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Use of Synoptic Temperature Data To Reduce Inter-Year Stream Temperature Variability Within the Umpqua Basin

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The objective of this project is to gain more information from the abundant stream temperature data that is available within the Umpqua Basin. Obviously, there is much more work to be done. Comments and suggestions are welcome. Please address them to:

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Use of a Control Site with Other Synoptic Temperature Data To Reduce Inter-Year Variability in Stream Temperature Data Within the Umpqua Basin

Summary:

Stream temperature is a key consideration while assessing watershed conditions and the availability of low-cost digital dataloggers has, over the last decade, resulted in the availability of hundreds of 30-minute data files from sites throughout the Umpqua Basin. Typically, the data are highly variability with much of the information associated with the diurnal pattern and the prevailing weather conditions. However, the data also contains information about the unique physical thermal characteristics of each site that, if quantified, would be very helpful for assessment purposes.

Examination of the synoptic Umpqua data shows a similarity in the characteristic summer seasonal patterns that suggests that the in-common variability could be extracted, revealing the relatively constant site characteristic information.

This report compares synoptic summer stream temperature data from six locations in the North Umpqua Watershed over a period of four years. Variability of selected statistics was normalized to one control site by simply finding the average ratio between it and the other sites for the reference year (1997) for a specific interval. These ratios were then applied back to the control site for the subsequent years to calculated predicted values for each site. Comparison of actual to predicted values showed typical differences of less than 1°F for most of the statistics. These normalization ratios may be useful for assessment purposes since they provide a quantified index of the relative thermal response characteristics of each site.

There is high interest in obtaining this type of site information. However, further work is needed to find the optimal normalization algorithm to apply to the available data. Excel macros been developed to facilitate the application of the methodology to the Umpqua data files. Charts of all of the results are available in the Supplemental Appendix.

Background:

The importance of temperature as a physical property of natural flowing waters has been well documented (Webb, Hannah et al. 2008). Stream temperature often is identified as a key parameter when assessing watershed conditions. For example, assessing the effect of fire on stream temperature (Dunham, Rosenberger et al. 2007) or the relationship between temperature and fish use (Howell, Dunham et al. 2010). There is also interest in having diagnostic site factors to quantify the physical basis for temperature changes at a point of interest as well as points downstream (Moore, Spittlehouse et al. 2005).

The development of inexpensive digital dataloggers has made the collection of large quantities of stream temperature data possible. In the Pacific Northwest, stream temperature in the late summer months is often of interest and seasonal data files of the order of 4000 readings, typically taken at 30-minutes intervals, can be easily collected at each site. For the past ten years several agencies have deployed a total of about 200 dataloggers within the Umpqua Basin and most of the data files are available through the PUR Watershed Council. Having a large collection of synoptic data (estimated at over one thousand files) can be particularly useful in identifying and reducing the within-year common variability (the topic of this report). Also, at several sites, data has been collected routinely every year, providing the means to identify and compare the annual seasonal patterns.

Currently, the data is typically used to extract specific statistics over a specified time-interval and create charts that show the seasonal thermograph pattern for the site for a particular year. A commonly sought statistic is the maximum value of the 7-day moving average of the daily maximum values that is related to the EPA stream temperature assessment criteria procedures. Seasonal extreme values can also provide an indication of the relative thermal conditions between sites with synoptic data. Comparison of synoptic diurnal statistics for a given day can provide relative information about the solar insolation of the sites. However, inter-year variability makes extrapolation of this information between years problematic.

Examples of Typical Stream Temperature Data in the Umpqua Basin

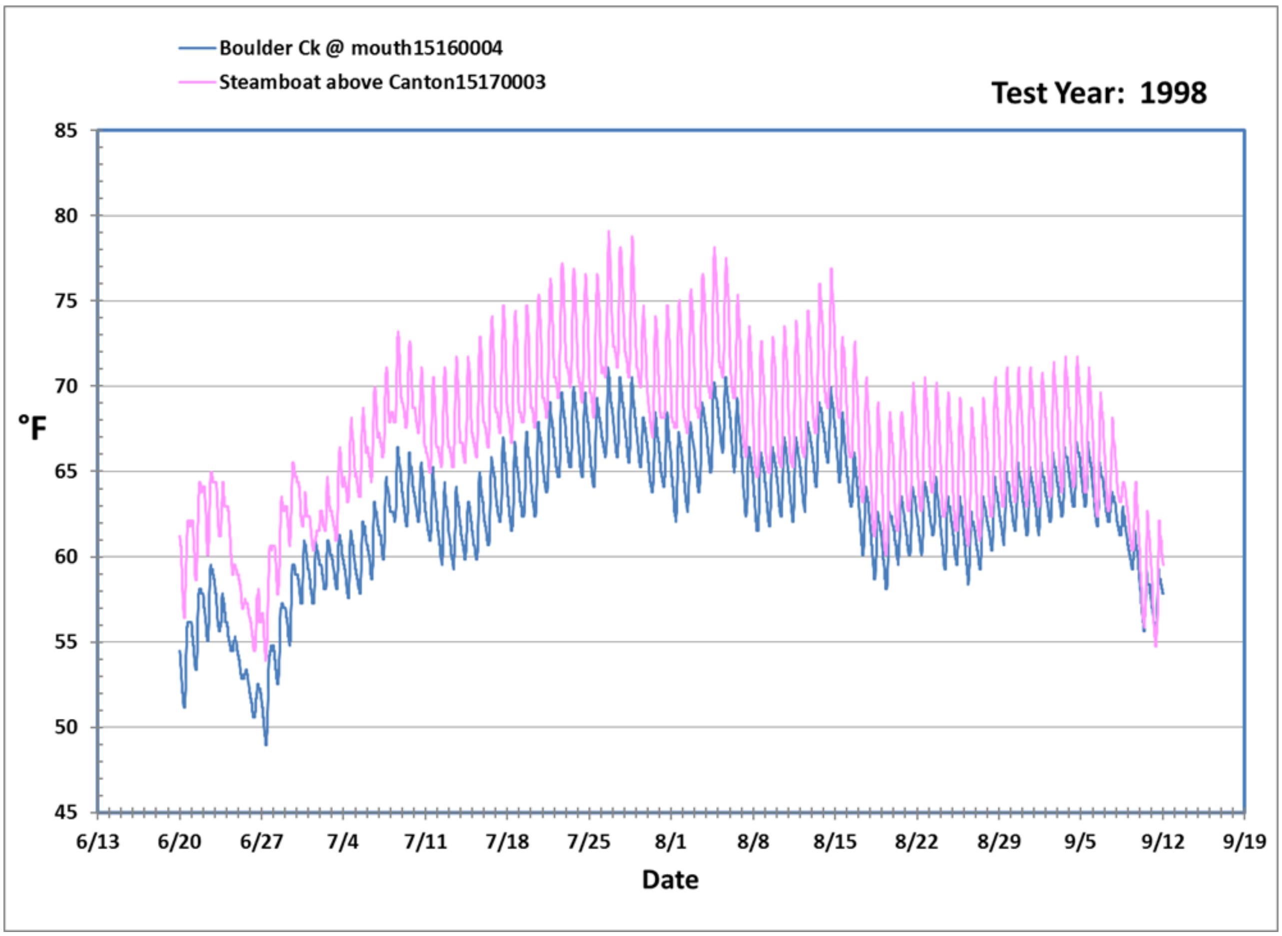

Figure 1 Representative Data From 1998

Figure 1 shows 30-minute summer seasonal temperature data for two sites for a given year. The general over-all pattern is a gradual increase in temperature until August when the energy flux from the solar insolation component diminishes to the point that there is a net daily loss of thermal energy to the system and a corresponding reduction in temperature. Superimposed on this pattern is the daily diurnal fluctuation as well as longer term characteristic pattern can be largely attributed to prevailing weather conditions – an observation that is consistent with the concept that air temperature can be an effective input in statistical models (Larnier, Roux et al. 2010).

Note the similarity in the seasonal patterns between the two sites. The summer weather patterns in Western Oregon and the lower Umpqua Basin are quite moderate and tend to be spatially homogeneous during stable weather conditions. On warm clear days most of the basin is experiencing similar weather conditions that may last for several days. Typically there are few days with cloudy conditions but these transition periods can be easily identified. The seasonal scarcity of precipitation results in a drought condition with corresponding low-flow conditions in the streams.

The 30-minute data in Figure 2 shows the similarity in more detail. Note that each site has a distinctive response to the solar input that is defined by its shade characteristics. Since the solar angle, for a particular time of day, changes every day, the daily thermograph patterns show subtle differences in the instantaneous shade situation. For example, at 6 PM on August 3 the data logger in Canton Creek is experiencing a shade condition and direct solar exposure persists until 9 PM. Also, conditions at City Ck appear to have changed - apparently the data logger became exposed to the surface air temperature in the year 2000. The City Ck section of the Appendix has more details on this topic.

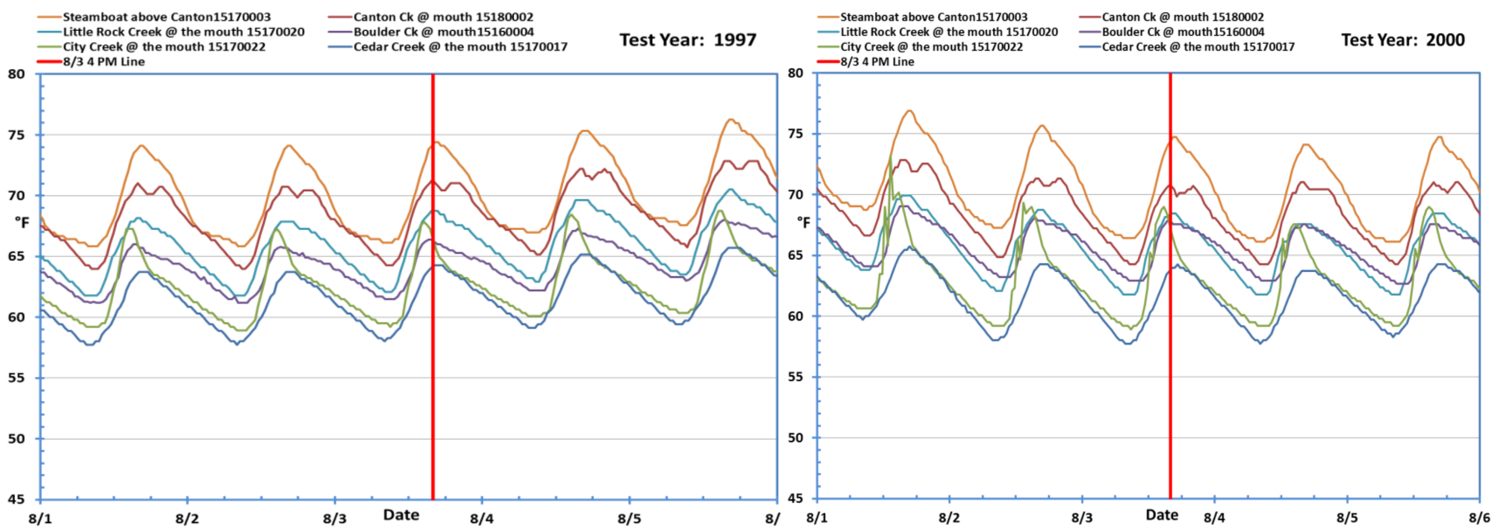

Figure 2 Detail of 30-minute data over the 5-day interval

Figure 3 shows typical season patterns that, for the most part, are influenced by the seasonal weather pattern. As Figure 1 suggests, the pattern for a given year tends to have a unique, characteristic shape that has a common variable component within the individual thermographs.

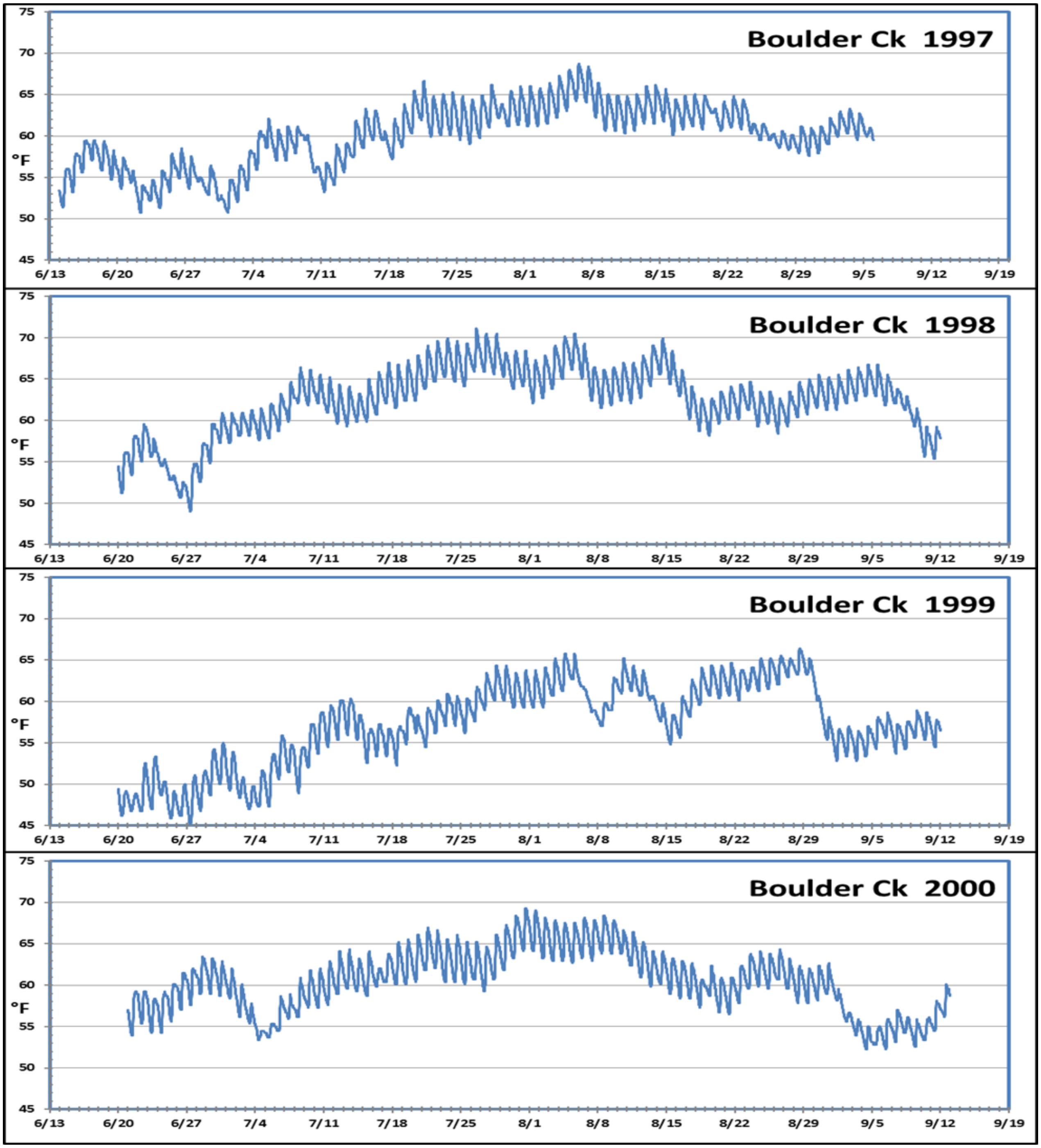

Figure 3 Typical Characteristic Season Patterns

Inter-Year Variability of Commonly Used Statistics.

Since summer stream temperature data is highly variable, specific statistics are typically used to describe a particular process or condition. Generally these statistics are applied to diurnal data or to a specified time interval. Maximum, minimum, mean and moving average values are typically used.

Instantaneous data is typically used with caution since the diurnal temperature fluctuation can be several degrees and the value is highly dependent upon the time of day.

Figures 4 and 5 show typical results over the four-year interval. There are several points to be noted:

1. The inter-year deviation is significant and, and data taken from an individual site without attention to context could easily be misinterpreted.
2. With the exception of City Ck, the plot patterns are quite parallel, suggesting a similar response to prevailing conditions that are offset by individual site characteristics.
3. The results from City Ck are related to the data error mentioned earlier. The Appendix

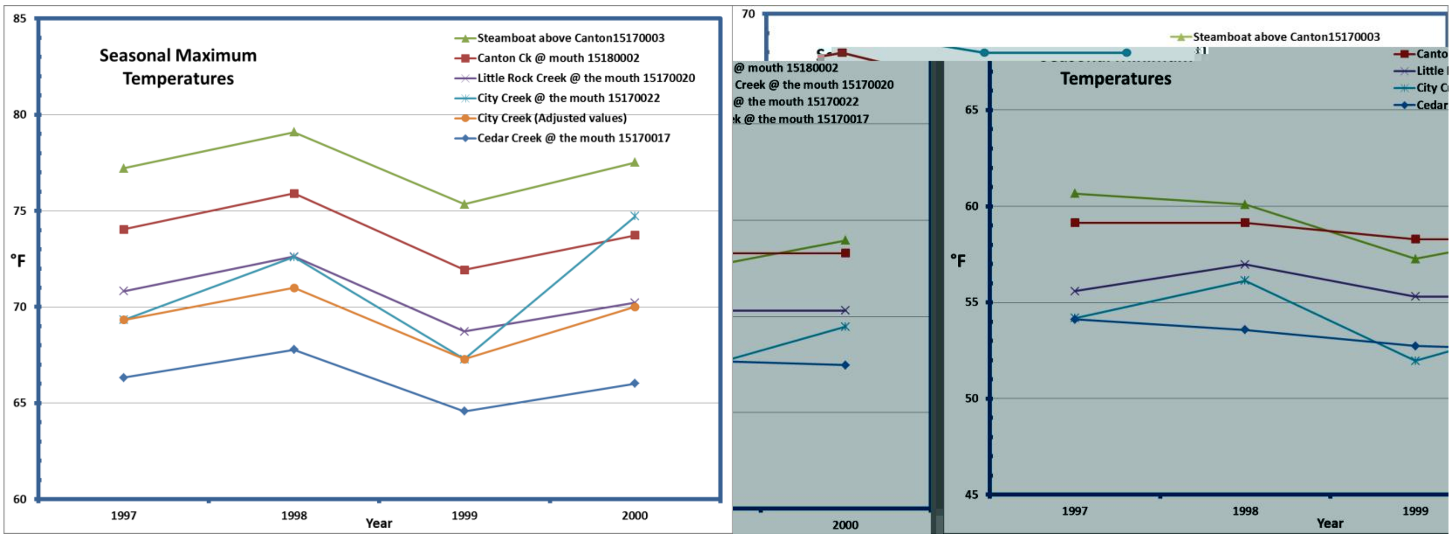

Figure 4 Inter-year variability of the seasonal maximum and minimum values over the 4-year test period

exposed to air as the stream flow diminished. The erroneous data were retained in the

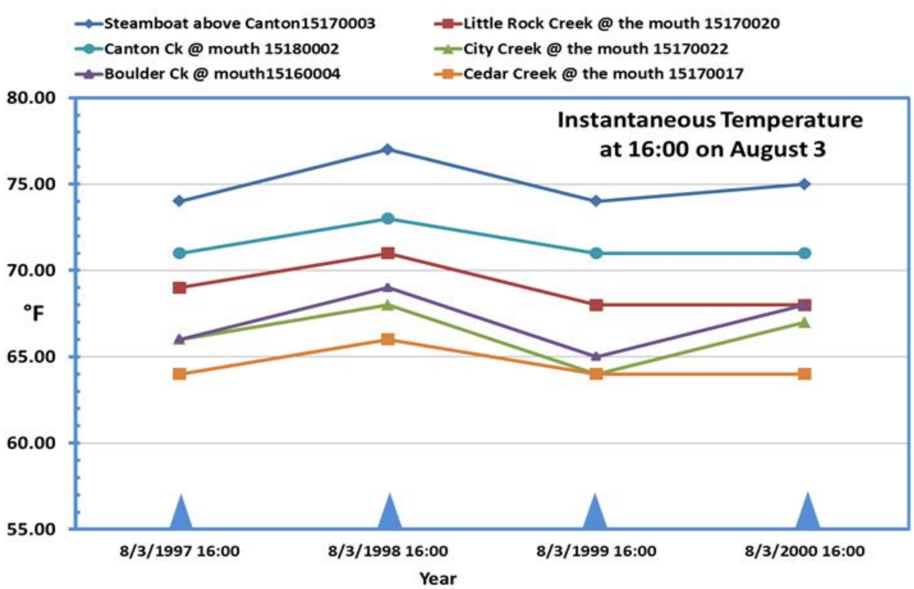

Figure 5 Inter-Year variability of instantaneous values for August 3 at 4 PM

study to quantify the relative error associated with this type of situation.

It is apparent from these charts that the inter-year variability as well as the variability between sites can significantly affect annual statistics. This variability has been cited as problematic in general (Dunham, Rosenberger et al. 2007) and specifically to extrapolating experimental results to other situations. (Moore, Spittlehouse et al. 2005). The objective of this project is to try to reduce some of the variability.

Sources of Inter-Year Variability

In order to reduce the variability shown in Figure 3, it is helpful to consider the possible sources. There appear to be five general factors affecting the stream temperature variability: (1) solar path, (2) solar insolation, (3) seasonal weather pattern, (4) prevailing flow conditions and (5) the physical site characteristics that influence the dynamic thermal response of a site. For the Umpqua region the first four factors may have a common effect on all of the sites while the physical condition is a unique property of the individual site.

1. Solar Path:

The dynamics of the solar path are well known and the annual location of the sun can be determined precisely for any date and time. Since the pattern repeats each year, the inter-annual variability associated with solar position can be effectively eliminated by using the same date/time interval for each year of the study.

2. Solar Insolation: The net solar energy reaching the site area depends upon cloud cover and other atmospheric conditions. On warm, clear days the atmospheric conditions in Western Oregon tend to be quite uniform with all sites responding to similar input conditions. Consequently, much of the variability associated with the atmospheric conditions might be fairly uniformly distributed across the watershed and in common to all of the sites.

3. Seasonal Weather Pattern: The seasonal weather patterns in western Oregon are strongly influenced by annual oceanic conditions and the summer weather systems are generally fairly uniformly distributed across the basin. The similarity in the thermograph patterns from different sites throughout the basin supports this conclusion

4. Prevailing Flow Conditions: Many of the streams in the Umpqua Basin are cascade type that consists of a series of well-developed pools that are formed by the winter flood flows. Summer drought flow is typically reduced by a factor of 1000 and the streams transform into a series of relatively large interconnected pools that act as small reservoirs which dominate the heat transfer process. Therefore, since pool depth changes slowly with changes in flow, the thermal response for most sites should not be particularly sensitive to changes in flow.

5. Physical Site Characteristics: The physical site conditions determine how all of the external thermal processes combine to affect the water temperature. Local topographic and shade conditions, hyporheic exchange, pool depth, aspect, location and condition of the datalogger, etc. create a characteristic response to a particular set of conditions that is unique to the site and relatively constant over time. An indexed value that quantifies this unique characteristic value could be a useful tool for stream assessment.

It is apparent that the source of most of the variability in the temperature data is associated with the diurnal input, seasonal weather, and the related solar insolation component while the physical site component is relatively stable. An implication is that most of the information contained in the temperature data files is simply tracking the effects of the annual weather pattern and that a relatively small amount of data is needed to determine the local site characteristics.

Removal of the Inter-Year Variability within Selected Intervals

Over the years, an immense effort has been made to develop models that will enable the prediction of the water temperature and effectively account for the various variable components. These models are often categorized into two major groups: deterministic models and statistical/stochastic models (Benyahya, Caissie et al. 2007). However, the limitation of these models often is directly related to the difficulty of obtaining sufficient accurate data to fully describe the thermal response of the various components. A simple empirical approach is needed that can easily be applied using available information.

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 and this approach was evaluated in this project.

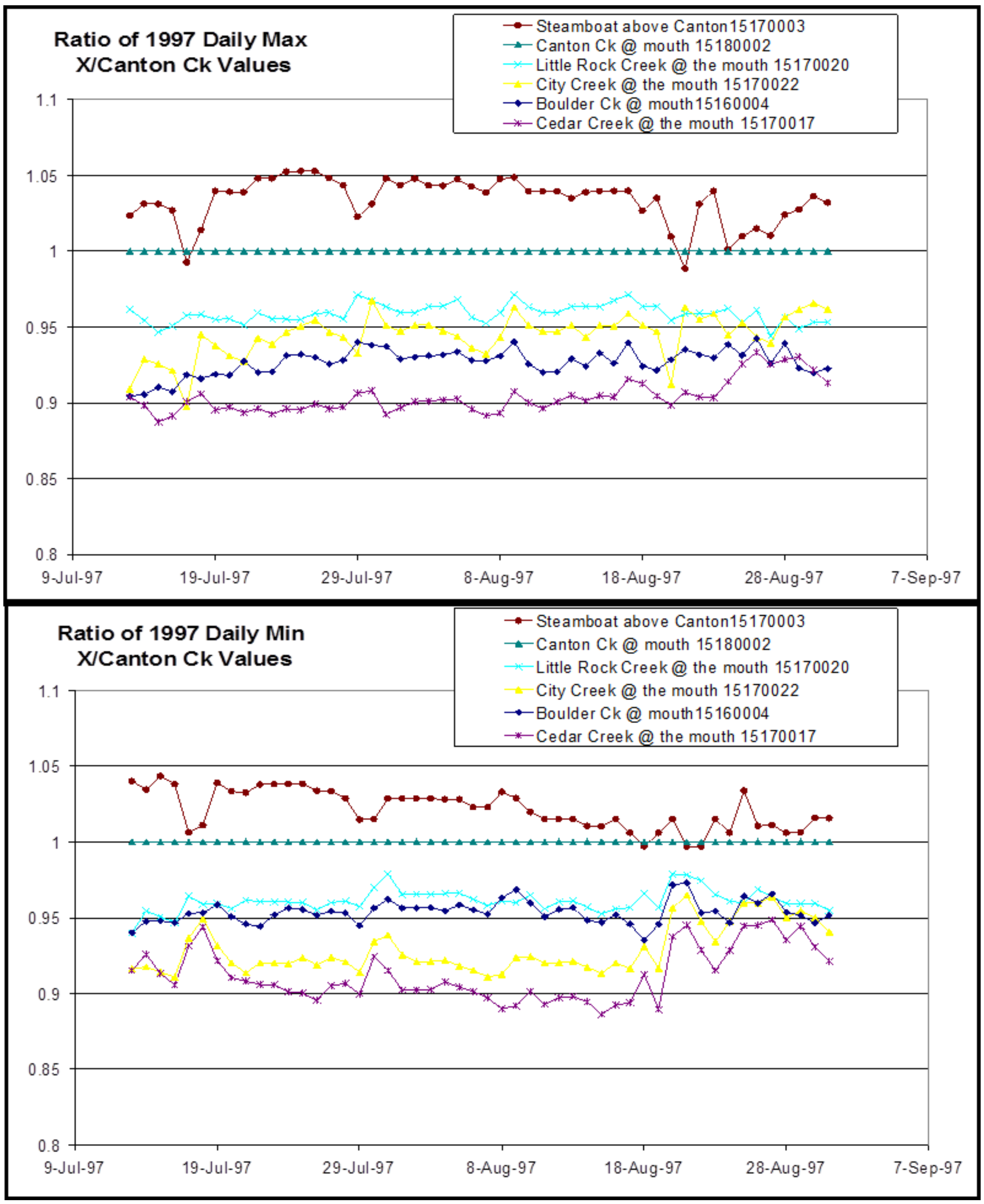

Figure 6 Calculated Max and Min ratios relative to Canton Ck

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. The data collected in 1997 was selected arbitrarily as the "Base Reference Year" and Canton Creek at the mouth was selected arbitrarily as the "Control Site." Three time intervals were studied: A 50-day interval between July 13 and August 31, a 5-day interval from August 1 through August 5, and a one-day interval on August 3. The interval statistics examined were the maximum and minimum values as well as the 4 PM instantaneous value on August 3.

A simple ratio of the respective values in degrees Fahrenheit was used to quantify the variability between sites. Obviously, there are many other values that could be used such as the simple difference between the respective values. The ratio of the deviation from the annual mean temperature of 54°F was tried but produced poorer results. Finding the optimal algorithm for extracting the variability remains a challenge for this project.

The 1997 data from Canton Ck were used to derive the daily ratios of the statistics from the other sites. Figure 6 shows the calculated daily ratios for the 50-day interval for the maximum and minimum values. The ideal result would be a set of parallel horizontal lines representing the thermal characteristics of each site. The "noise" in the series indicates variability that was not eliminated by the procedure.

The average of the daily ratio for each interval and each site was calculated and is shown in Tables 1 and Table 2. The standard deviation of these values provides a relative indication of the remaining variability. Note that the August 3 data does not show a deviation because only one value was used to determine the ratio.

Monitoring Site	50 Day Sample Interval				5 Day Sample Interval			
	Daily Maximum		Daily Minimum		Daily Maximum		Daily Minimum	
	Average Ratio	Standard Deviation	Average Ratio	Standard Deviation	Average Ratio	Standard Deviation	Average Ratio	Standard Deviation
Canton Creek	1	na	1	na	1.000	na	1.000	na
Steamboat	1.034	0.015	1.021	0.013	1.045	0.002	1.028	0.000
Boulder Ck	0.927	0.009	0.954	0.007	0.931	0.002	0.956	0.001
Cedar Creek	0.904	0.011	0.912	0.018	0.901	0.002	0.904	0.002
Little Rock Ck	0.959	0.006	0.961	0.007	0.963	0.004	0.966	0.000
City Creek	0.945	0.014	0.929	0.016	0.948	0.003	0.921	0.003

Table 1 Ratios for 50 Day 5 Day Sample

Monitoring Site	August 3, 1997 Values			
	4 PM Value	Maximum	Minimum	Mean
Canton Creek	1.000	1.000	1.000	1.000
Steamboat	1.048	1.043	1.028	1.021
Boulder Ck	0.932	0.932	0.955	0.937
Cedar Creek	0.905	0.902	0.908	0.900
Little Rock Ck	0.968	0.964	0.966	0.964
City Creek	0.935	0.948	0.922	0.914

Table 2 Ratios for August 3 Values

The five sets of site ratios were then applied to the Canton Ck control site values for the years 1998-2000 to generate calculated estimates of the daily maximum and minimum values for each site. .

Results

Figures 7-9 compare the calculated results with actual values for the Cedar Ck site for the 50-day, 5-day and one day sample intervals respectively. The Appendix contains similar charts for all of the sites. Note that the results for 1997 tend to be superior because the applied ration was derived from the same data set. There is no error in the 1997 August 3 results because only a single value was used.

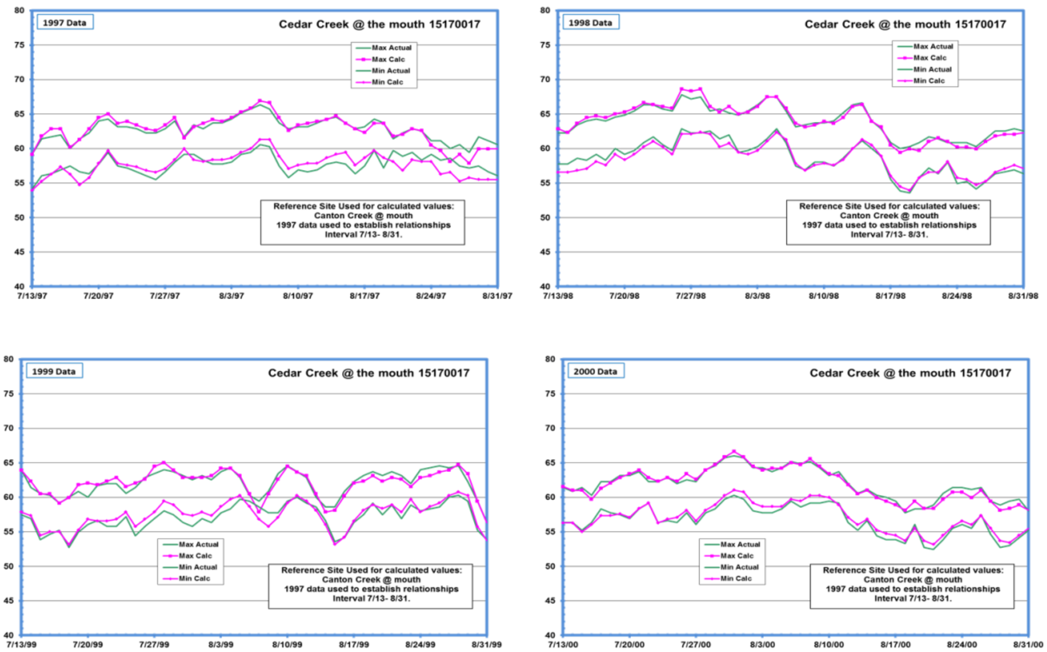

Figure 7 Max Min Values for Cedar Ck - 50 day sample

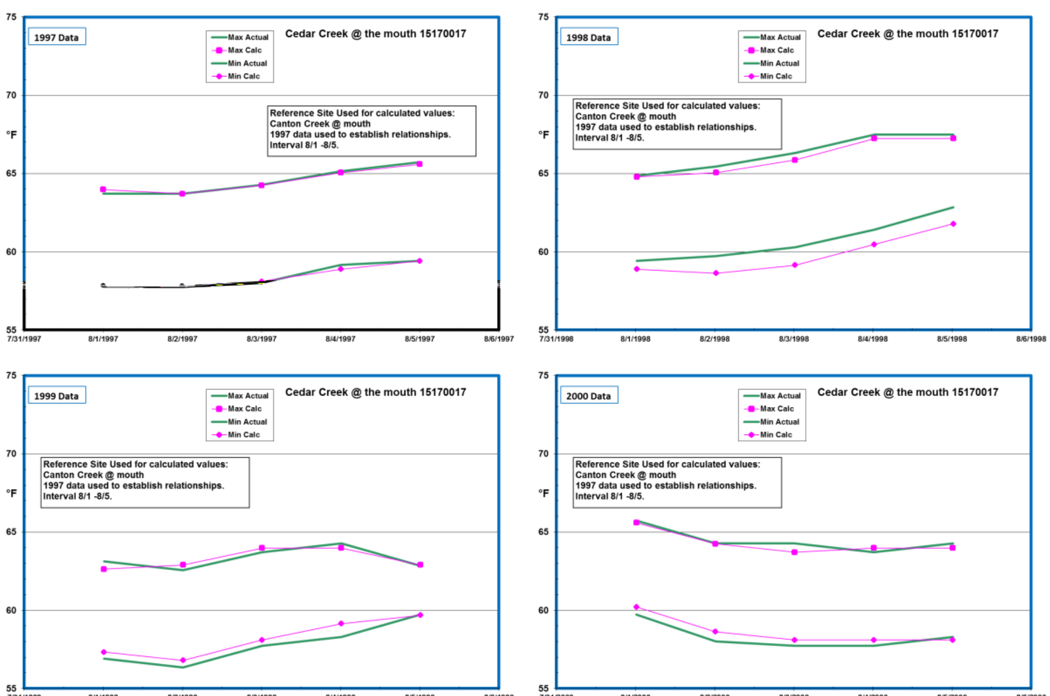

Figure 8 Max Min Values for Cedar Ck - 5 day sample

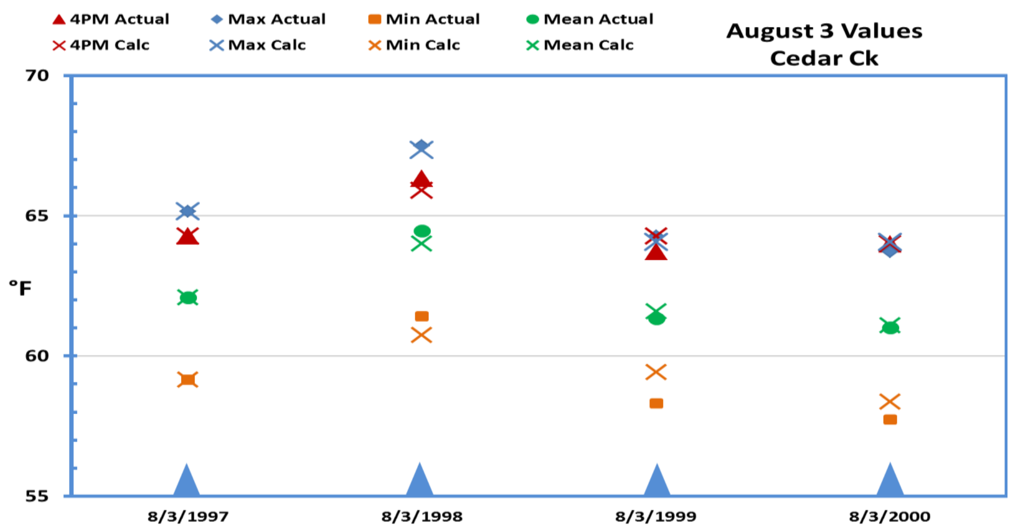

Figure 9 One-Day Values For Cedar Ck On August 3

The following interval statistics were calculated for observed and derived values for the 50-Day and 5-Day sample as shown in Tables 3and 4:

MaxMaxT - Maximum temperature in the sample interval
MinMinT - Minimum temperature in the sample interval
AveMaxT - Simple average of the daily maximum temperatures
AveMinT - Simple average of the daily minimum temperatures

50 Day Sample Interval 7/13-8/31																
Year	Stat	Boulder Ck			Cedar Ck			City Ck			Little Rock Ck			Steamboat Ck		
		Actual	Calc	Diff	Actual	Calc	Diff	Actual	Calc	Diff	Actual	Calc	Diff	Actual	Calc	Diff
1997	MaxMaxT	68.70	68.62	0.08	66.32	66.92	-0.60	69.32	69.93	-0.61	70.82	71.00	-0.18	77.21	76.54	0.67
	MinMinT	55.60	56.40	-0.80	54.12	53.95	0.17	54.18	54.93	-0.75	55.58	56.84	-1.26	60.66	60.41	0.25
	AveMaxT	64.36	64.36	0.00	62.74	62.76	0.00	65.58	65.58	0.00	66.59	66.59	0.00	71.80	71.78	0.00
	AveMinT	60.29	60.30	0.00	57.66	57.68	0.00	58.71	58.73	0.00	60.77	60.77	0.00	64.58	64.58	0.00
1998	MaxMaxT	71.11	70.35	0.76	67.78	68.61	-0.83	72.60	71.69	0.91	72.62	72.79	-0.17	79.09	78.46	0.63
	MinMinT	58.12	56.40	1.72	53.57	53.95	-0.38	56.13	54.93	-0.32	56.97	56.84	0.13	60.09	60.41	-0.32
	AveMaxT	66.80	65.59	1.21	63.95	63.97	-0.02	68.00	66.84	1.16	67.89	67.87	0.02	73.57	73.16	0.41
	AveMinT	62.26	61.07	1.20	58.64	58.42	0.22	59.85	59.48	0.37	61.81	61.54	0.27	66.00	65.41	0.59
1999	MaxMaxT	66.42	66.67	-0.25	64.57	65.02	-0.45	67.28	67.94	-0.66	68.73	68.98	-0.25	75.35	74.36	0.99
	MinMinT	52.28	55.59	-3.31	52.73	53.18	-0.45	51.95	54.14	-2.19	55.30	55.30	0.00	57.26	59.54	-2.28
	AveMaxT	62.33	63.65	-1.32	62.08	62.07	0.01	63.37	64.86	-1.49	65.37	65.86	-0.49	70.82	71.16	-0.34
	AveMinT	58.51	60.08	-1.57	57.10	57.48	-0.38	57.08	58.52	-1.44	59.98	60.55	-0.57	63.21	64.73	-1.52
2000	MaxMaxT	69.33	68.34	0.99	66.02	66.64	-0.62	74.72	69.64	5.08	70.22	70.71	-0.49	77.52	76.22	1.30
	MinMinT	56.45	55.59	0.86	52.46	53.18	-0.72	54.46	54.14	0.32	55.30	56.02	-0.72	58.95	59.54	-0.59
	AveMaxT	65.01	63.46	1.55	61.99	61.88	0.11	67.33	64.66	2.67	65.87	65.65	0.21	72.24	70.77	1.47
	AveMinT	60.48	59.61	0.87	56.62	57.03	-0.41	57.77	58.06	-0.29	59.82	60.08	-0.26	63.90	63.85	0.05
Average Difference				0.12			-0.27			0.17			-0.23			0.08
Max Absolute Difference				3.31			0.83			5.08			1.26			2.28

Table 3 Comparison of statistics for the 50-day sample

5 Day Sample Interval 8/1-8/5

Year	Stat	Boulder Ck			Cedar Ck			City Ck			Little Rock Ck			Steamboat Ck		
		Actual	Calc	Diff	Actual	Calc	Diff	Actual	Calc	Diff	Actual	Calc	Diff	Actual	Calc	Diff
1997	MaxMaxT	68.00	67.82	0.18	65.73	65.60	0.13	68.73	69.06	-0.33	70.52	70.13	0.39	76.28	76.11	0.17
	MinMinT	61.20	61.21	-0.01	57.74	57.84	-0.10	58.93	58.98	-0.05	61.79	61.80	-0.01	65.83	65.81	0.02
	AveMaxT	66.70	66.70	0.00	64.52	64.51	0.00	67.92	67.92	0.00	68.98	68.97	0.00	74.86	74.86	0.00
	AveMinT	61.82	61.82	0.00	58.42	58.42	0.00	59.56	59.56	0.00	62.42	62.42	0.00	66.47	66.47	0.00
1998	MaxMaxT	70.51	69.51	1.00	67.49	67.24	0.25	70.80	70.78	0.02	72.02	71.88	0.14	78.15	78.01	0.14
	MinMinT	62.08	62.04	0.04	59.43	58.62	0.81	60.65	59.78	0.87	62.36	62.64	-0.28	67.28	66.71	0.57
	AveMaxT	68.98	68.27	0.71	66.32	66.04	0.28	69.91	69.52	0.39	70.52	70.60	-0.08	76.59	76.62	-0.03
	AveMinT	63.92	63.27	0.66	60.74	59.78	0.96	61.56	60.96	0.60	64.09	63.88	0.21	68.57	68.03	0.54
1999	MaxMaxT	65.83	66.14	-0.31	64.28	63.97	0.31	66.98	67.35	-0.37	68.73	68.40	0.33	73.81	74.23	-0.42
	MinMinT	59.25	60.11	-0.86	56.35	56.80	-0.45	56.96	57.92	-0.96	60.64	60.69	-0.05	60.94	64.63	-3.69
	AveMaxT	64.96	65.42	-0.46	63.31	63.28	0.03	65.87	66.62	-0.74	67.69	67.65	0.04	73.21	73.42	-0.21
	AveMinT	60.61	61.60	-0.99	57.80	58.21	-0.41	58.20	59.35	-1.15	61.79	62.20	-0.41	63.53	66.24	-2.71
2000	MaxMaxT	69.03	67.82	1.21	65.73	65.60	0.13	73.20	69.06	4.14	69.92	70.13	-0.21	76.90	76.11	0.79
	MinMinT	62.65	61.49	1.16	57.74	58.10	-0.36	58.93	59.24	-0.31	61.79	62.08	-0.29	66.12	66.11	0.01
	AveMaxT	68.04	66.48	1.57	64.46	64.30	0.16	69.63	67.69	1.93	68.62	68.74	-0.12	75.23	74.61	0.62
	AveMinT	63.17	62.04	1.13	58.30	58.63	-0.32	59.45	59.78	-0.33	62.25	62.65	-0.40	66.93	66.71	0.22
Average Difference				0.31			0.09			0.23			-0.05			-0.25
Max Absolute Difference				1.57			0.96			4.14			0.41			3.69

Table 4 Comparison of statistics for the 5-day sample

For the August 3 data the temperature at 4 PM, and the daily maximum, minimum and mean values were derived from the 1997 ratio values. Table 5 compares the derived results with the observed values. Note that the zero difference values in the 1997 data is because the ratio was determined from a single value rather than from interval average.

1 Day Sample 8/3 @16:00

Year	Stat	Boulder Ck			Cedar Ck			City Ck			Little Rock Ck			Steamboat Ck		
		Actual	Calc	Diff	Actual	Calc	Diff	Actual	Calc	Diff	Actual	Calc	Diff	Actual	Calc	Diff
1997	CurrentT	66.20	66.20	0.00	64.28	64.28	0.00	66.40	66.40	0.00	68.73	68.73	0.00	74.42	74.42	0.00
	MaxT	67.30	67.30	0.00	65.15	65.15	0.00	68.44	68.44	0.00	69.62	69.62	0.00	75.35	75.35	0.00
	MinT	62.20	62.20	0.00	59.15	59.15	0.00	60.08	60.08	0.00	62.94	62.94	0.00	66.99	66.99	0.00
	AveT	64.65	64.65	0.00	62.09	62.09	0.00	63.06	63.06	0.00	66.46	66.46	0.00	70.44	70.44	0.00
1998	CurrentT	68.74	67.88	0.86	66.32	65.91	0.41	67.86	68.08	-0.22	70.52	70.47	0.05	76.59	76.31	0.28
	MaxT	70.21	69.55	0.66	67.49	67.33	0.16	70.80	70.73	0.07	72.02	71.95	0.07	78.15	77.87	0.28
	MinT	64.96	63.87	1.09	61.42	60.74	0.68	62.06	61.69	0.37	64.96	64.63	0.33	69.33	68.79	0.54
	AveT	67.58	66.64	0.93	64.46	64.01	0.45	65.28	65.01	0.27	68.61	68.50	0.10	72.93	72.61	0.31
1999	CurrentT	65.25	66.20	-0.95	63.71	64.28	-0.57	64.07	66.40	-2.33	68.15	68.73	-0.58	73.81	74.42	-0.61
	MaxT	65.83	66.18	-0.35	64.28	64.07	0.21	66.98	67.30	-0.32	68.73	68.46	0.27	73.81	74.10	-0.29
	MinT	61.24	62.48	-1.24	58.30	59.41	-1.11	58.65	60.35	-1.70	62.07	63.22	-1.15	66.41	67.29	-0.88
	AveT	63.46	64.12	-0.66	61.34	61.59	-0.24	61.68	62.55	-0.87	65.41	65.91	-0.50	69.35	69.86	-0.52
2000	CurrentT	67.58	65.92	1.66	63.99	64.01	-0.02	66.69	66.12	0.57	68.44	68.44	0.00	74.73	74.11	0.62
	MaxT	67.58	66.18	1.40	63.71	64.07	-0.36	67.57	67.30	0.27	67.57	68.46	-0.89	74.12	74.10	0.02
	MinT	62.94	61.37	1.57	57.74	58.36	-0.62	59.22	59.28	-0.06	61.79	62.10	-0.31	66.12	66.10	0.02
	AveT	65.30	63.60	1.70	61.01	61.09	-0.08	62.46	62.04	0.42	64.96	65.38	-0.42	69.71	69.30	0.42
Average Difference				0.42			-0.07			-0.22			-0.19			0.01
Max Absolute Difference				1.70			1.11			2.33			1.15			0.88

Table 5 Comparison of the derived and the observed values for the August 3 data

Discussion:

The objective of this project was to extract quantifiable site-specific information from the hundreds of digital temperature data files available for the Umpqua Basin. The results seem to indicate that synoptic data sites with data from a specified reference year site can be used create a set of relative site indices for specific statistics that provides an indication of the thermal response of the sites with respect to a control site. Also, as shown in tables 3-5, the indices can be used with control site data from a different year to create estimated results for the other sites for that year. These results validate the assumption that it is possible to extract additional quantifiable information from the Umpqua data by using synoptic data from paired sites.

Caveats to consider

- The use of simple ratios between the control and the other sites was used to test the paired site concept and is not necessarily the optimum parameter to use.

- This method assumes similar responses between the watersheds being compared and this study was confined to a relatively small area. If applying the method to a different area, the data for the calibration year should show patterns with similar shape and the corresponding daily ratios should be reasonably constant across the sample interval as shown in Figure 6. 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.

- Riparian areas are dynamic and changing conditions will change the thermal site characteristics over time. Generally these changes take place at a slow rate but drastic or episodic events can occur and need to be taken into account. Trend type changes identified by this method will be the result of changes in both the control site and the site of interest. It is expected that the change associated with changes in the control site would produce a fixed error in all of the results that could be identified by analysis of the data.

- Inter-year changes in the datalogger locations can introduce significant variability and care should be taken to replicate the logger location exactly. Unfortunately, detailed deployment records are not usually available for the historic data and location-change-error may be inherent at some of the sites.

- The selected sample interval should be made for the same time period each year to eliminate the solar path effects. Stable weather conditions during the sample interval will produce the best results.

- 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.

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

Next steps:

A set of Excel macros have been developed to facilitate the creation of a set of ratios and corresponding calculated values any of the temperature data files available for the Umpqua Basin.

Continue outreach to recommendations optimizing the method.

Test the effective range of the control site. The selected sites were within about a 20-mile radius of each other. Data from more distant points in the lower basin indicate that the seasonal patterns are similar but use of a more distant site for a control has not been tried at this time.

If this method is used, it is recommended that the calculated results be compared with measured values for at least one year other than the reference year. Extrapolation of the method to sites with only one synoptic paring with the control site should be done with caution.

Transient weather conditions during the selected interval may affect the sensitivity of the ratio value or produce more variability in the calculated values.

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