Umpqua Basin Watershed Council

Use of a Control Site to Reduce Inter-Year Variability in Stream Temperature Data in the Umpqua Basin

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Summary:

This report compares summer stream temperature data from six locations in the North Umpqua Watershed over a period of four years. The simple average of the ratios of the daily maximum and minimum values with corresponding values in a control stream over a 50-day period appear to effectively reduce the inter-year variability in the stream temperature data. These ratios can serve as an index of the heating characteristics of the individual sites and can facilitate the comparison of data from different years.

The Problem:

Stream temperature often is identified as an important parameter when assessing watershed conditions. The development of thermistor type data loggers has made the collection of large quantities of digital data possible. In the Pacific Northwest, stream temperatures in the late summer months are often of interest and seasonal data files of the order of 4000 readings can be easily collected at a point of interest.

Figure 1 shows a pair of typical patterns from the Umpqua Basin for a given year. Note the similarity between the patterns, suggesting that both sites are responding to similar conditions. The differences in the data between these sites are an indication of the relative thermal response of each site to prevailing conditions and are of particular interest for stream temperature assessment.

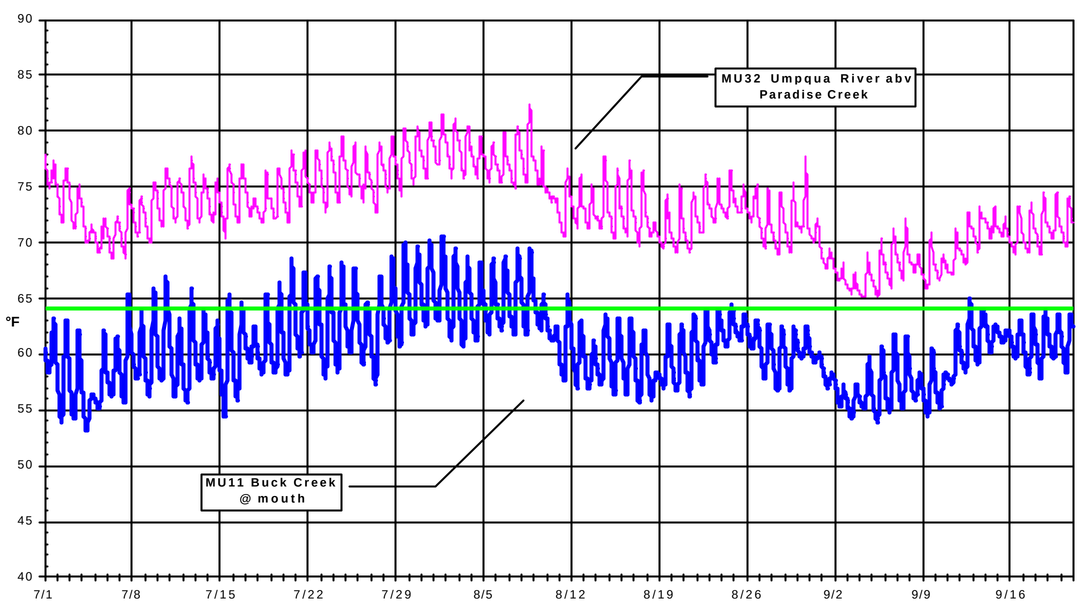


Figure 1 Typical data from year 2000.

Figure 2 shows the temperature response of a typical site for three different summer seasons. The changes between seasons are due to different weather patterns and streamflow conditions as well as any change in the physical condition of the site. This variability makes it difficult to compare the thermal response of different sites for different years.

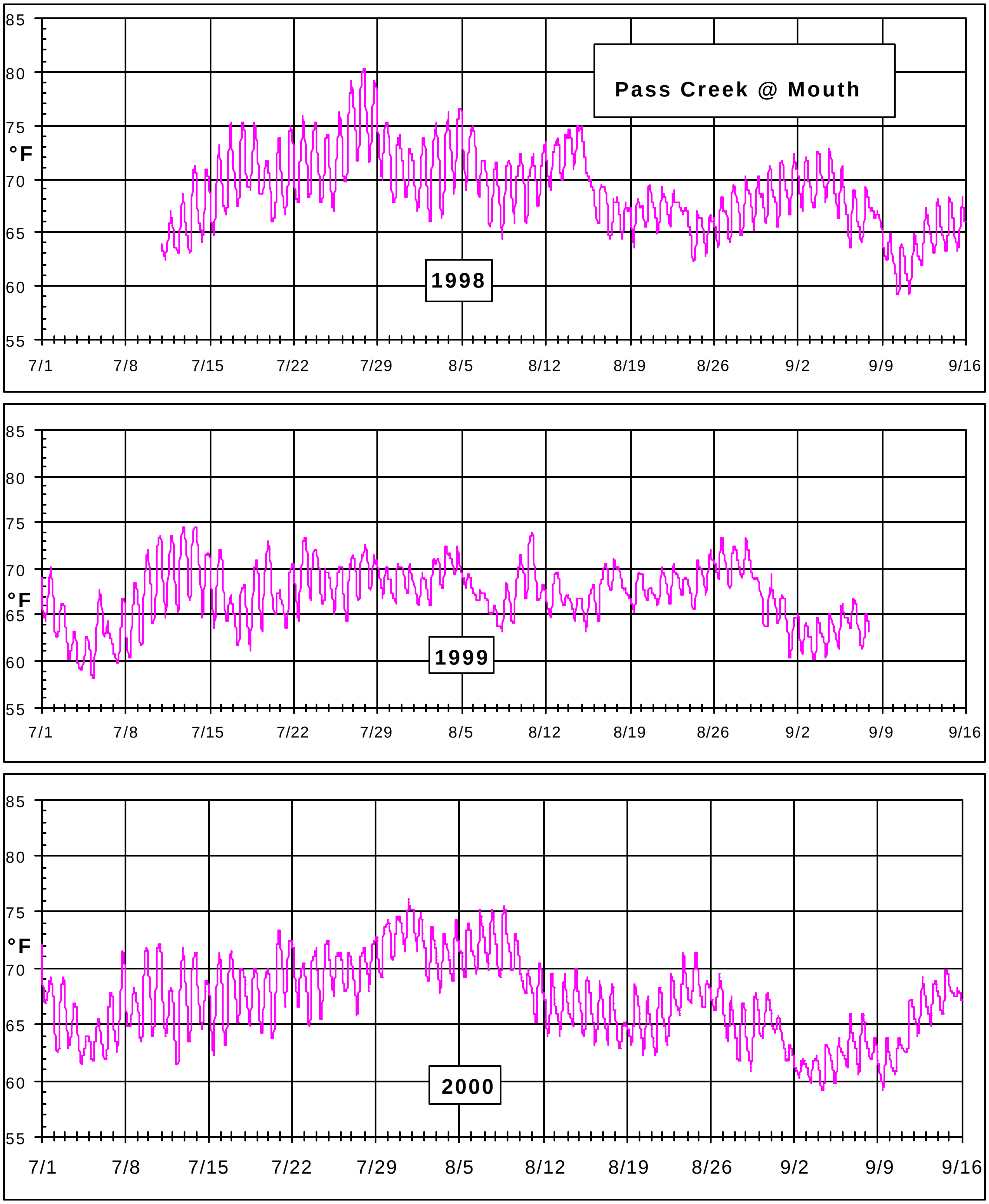


Figure 2 Three years of data from one monitoring site.

The goal is to develop an index that quantifies the relative thermal response of a site that is independent of the year of collection.

Rationale: Stream heating is a complex process with many factors that influence the final temperature. The basic principals are well understood and there are many models that attempt to predict stream temperature for a given set of conditions. The limitation of the models often is directly related to the difficulty of obtaining sufficient accurate data to fully describe the thermal response of the various components. An empirical approach compares the actual net effect of these factors under changing conditions.

The similarities between the graphs of the empirical data suggest that a simple relationship may exist between them and the use of one site as a control may effectively reduce some of the variability. The use of a control site to reduce inter-year variability is a common practice for "paired watershed" studies.

Several factors contribute to the seasonal variability and may affect stream temperatures at different locations in different ways. The following is a discussion of the relative significance of these factors.

> ***Solar Path:*** Since the streams have different aspects, topographic features and shade conditions, the relative effect of the changing solar path at the various sites would be different at different times of the summer. To minimize this effect, the same 50-day time interval was used for each year.
>
> ***Flow Conditions:*** Under low flow - high temperature conditions, the interrelationship between surface flow, groundwater inflow and hyporheic flow becomes increasingly important. For example, as surface flow decreases, the proportion of cooler ground water contribution may increase with a corresponding shift in the stream temperature. Likewise, as flow recedes the stream becomes more like a series of interconnected pools that act as small reservoirs relative to the flow passing through them. A consequence of these trends is that the local environment has an increasing influence over the stream temperature.
>
> A basic assumption of this procedure is that the temperature of all of the streams in the same general vicinity (1,000 square miles) is responding in a similar (proportional) manner to the prevailing flow conditions. The accuracy of the results is a measure of the extent that this assumption is true. It is apparent from the results that it is not equally valid for all sites.
>
> ***Local Heat Capacity:*** High temperatures occur in the late summer later than the summer solstice because the earth is still heating more than it is cooling each day and the excess heat accumulates in the environment. At the local level, surface conditions can influence the rate and extent of this accumulation. For instance, a bedrock-dominated system may accumulate heat in a different manner than a soil/gravel riparian zone. These differences would contribute error in this method that may appear as a uniformly changing error over the sample period.

The Method: The procedure used in this report consists of simply finding the average of the ratio of the daily maximums and the daily minimums between the site of interest and a "control site" for the "reference year." The pair of ratios associated with a site can then be applied to the daily maximum and minimum values at the control site for another year to generate the corresponding calculated daily maximum and minimum for the site of interest. In this study, a 50-day interval between July 13 and August 31 was used.

To test this method it was necessary to have multi-year data from several sites that was collected in a consistent manner over the same period. This study used stream temperature data collected over 4 years from six sites on the Umpqua National Forest in the Steamboat Creek area in the North Umpqua Watershed (See Table 1) The data collected in 1997 was selected arbitrarily and used as the "Base Reference Year" and Canton Creek at the mouth was selected arbitrarily as the "Control Site." The 50-day period of July 13 to August 31 was selected as representative of the "high temperature" period for the streams.

Table 1 1997 Average Ratios

Monitoring Site	Daily Maximum		Daily Minimum		Watershed Area
	Average Ratio	Standard Deviation	Average Ratio	Standard Deviation	Square Miles
Canton Creek @ Mouth (Control)	1	na	1	na	62
Steamboat above Canton	1.034	0.015	1.021	0.013	165
Boulder Ck @ mouth	0.927	0.009	0.954	0.007	35
Cedar Creek @ the mouth	0.904	0.011	0.912	0.018	12
Little Rock Creek @ the mouth	0.959	0.006	0.961	0.007	15
City Creek @ the mouth	0.945	0.014	0.929	0.016	10

The ratios Max Site X/Max Control and Min Site X/ Min Control were determined for each day at each site in the 1997 period and are shown in Figure 3.

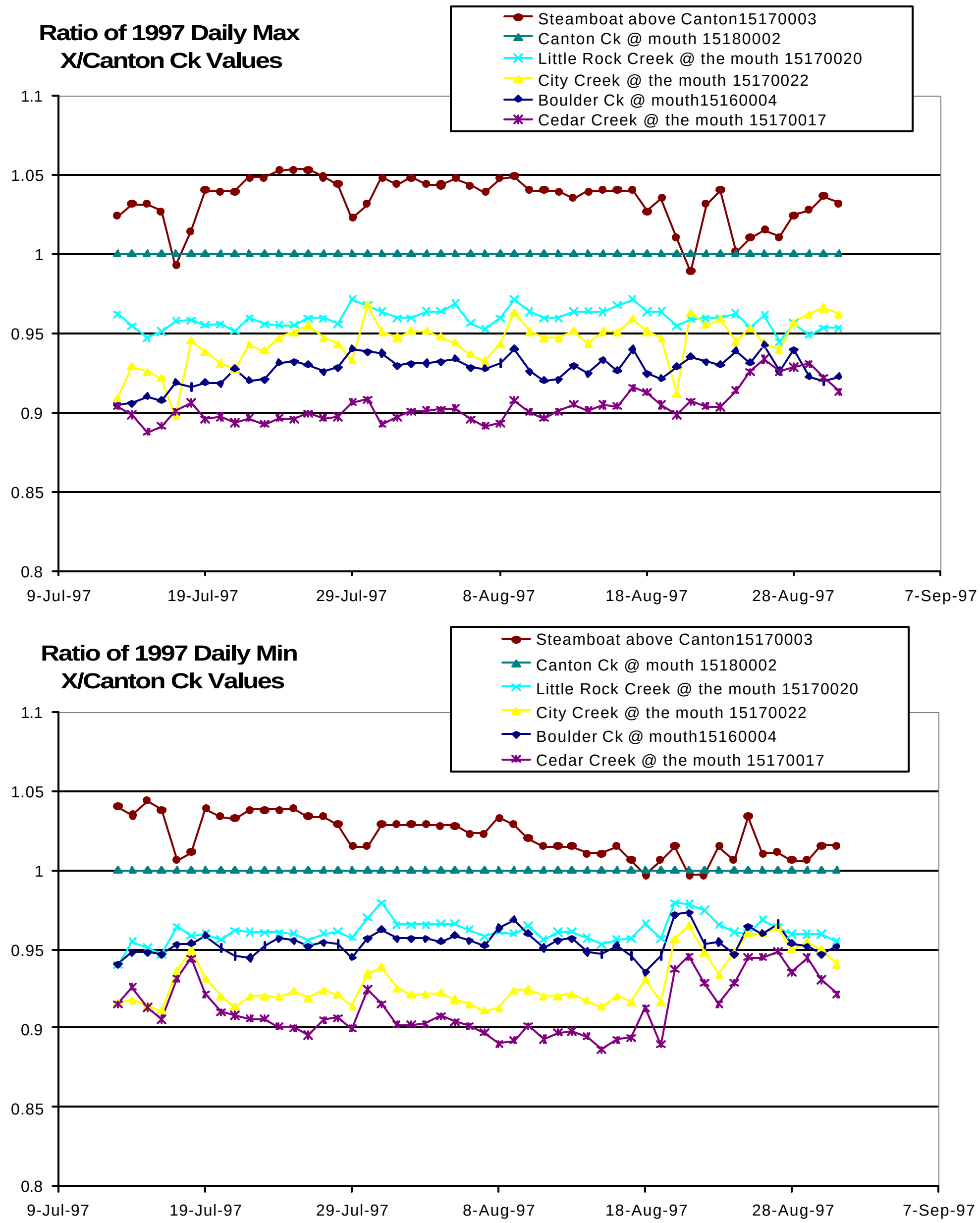


Figure 3 Ratios of 1997 daily maximum and minimum temperatures for several streams compared to the reference stream (Canton Creek).

The average of these ratios over the 1997 50-day interval was determined for each site (Table 1). The standard deviation in the ratio table provides an indication of the quality of the proportional relationship.

The five sets of site ratios were then applied to the control site values for the years 1998-2000 to generate calculated daily maximum and minimum values for each site for the years 1998-2000. The Appendix shows the calculated results compared with the actual stream temperatures measured at the five sites.

Table 3 compares some common summary statistics generated from the calculated values with those generated from the actual temperatures data.

MaxMaxT - Maximum temperature for the period of record for each year (7/13-8/31).
MinMinT - Minimum temperature for the period of record (7/13-8/31).
AveMaxT - Simple average of the daily maximum temperatures.
AveMinT - Simple average of the daily minimum temperatures.
HrAbv64 - The total hours that the stream temperature was above 64 °F for the period of record.
Max7DayAve - The maximum value of the seven-day average of the daily maximums for the period of record.
Note: All temperatures in degrees Fahrenheit

The value for the "Hours above 64 °F" statistic was derived for each day by simple interpolation between the daily maximum and minimum temperatures. Since the time of the daily maximum and minimum was not exactly the same for the control site and the stream of interest, the average difference was determined from the 1997 data and applied to the reference sited data for the subsequent years to get an estimated time for the stream of interest.

Table 2 shows the time correction values used in the calculations.

Monitoring Site	Average Time Shift (hours)			
	Maximum Hours	Standard Deviation	Minimum Hours	Standard Deviation
Steamboat above Canton	0.009	4.090	-0.211	4.123
Boulder Ck @ mouth	-1.774	2.689	-0.004	2.636
Cedar Creek @ the mouth	-0.180	2.652	-1.440	3.138
Little Rock Creek @ the mouth	-0.345	2.768	-0.555	2.440
City Creek @ the mouth	-1.616	2.765	-1.546	3.344

Table 2 Time correction used to compute exceedance hours.

Table 3 Comparison of common seasonal statistics - Actual values Vs Calculated values

1997 **Calibration Year**

Steamboat above Canton	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	77.21	60.66	71.80	64.58	1078	75.53
Calculated Value	76.54	60.41	71.78	64.58	1096	74.76
Difference	0.67	0.25	0.02	0.00	-17	0.77

Boulder Ck @ mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	68.70	55.60	64.36	60.29	287	67.29
Calculated Value	68.62	56.40	64.36	60.30	270	67.03
Difference	0.08	-0.80	0.00	0.00	17	0.26

Cedar Creek @ the mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	66.32	54.12	62.74	57.66	34	64.95
Calculated Value	66.92	53.95	62.76	57.68	54	65.37
Difference	-0.60	0.17	-0.02	-0.02	-19	-0.42

Little Rock Creek @ mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	70.82	55.58	66.59	60.77	555	69.46
Calculated Value	71.00	56.84	66.59	60.77	530	69.35
Difference	-0.18	-1.26	0.00	0.00	25	0.11

City Creek @ the mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	69.32	54.18	65.58	58.71	313	68.23
Calculated Value	69.93	54.93	65.58	58.73	324	68.31
Difference	-0.61	-0.75	0.00	-0.01	-11	-0.07

1998

Steamboat above Canton	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	79.09	71.11	73.57	66.00	1101	77.61
Calculated Value	78.46	69.83	73.16	65.41	1114	76.87
Difference	0.63	1.28	0.41	0.59	-13	0.75

Boulder Ck @ mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	71.11	66.13	66.80	62.26	667	70.09
Calculated Value	70.35	65.20	65.59	61.07	498	68.92
Difference	0.76	0.93	1.21	1.20	168	1.17

Cedar Creek @ the mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	67.78	62.85	63.95	58.64	214	66.61
Calculated Value	68.61	62.37	63.97	58.42	213	67.21
Difference	-0.83	0.48	-0.02	0.22	0	-0.60

Little Rock Creek @ mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	72.62	66.41	67.89	61.81	721	70.95
Calculated Value	72.79	65.71	67.87	61.54	679	71.31
Difference	-0.17	0.70	0.02	0.27	41	-0.36

City Creek @ the mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	72.60	63.49	68.00	59.85	592	70.77
Calculated Value	71.69	63.50	66.84	59.48	473	70.23
Difference	0.91	-0.01	1.16	0.37	119	0.53

Table 2 Continues

1999

Steamboat above Canton	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	75.35	66.70	70.82	63.21	835	73.95
Calculated Value	74.36	68.05	71.16	64.73	927	72.72
Difference	0.99	-1.35	-0.34	-1.52	-92	1.22

Boulder Ck @ mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	66.42	63.23	62.33	58.51	117	65.29
Calculated Value	66.67	63.53	63.65	60.08	190	65.20
Difference	-0.25	-0.30	-1.32	-1.57	-72	0.09

Cedar Creek @ the mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	64.57	60.29	62.08	57.10	13	63.83
Calculated Value	65.02	60.78	62.07	57.48	18	63.59
Difference	-0.45	-0.49	0.01	-0.38	-5	0.24

Little Rock Creek @ mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	68.73	63.80	65.37	59.98	375	67.74
Calculated Value	68.98	64.03	65.86	60.55	470	67.46
Difference	-0.25	-0.23	-0.49	-0.57	-95	0.27

City Creek @ the mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	67.28	60.93	63.37	57.08	167	65.66
Calculated Value	67.94	61.88	64.86	58.52	259	66.45
Difference	-0.66	-0.95	-1.49	-1.44	-92	-0.79

2000

Steamboat above Canton	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	77.52	69.03	72.24	63.90	999	75.88
Calculated Value	76.22	68.34	70.77	63.85	997	74.45
Difference	1.30	0.69	1.47	0.05	2	1.44

Boulder Ck @ mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	69.33	64.09	65.01	60.48	382	68.29
Calculated Value	68.34	63.81	63.46	59.61	229	66.75
Difference	0.99	0.28	1.55	0.87	152	1.54

Cedar Creek @ the mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	66.02	60.29	61.99	56.62	41	64.94
Calculated Value	66.64	61.04	61.88	57.03	52	65.09
Difference	-0.62	-0.75	0.11	-0.41	-11	-0.15

Little Rock Creek @ mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value	70.22	64.09	65.87	59.82	434	69.07
Calculated Value	70.71	64.31	65.65	60.08	419	69.06
Difference	-0.49	-0.22	0.21	-0.26	15	0.01

City Creek @ the mouth	MaxMaxT	MinMinT	AveMaxT	AveMinT	HrAbv64	Max7DayAve
Actual Value		No	Data	Available		
Calculated Value		malfunctioning	Data	recorder		
Difference						

Discussion:

Errors

While the method appears to eliminate much of the variability in the data, the remaining variability shows up as errors between the calculated and actual values.

Table 2 and Figure 4 show some statistics for the error values (difference between actual and calculated) for the 7-day moving average results for the evaluation sample. It appears that the ratio method underestimated the measured 7-day mean by an average of .32 °F with a maximum error of 1.54 °F for the nineteen samples.

Table 3 Statistics of the error (°F) in the 7-day average results.

Mean	0.316083
Standard Error	0.156461
Median	0.241216
Standard Deviation	0.681997
Sample Variance	0.46512
Range	2.32652
Minimum	-0.78891
Maximum	1.537606
Largest(1)	1.537606
Smallest(1)	-0.78891

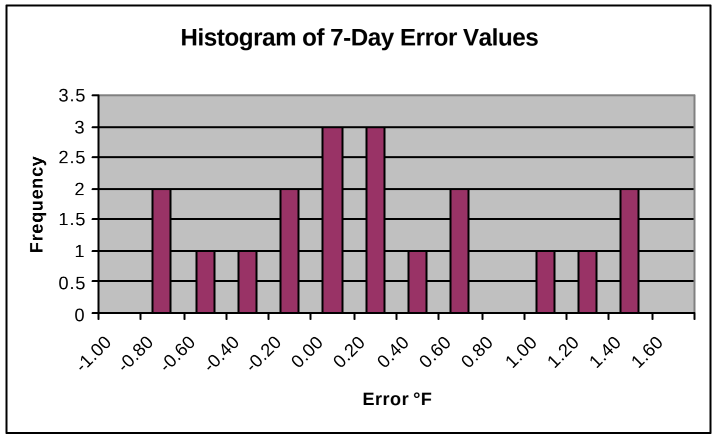


Figure 4 Histogram of the 7-day error values.

Figure 3 provides an indication of the variability that is not accounted for by the method. If the method eliminated all of the variability these the graphs would be a series of parallel horizontal lines. The uniform deviation from the horizontal suggests seasonal scale differences such as differences in the relative local heat capacity. Examination of the temperature charts for 1997 (appendix) shows that much of the "noise" in figure 3 appears to be associated with periods of rapid temperature change; suggesting that the streams do respond to change at different rates.

Likewise, the results for 1997 in the Appendix shows the error introduced by using the average ratio method compared to the actual data. This is an indication of the limitations of this methodology.

Site Information

The data provided by the Umpqua National Forest was part of their routine monitoring program and was not designed specifically for this type of study. The monitoring records indicate the following:

1. The same thermograph was used at each site throughout the study.
2. All units had a low probability of exposure to surface air.
3. The location for the Canton Creek site was changed after 1997 and the location of the Boulder Creek site was changed after 1998.
4. All sites had cobble-dominated substrate.
5. The 2000 data for City Creek was discarded by the Forest Service since the readings were erratic and not consistent with previous patterns observed by the agency.

Limitations of method

While the ratio method may prove to be a useful tool, several limitations need to be considered when using it.

1. Due to the nature of the method used, the temperature units used to develop the ratios must also be used to apply the method. In this example, Fahrenheit data must be used since the ratios were developed with Fahrenheit data. Celsius data must either be converted to Fahrenheit or used with the following formula:

$$T_{IC} = R \cdot T_{RC} + 32(R-1)/1.8$$

where:
T_{IC} Temperature of stream of interest in Celsius
T_{RC} Temperature of control stream in Celsius
R Ratio for stream of interest

2. This method assumes similar responses between the watersheds being compared. Examination of the data for the calibration year should show patterns with similar shape and the corresponding daily ratios should be constant across the season for the season as shown in figure 3. Sites strongly influenced by reservoir releases, erratic withdrawals / augmentation, tidal influences would probably produce poor results. Ratios with a large standard deviation (see Table 1) will produce less reliable results.

3. Riparian areas are dynamic and changing conditions can change temperature changes over time. Trend type changes identified by this method will be the result of changes in both the reference site and the site of interest. It is expected that the change associated with changes in the reference site could be determined by analysis of changes in data from multiple sites relative to the reference site.

4. For critical applications, further verification of the accuracy of the predicted values is highly recommended. While the preliminary evaluation has shown good results within the Umpqua Basin, additional verification is encouraged until more sites are checked.

4. This method assumes uniform weather conditions between the watersheds. This is a common condition in the Umpqua Basin during the summer months but may not hold as well in other areas.

Further Work

!. The ratio values may have potential for quantifying the thermal characteristics at a site. As an example, Figure 5 shows the relationship of watershed area and the corresponding ratios. Note that the data shows the familiar heating with increased stream size. However, the scatter in the data may provide a quantification of the physical differences between the sites (i.e. Little Rock Ck and Cedar Ck). Relating these differences to the differences in site characteristics and flow regime may provide some additional insights stream assessment and management.

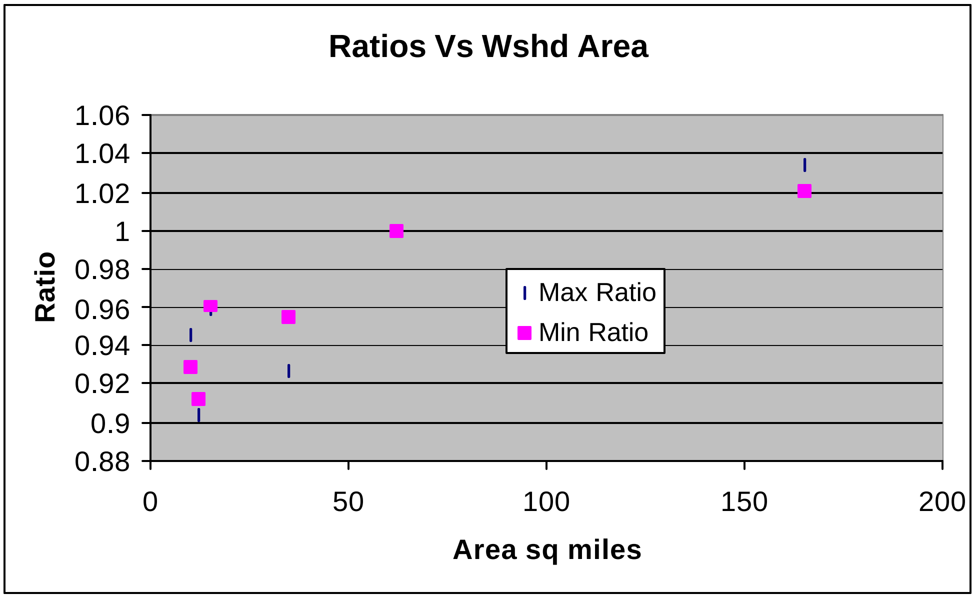


Figure 5 1997 Maximum and Mi nimum ratios vs. associated watershed area.

2. The central portion of the Umpqua Basin has summer stream temperature data from over 400 locations over the last three years. Several sites have been monitored each year that could serve as reference sites. The ratio method could be used to generate summer statistics for all the sites for a give year (i.e. summer 2000). This result would provide a look at the relative thermal condition of the entire central basin. This information could be helpful in identifying water quality concerns, evaluation of fish habitat, temperature management project development, and baseline monitoring in the Umpqua Basin.

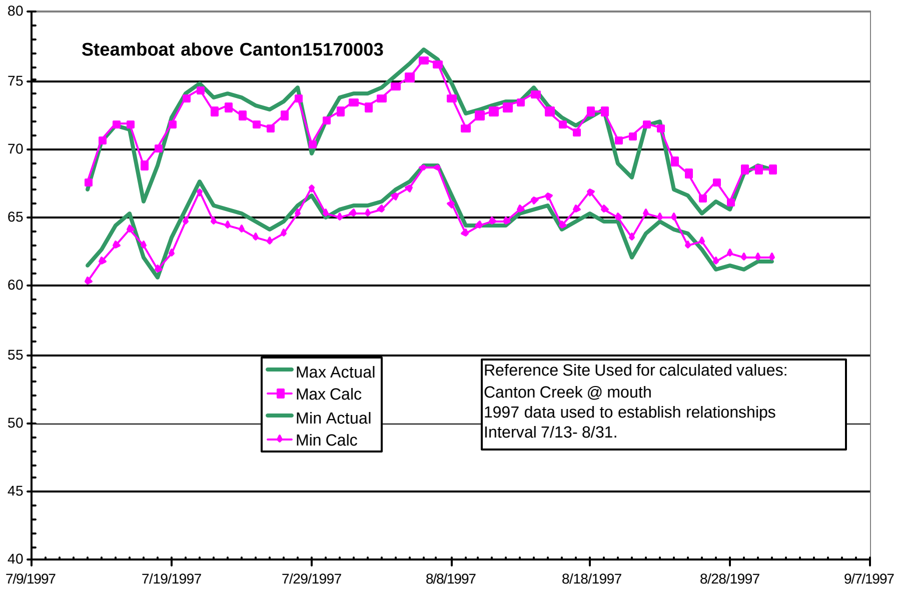
3. The development of the index could be refined by using a linear regression across the sample season in lieu of a simple ratio. Another option is to refine the ratio development by excluding rapid transition periods. This approach may give better estimates of the seasonal maximum values that usually occur during the more steady periods.

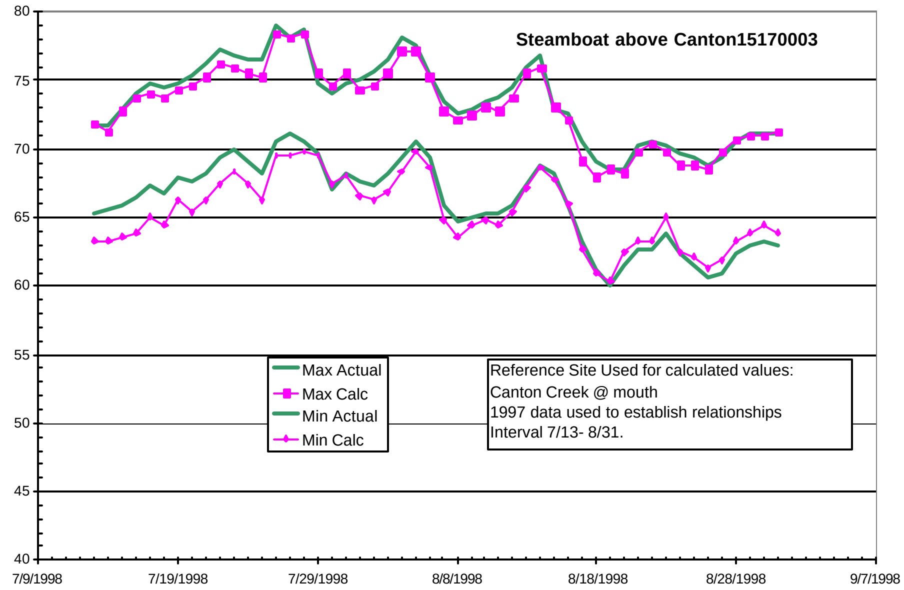
3. If the method is used extensively, verification should be continued and with a cumulative record of the statistics for all of the verified sites.

Appendix

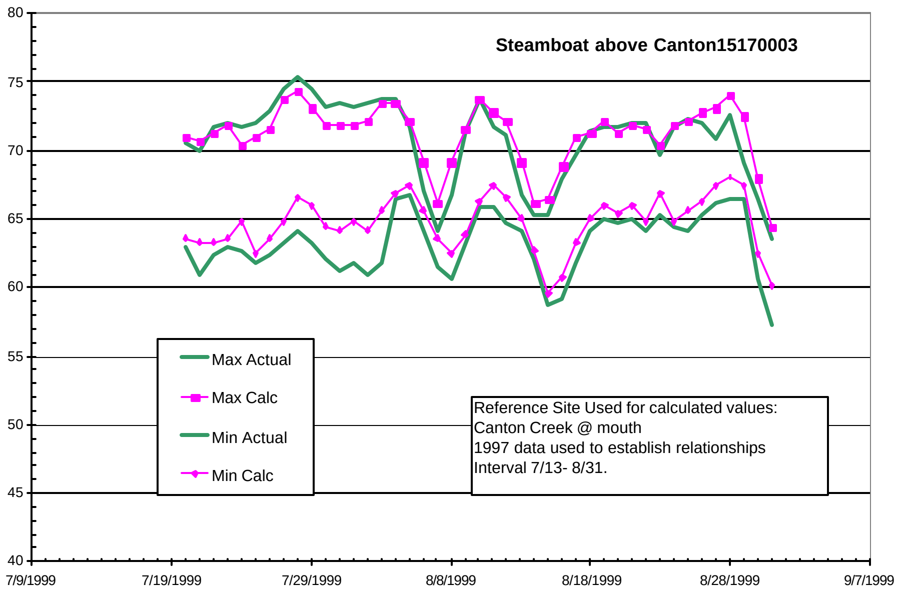
Stream Temperature Data for 7/13-8/31 for years 1997-2000:

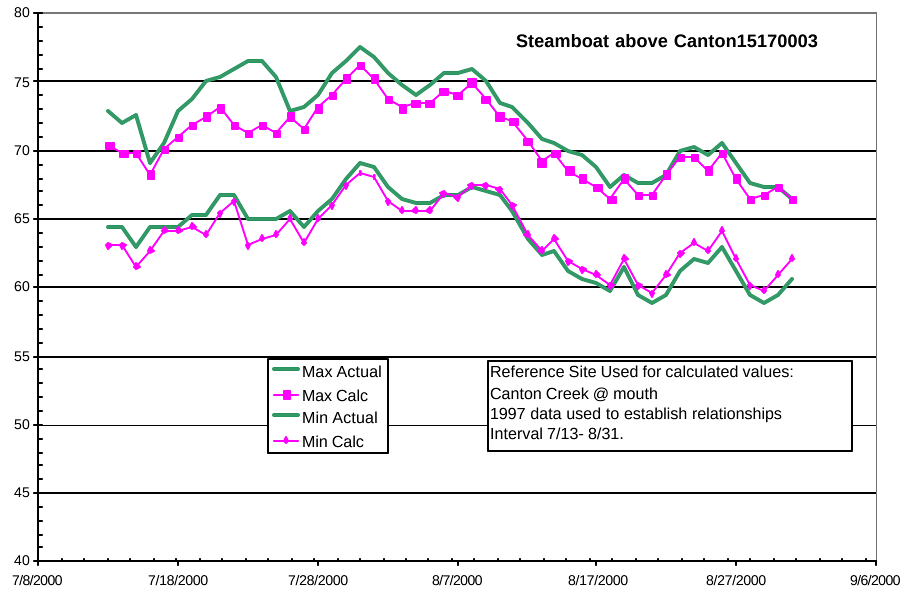
- Canton Creek @ mouth
- City Creek @ mouth
- Little Rock Creek @ mouth
- Cedar Creek @ mouth
- Boulder Creek @ mouth
- Steamboat Creek above Canton Creek

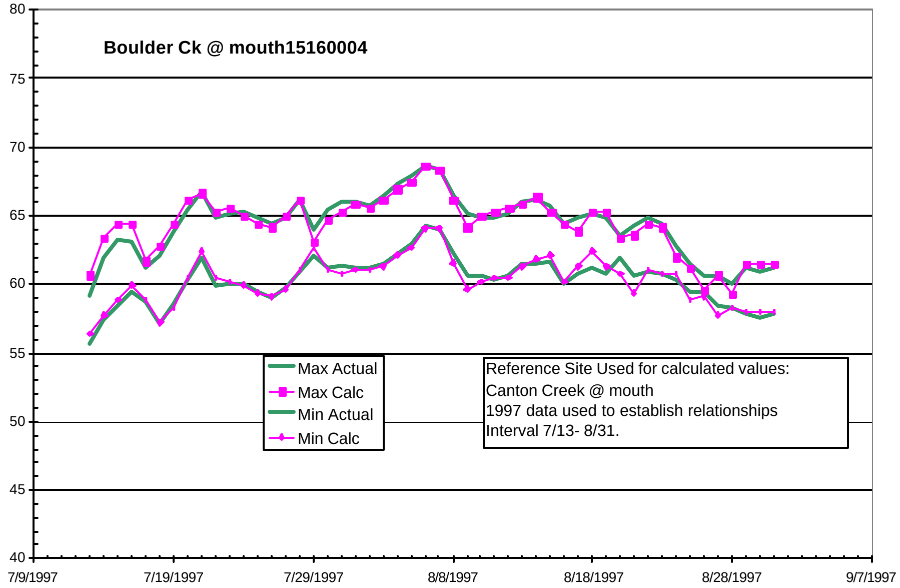


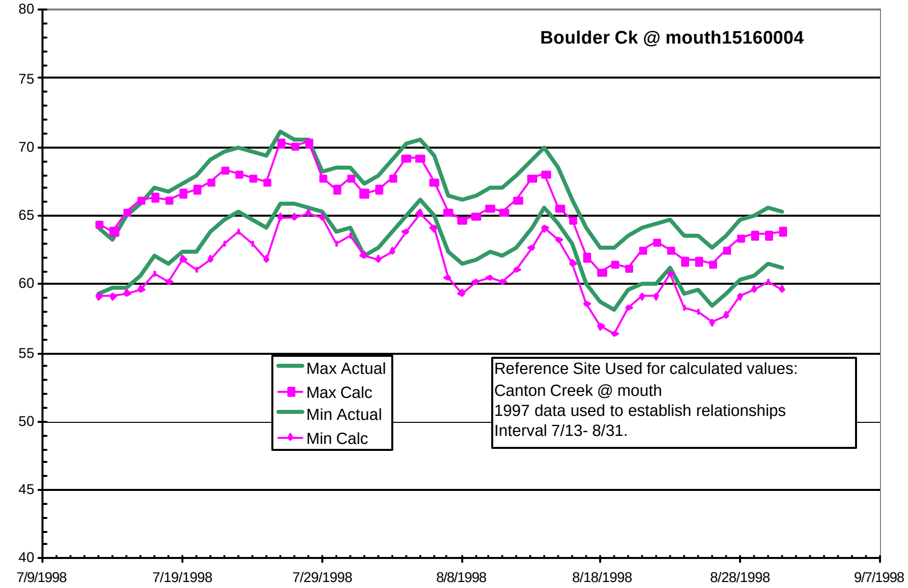


Steamboat above Canton

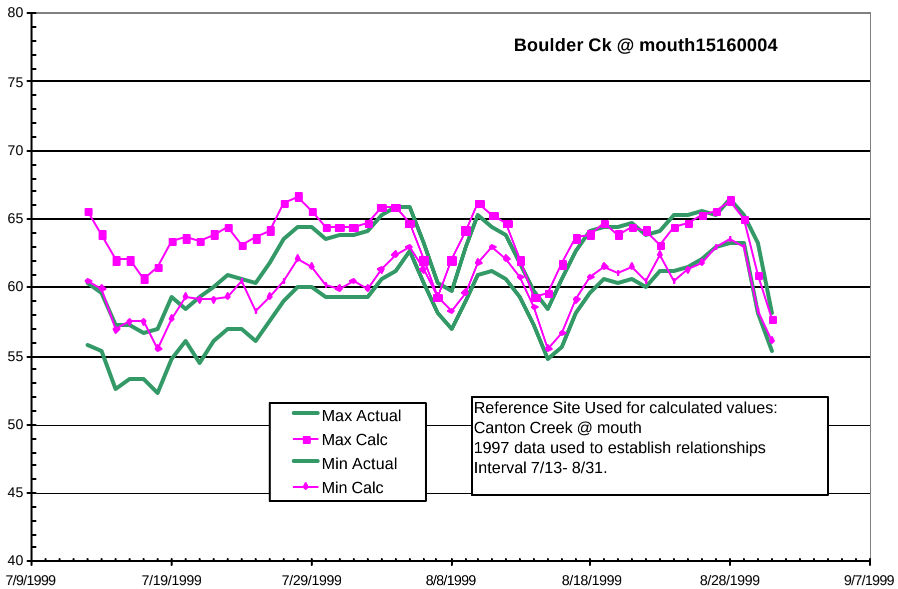


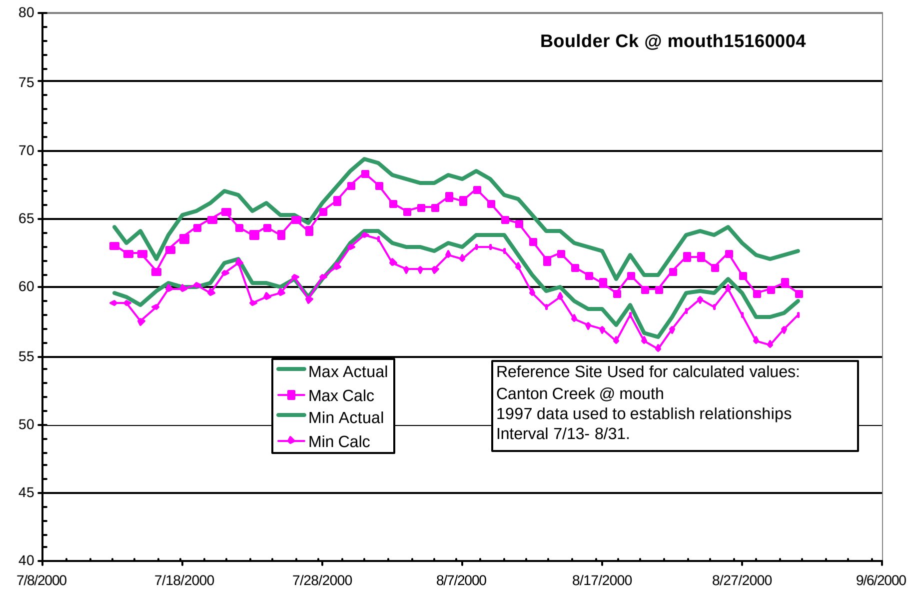


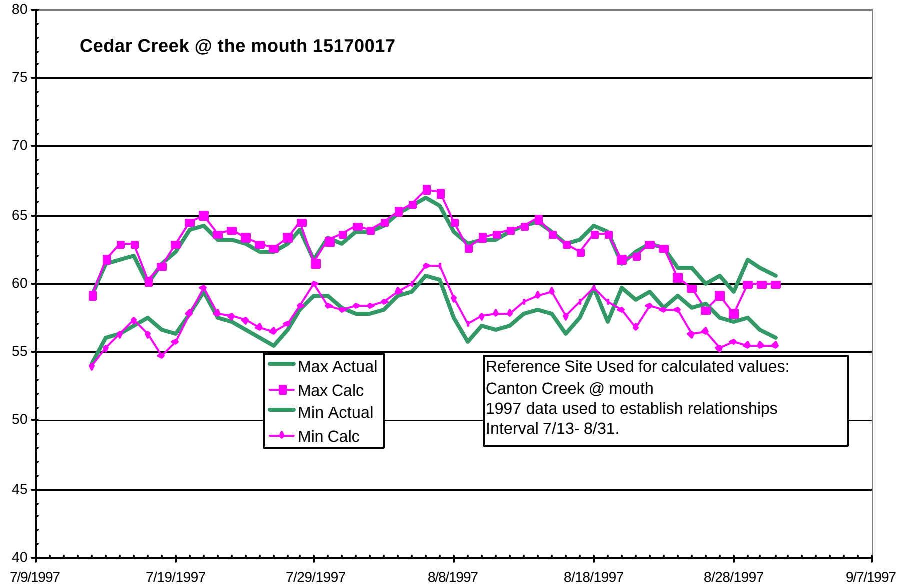


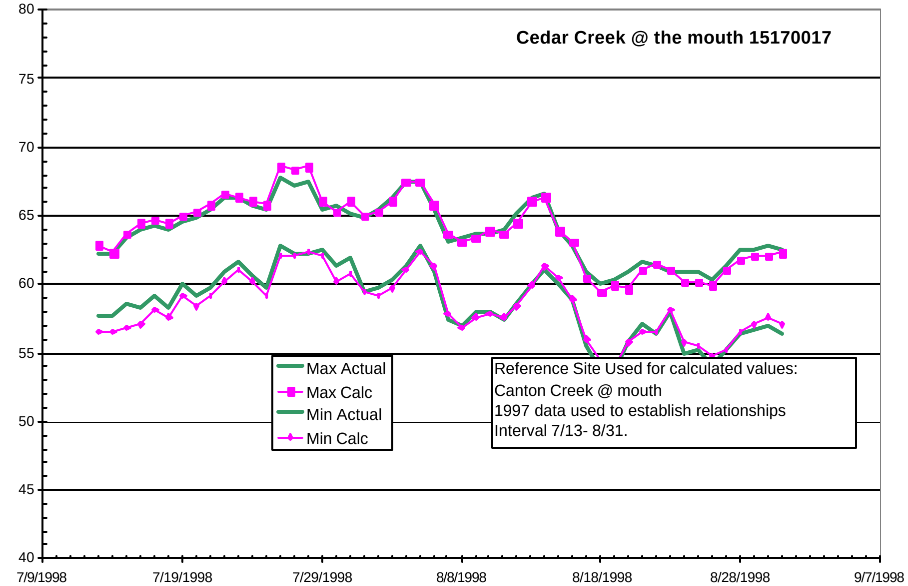


Boulder at mouth

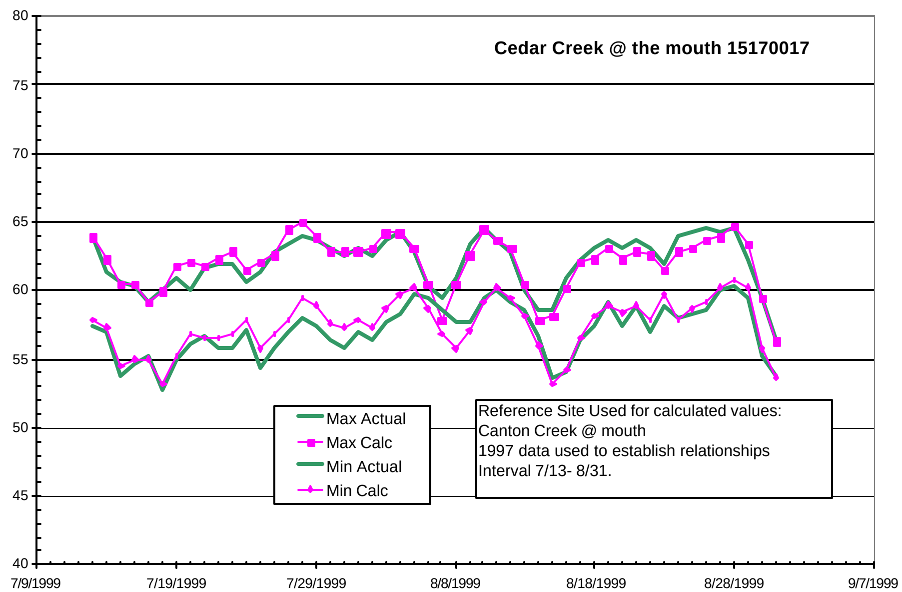


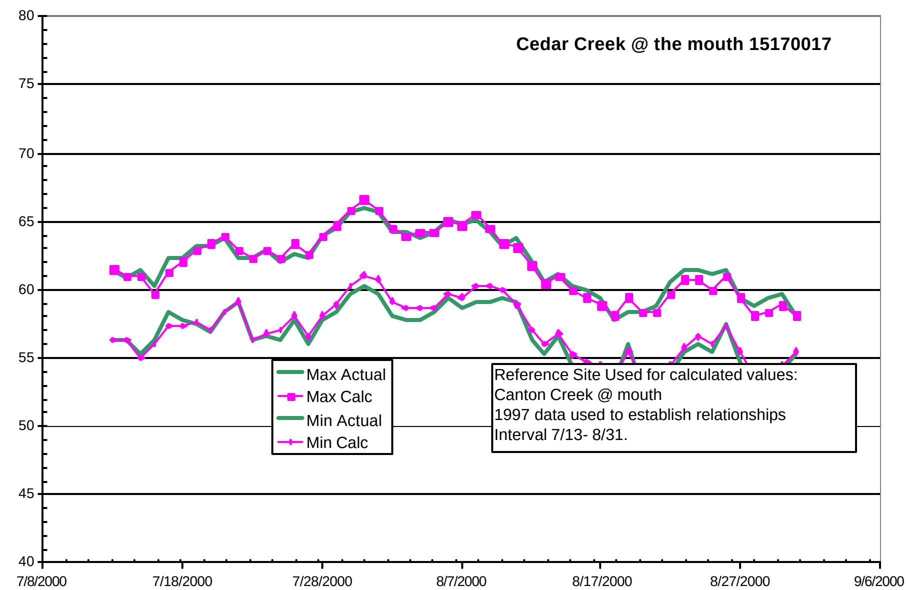


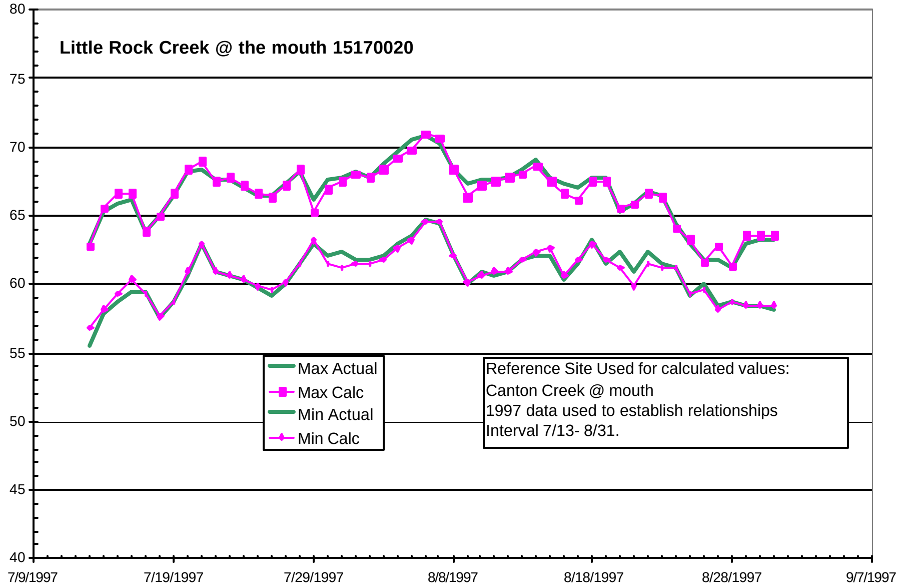


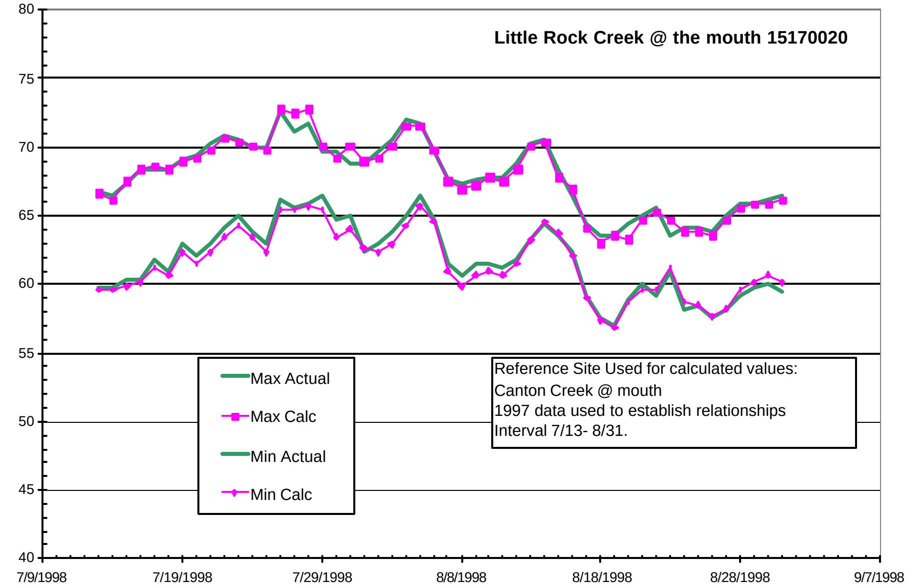


Cedar Creek at Mouth

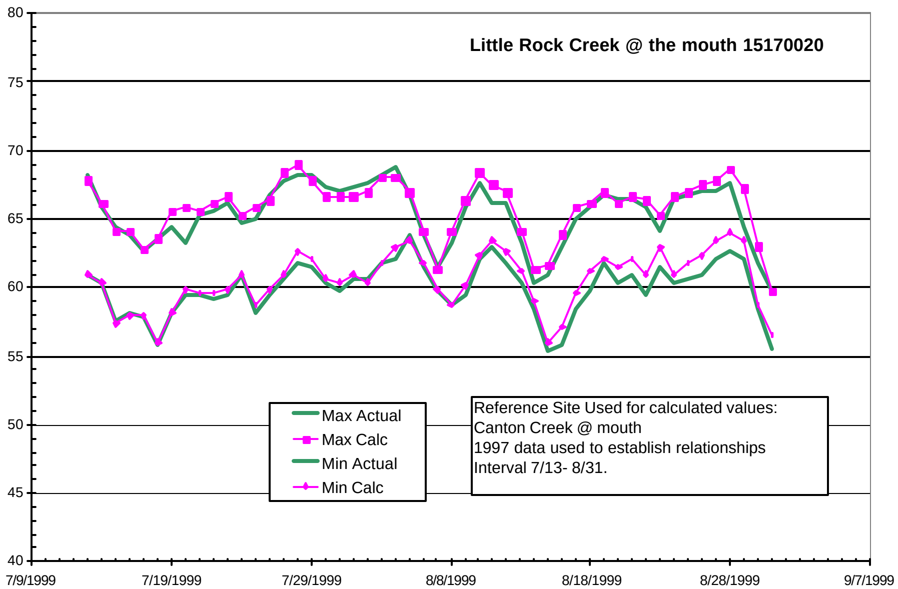


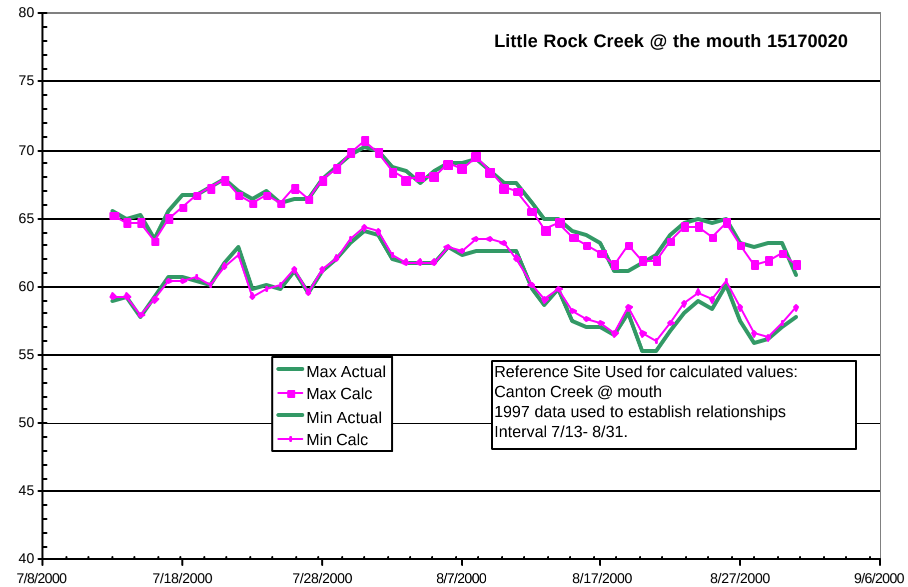


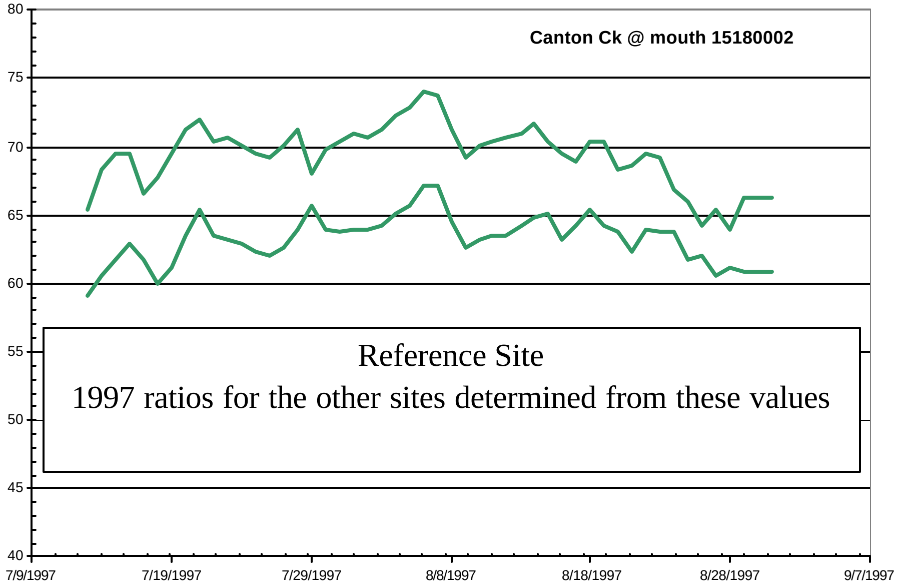


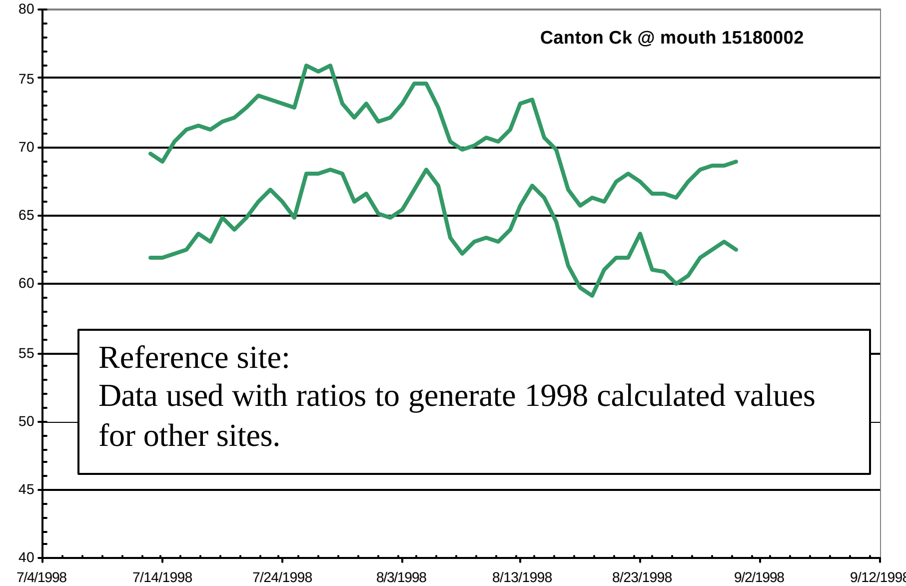


Little Rock Creek at mouth

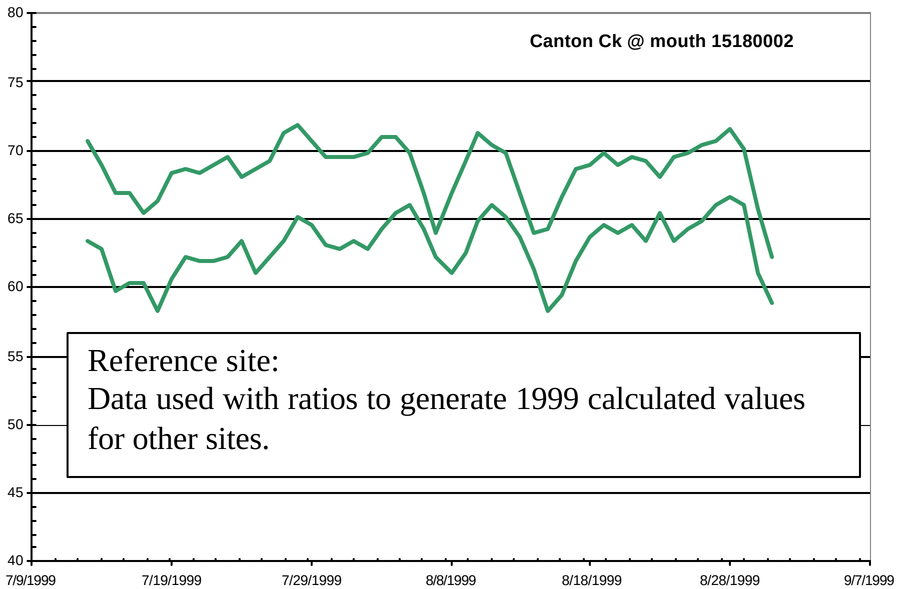


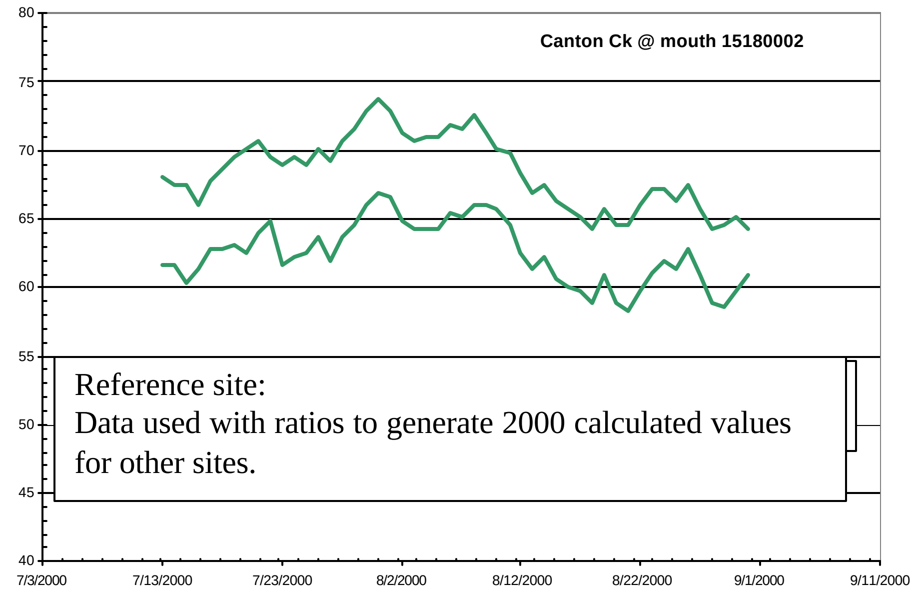


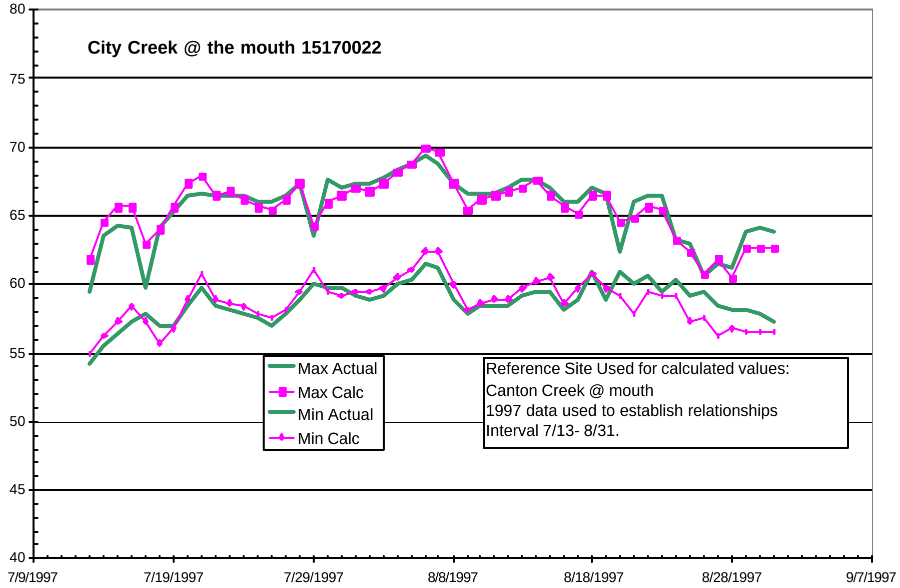


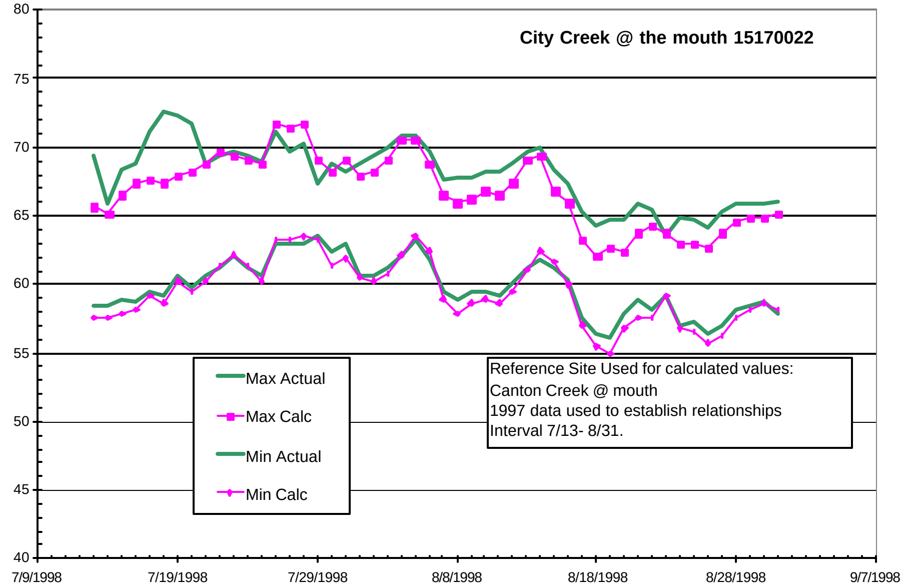


Canton Creek at mouth   Used to generate 1997 ratios and calculated values for subsequent years.









City Creek at mouth