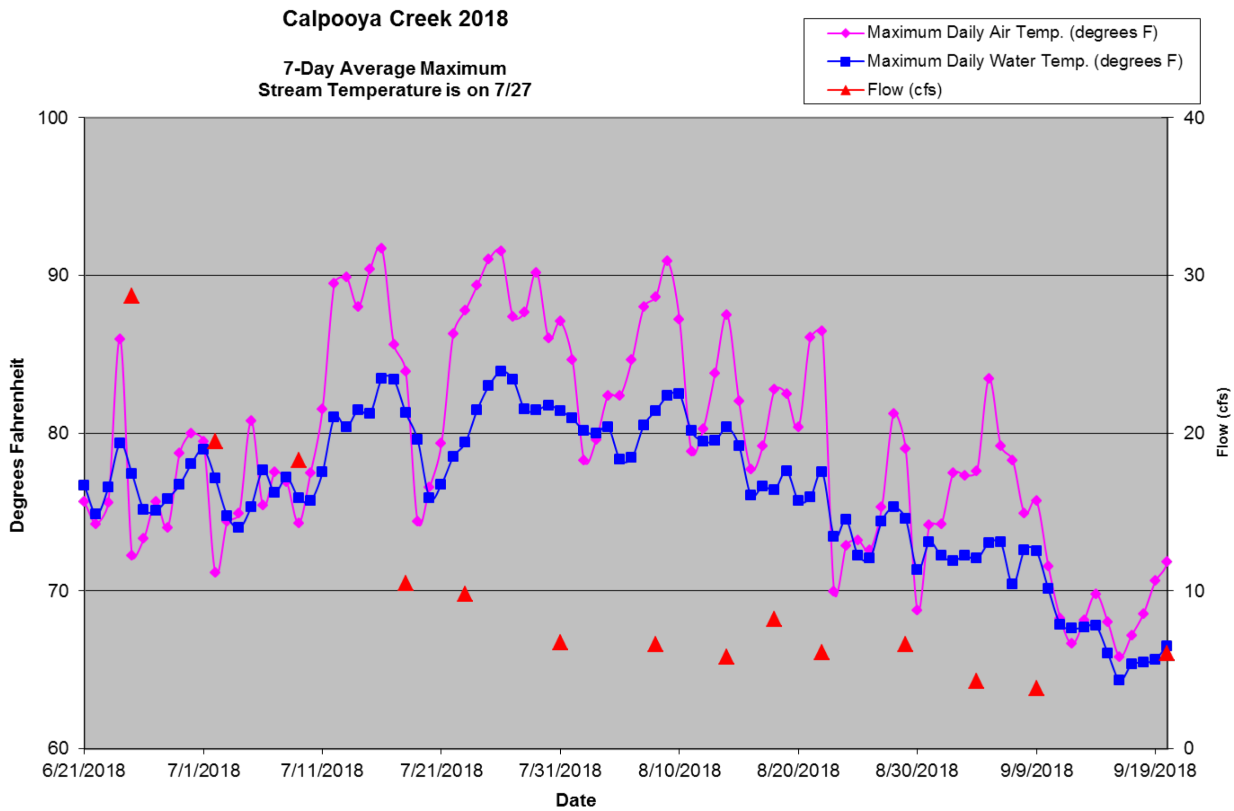


Figure 7. Continued. (Page 3 of 3)



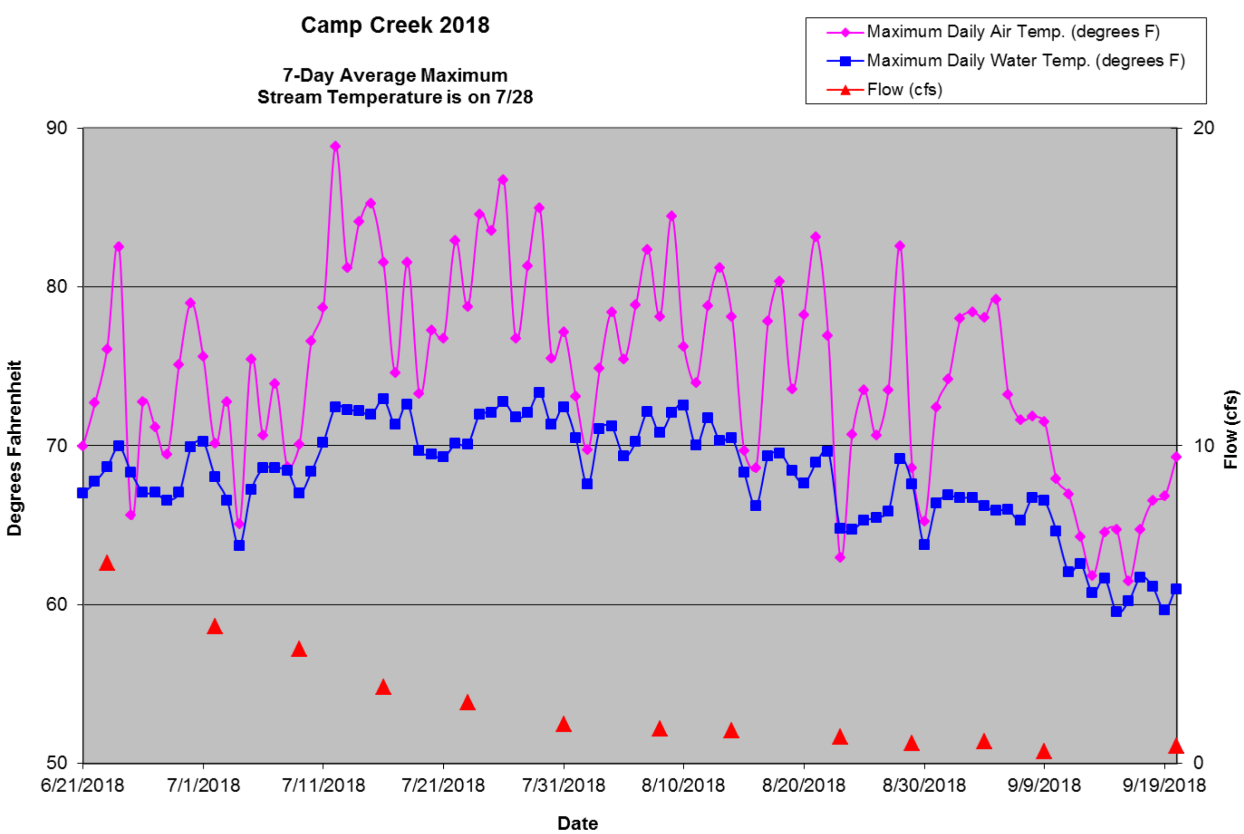
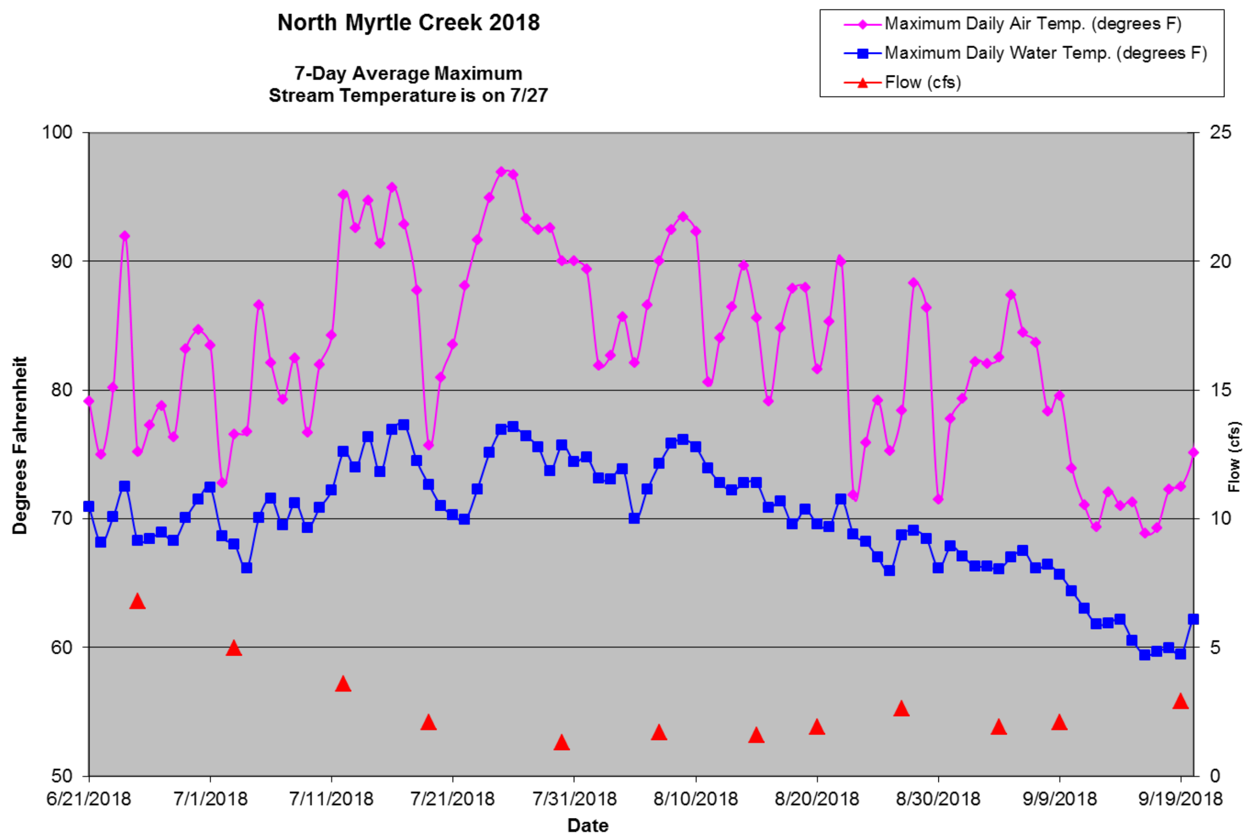


Figure 8. Maximum daily air temperature and flow compared to maximum daily stream temperature for the five reference sites for 2018. (Page 1 of 3)



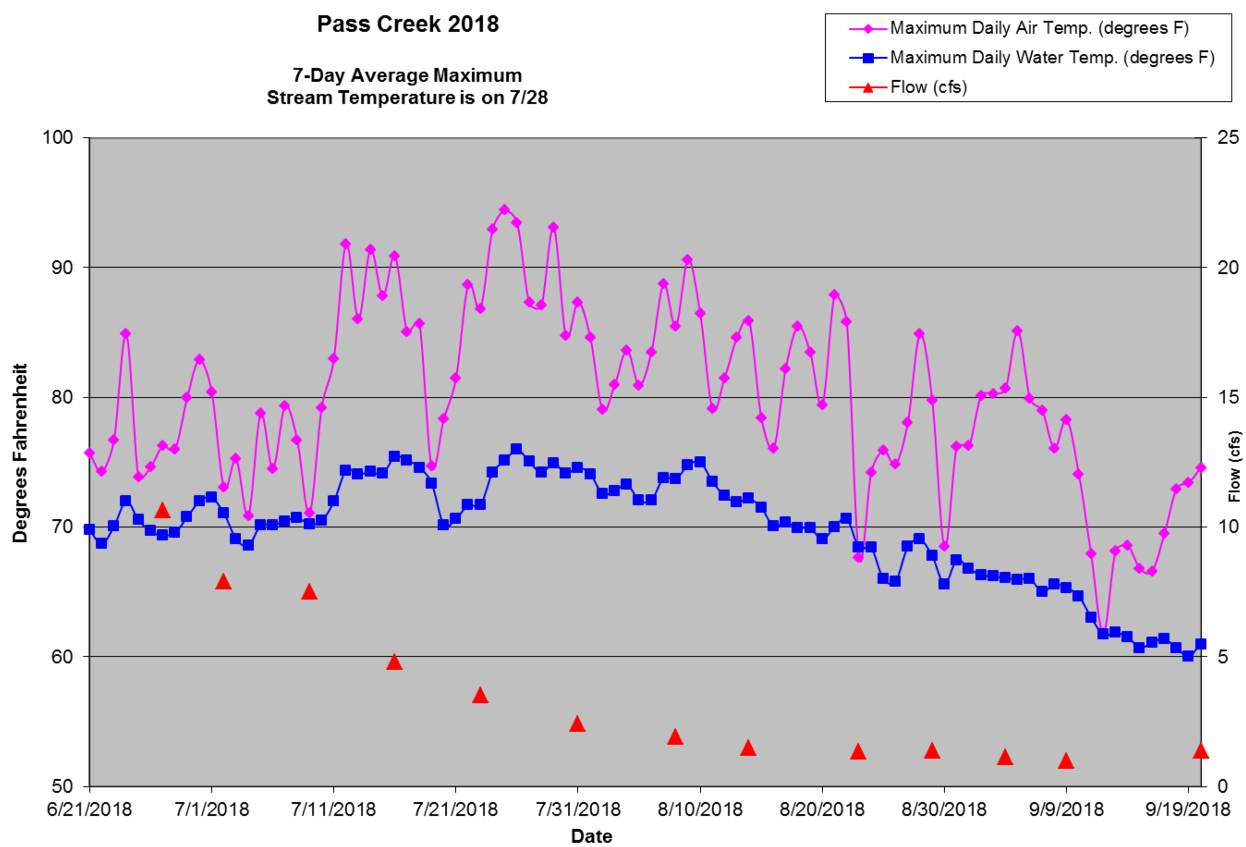


Figure 8. Continued. (Page 2 of 3)

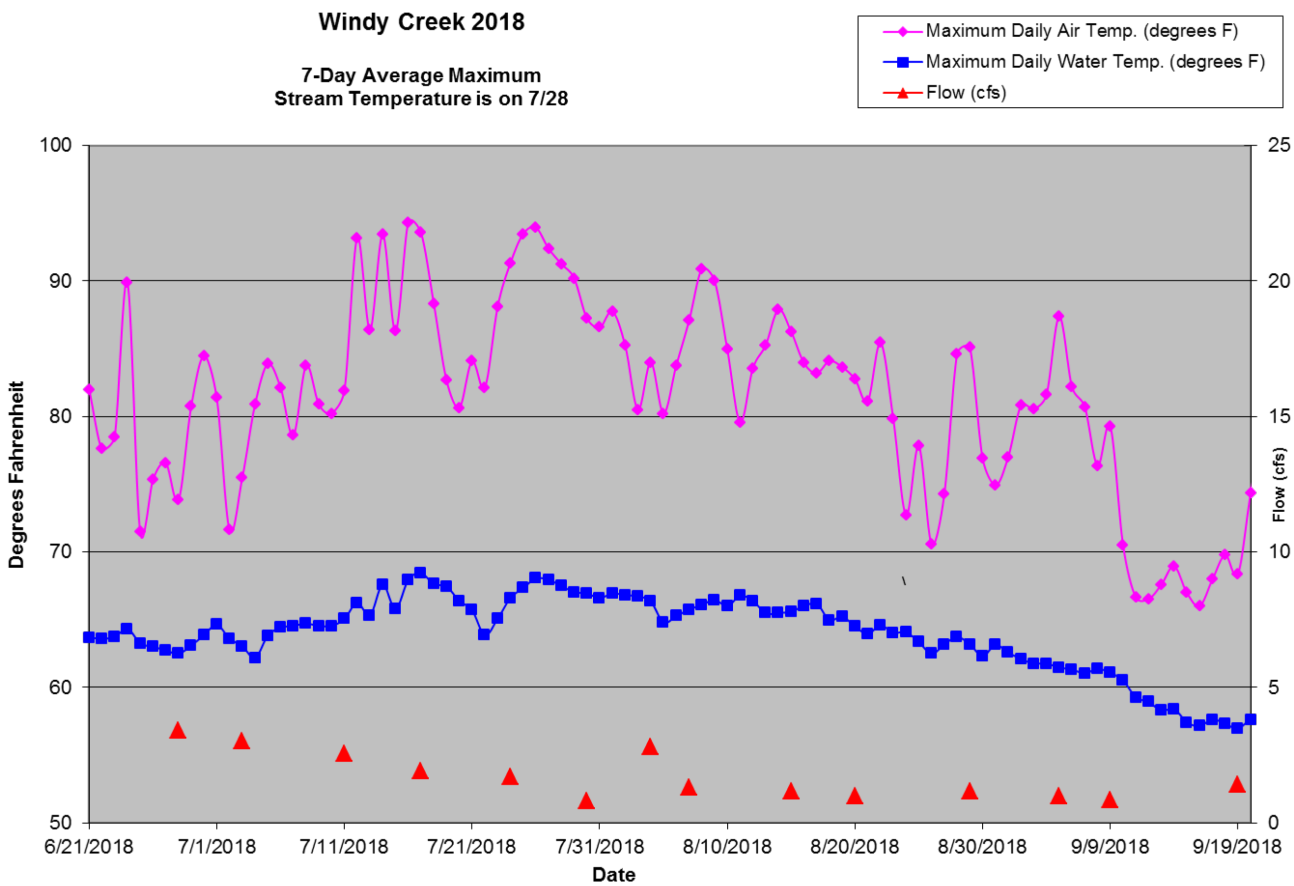


Figure 8. Continued. (Page 3 of 3)

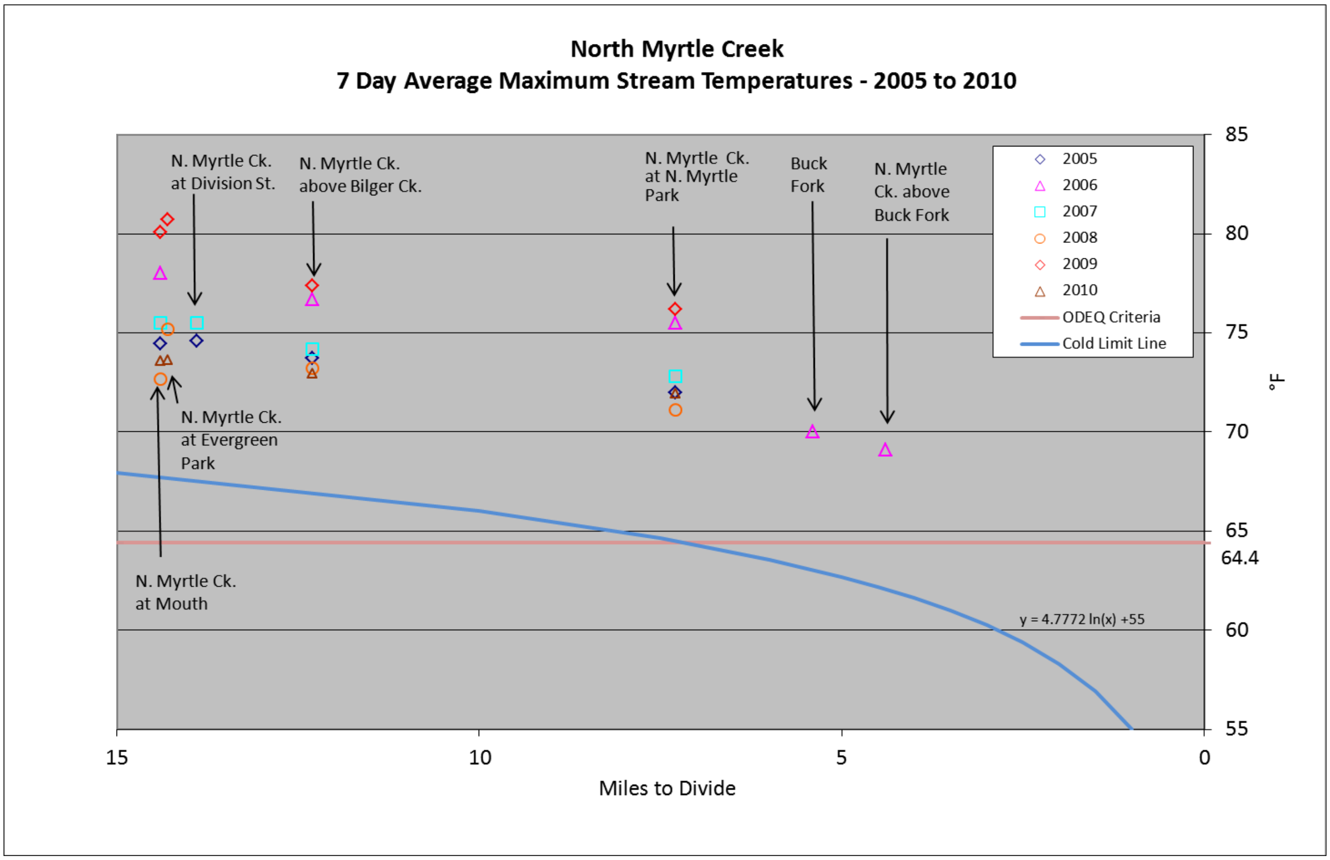
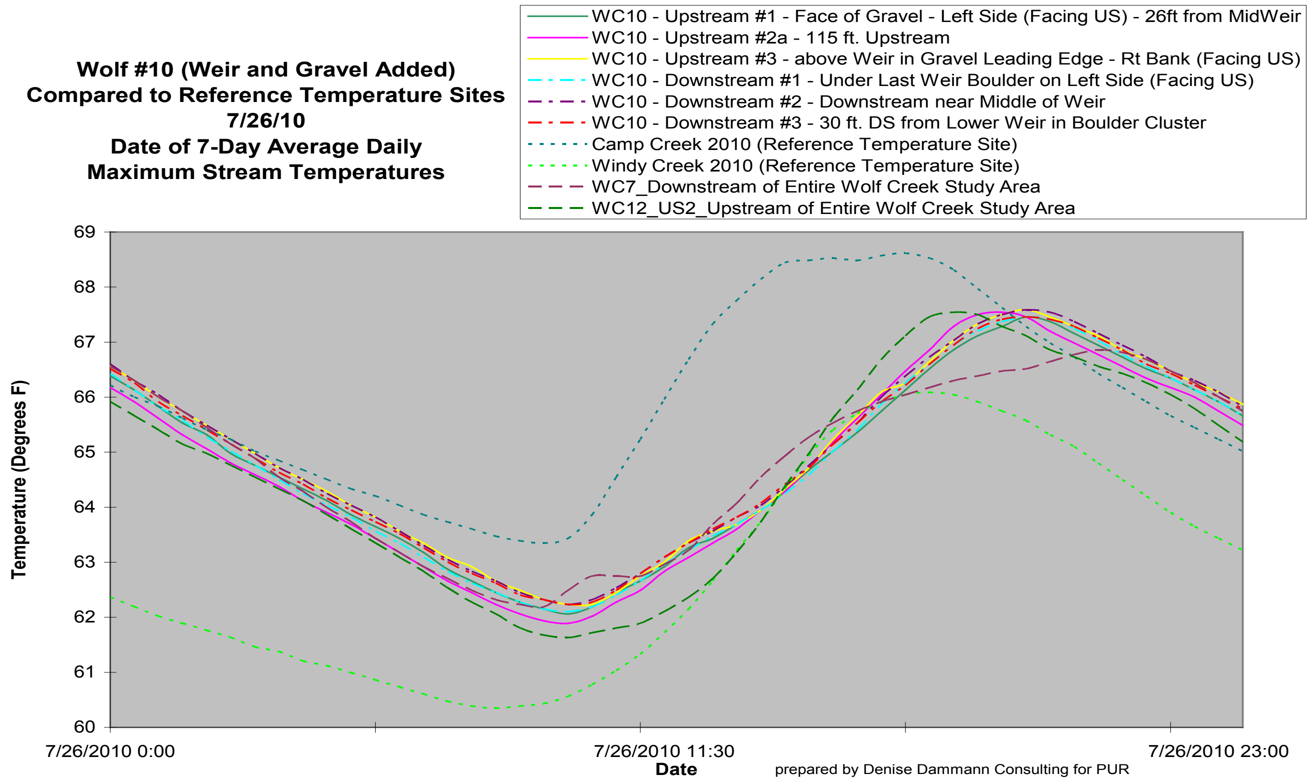


Figure 9. An example of using the North Myrtle Creek reference temperature site data for comparing to other sites in the basin, from Lyon, Smith, and Dammann (2012): North Myrtle Creek 7-day average maximum stream temperatures from 2005-2010 and corresponding land use map. Buck Fork is included since it has a similar distance to divide, drainage area, and flow as North Myrtle Creek at the confluence. The temperature criteria for streams in the Myrtle Creek area, which is designated salmon and trout rearing and migration use, is 64.4°F (ODEQ, 2003) and (ODEQ, 2011). The cold limit line represents the optimal stream temperatures for streams in the South Umpqua sub-basin as distance to the ridgeline divide increases (Smith, 2003). The North Myrtle Creek (at the mouth) Reference Site is a long-term stream characterization monitoring site (Smith, 2005), (Dammann and Smith, 2006), (Dammann, 2007, 2008, 2009, and 2010).



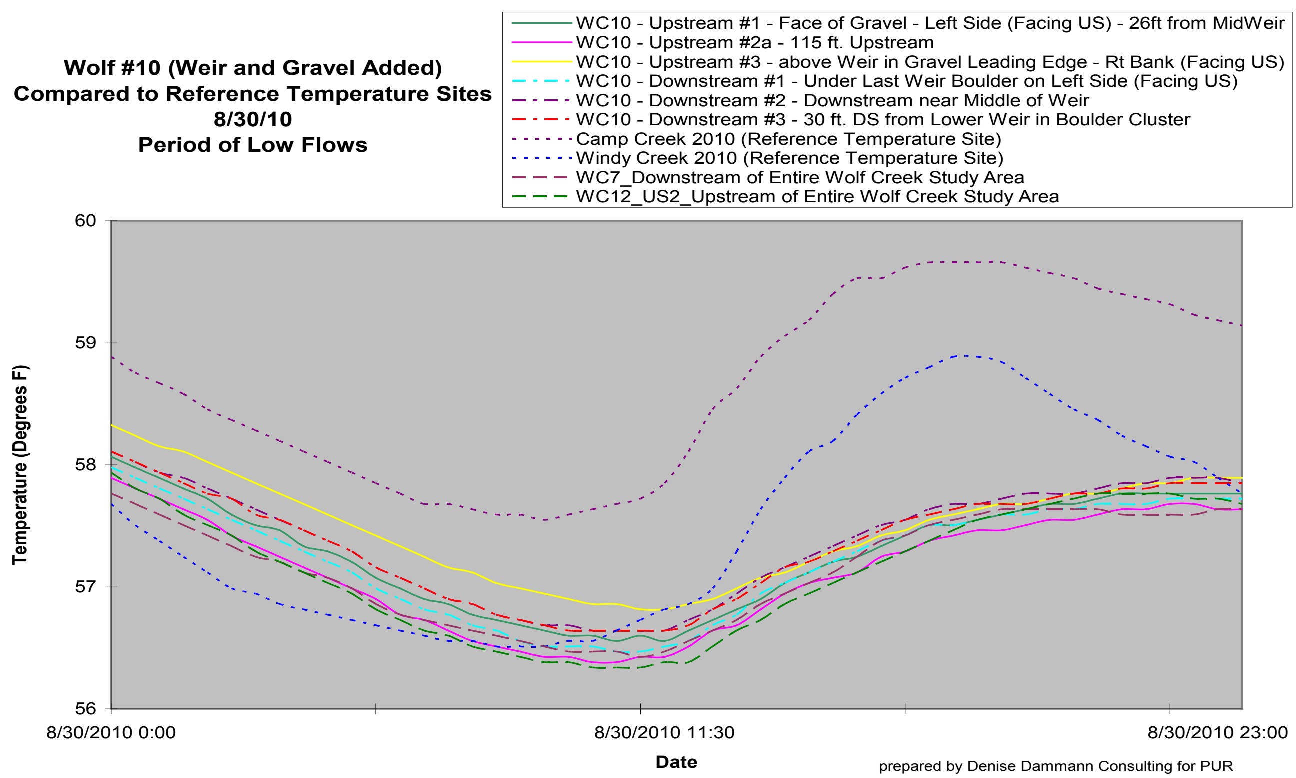
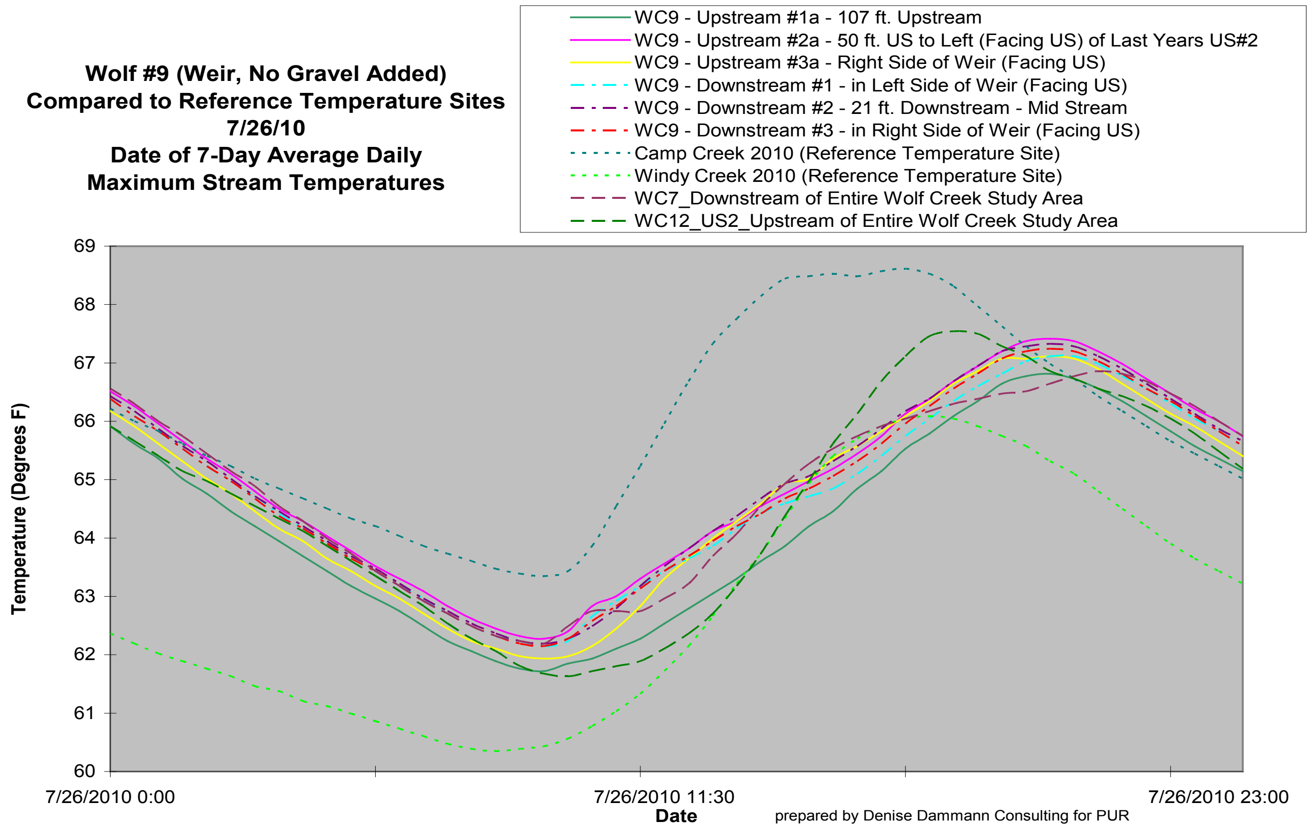


Figure 10. An example of using reference temperature data for comparing to other sites in the basin. 2010 Wolf Creek Restoration Sites #10 and #9 weir with gravel augmentation and weir without gravel augmentation compared with Reference Temperature Data (Dammann, 2010). The Wolf Creek drainage above this site is 17,180 acres, while Windy Creek is 15,260 and Camp Creek is 22,550 for comparison. Flow data used to determine low flow dates are from Oregon Water Resources Department (PUR, 2010). (Page 1 of 2)



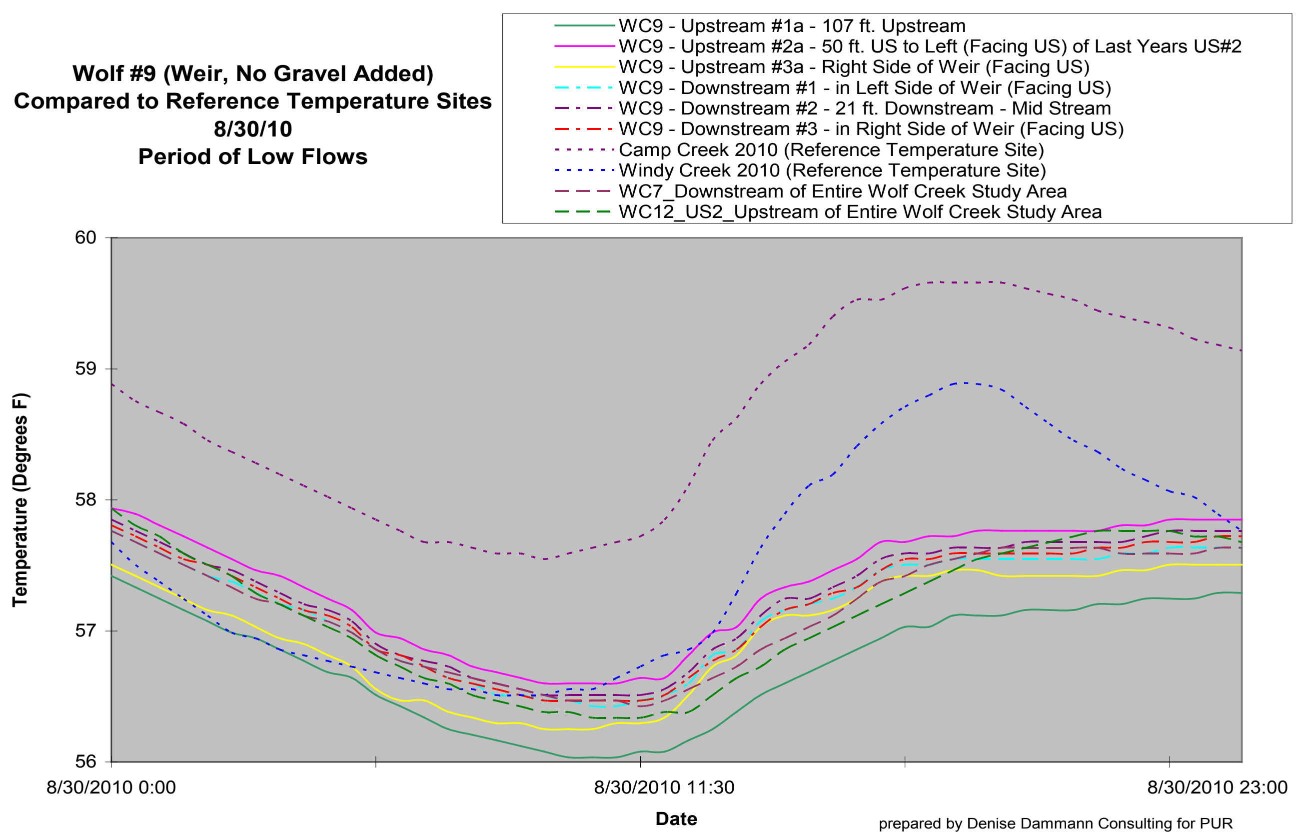


Figure 10. Continued. (Page 2 of 2)

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.

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.

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

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

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. 2018. Iowa Environmental Mesonet. http://mesonet.agron.iastate.edu/wx/afos/.

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.

Lyon, S., K. Smith and D.M. Dammann. 2012. Final Report OWEB Grant 209-2052 PUR Water Quality Monitoring / DEQ Grant 013-10 PUR Water Quality Monitoring & Thermal Refugia Investigation. PUR, Roseburg, OR.

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. 2018c. May 2018 Climate Summary. Medford, Oregon.

National Weather Service. 2018d. June 2018 Climate Summary. Medford, Oregon.

National Weather Service. 2018e. July 2018 Climate Summary. Medford, Oregon.

National Weather Service. 2018f. August 2018 Climate Summary. Medford, Oregon.

National Weather Service. 2018g. September 2018 Climate Summary. Medford, Oregon.

Natural Resource Conservation Service (NRCS). 2018. Oregon Basin Outlook Report: June 1, 2018. Portland, Oregon.

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. 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). 2014. Streamwalker – Summer 2014 Final Report. Roseburg, Oregon.

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

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

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

PUR. 2018. Streamwalker – Summer 2017 Final Report. Roseburg, Oregon.

Pritchard, T. 2018. (Unpublished) DEQ Trend Analysis of Umpqua Basin Reference Temperature Data. 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.

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.