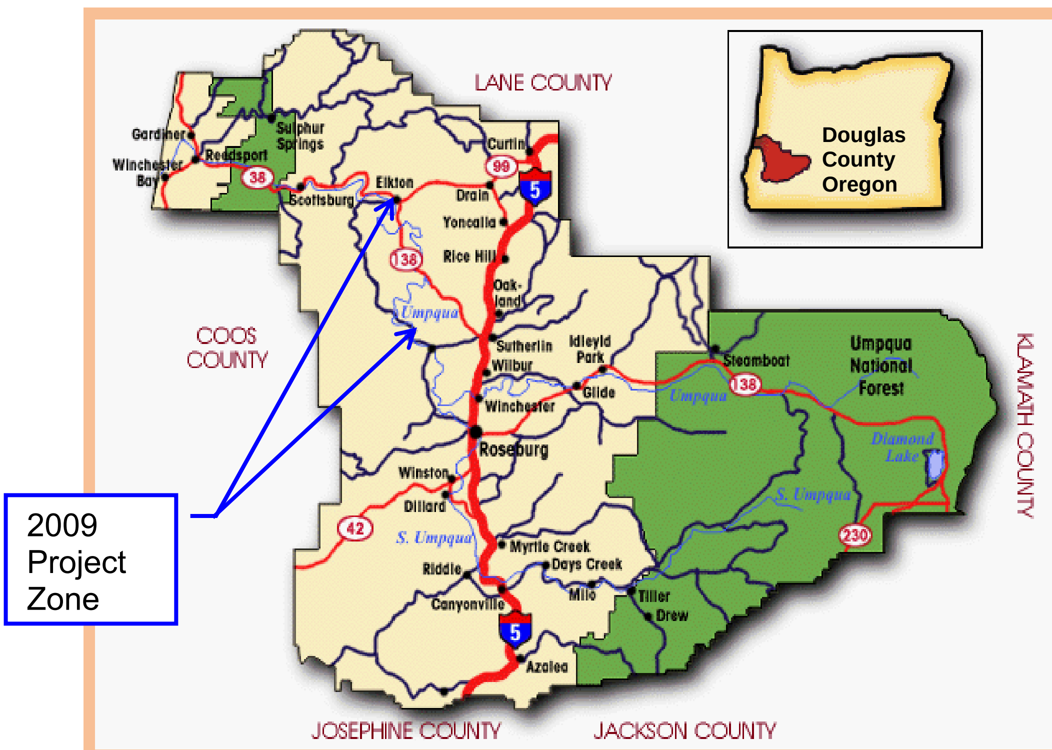
Partnership for the Umpqua Rivers

Your Watershed Council

River Temperature Variability on the Lower Umpqua 2009 Project



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About this report

This report addresses the topic of river temperature variability as identified in previous studies that included time-series data, grab samples and TIR data from the 2002 flight by Watershed Sciences of Corvallis, Oregon. Background and other relevant information are included in the following supplemental Appendices:

- **A.** PUR Supplemental Field Data
- **B.** Time Series Data
- **C.** Spatial Distribution Charts
- **D.** Site Data

This report with associated data is available online at Yoncalla.net/temperature_12.

Acknowledgments

Alan Bunce with data logger

Vince Fox & Sandy Lyon

Special thanks goes to Sandy Lyon of the PUR Watershed Council for her grant administration and project coordination work as well as her invaluable help with deployment and retrieval of the data loggers. Thanks also to Vince Fox, a master river boatman, who made access to the entire river as easy for us as a walk in the park.

Obtaining synoptic data from the thalweg of a large river is problematic to say the least. We are grateful for the assistance of Alan Bunce who enabled the retrieval of the concrete block weighted data loggers by snorkel diving in swift current to depths exceeding 20 feet.

Kudos to the Oregon Department of Environmental Quality for having the foresight to obtain the TIR data for the Umpqua System. This is a very rich information data resource for understanding the thermal characteristics of the Umpqua River system.

Disclaimers

This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement C9-00045108 to the Oregon Department of Environmental Quality. The content of this document does not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Comments Are Welcome

Suggestions and comments are welcome. The data files are also available upon request.

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River Temperature Variability on the Lower Umpqua 2009 Project

By Kent Smith, Hydrologist, Insight Consultants
February, 2012

Background – Previous Work

The Pacific Coastal River System contains habitat and spawning sites for several important fish populations and the 4700 square mile Umpqua Basin is one of the largest basins within the system. River temperature is particularly important in the larger basins because larger streams tend to experience higher temperatures which can create a "thermal barrier" for temperature sensitive fish species attempting the two hundred mile journey to the headwater spawning areas.

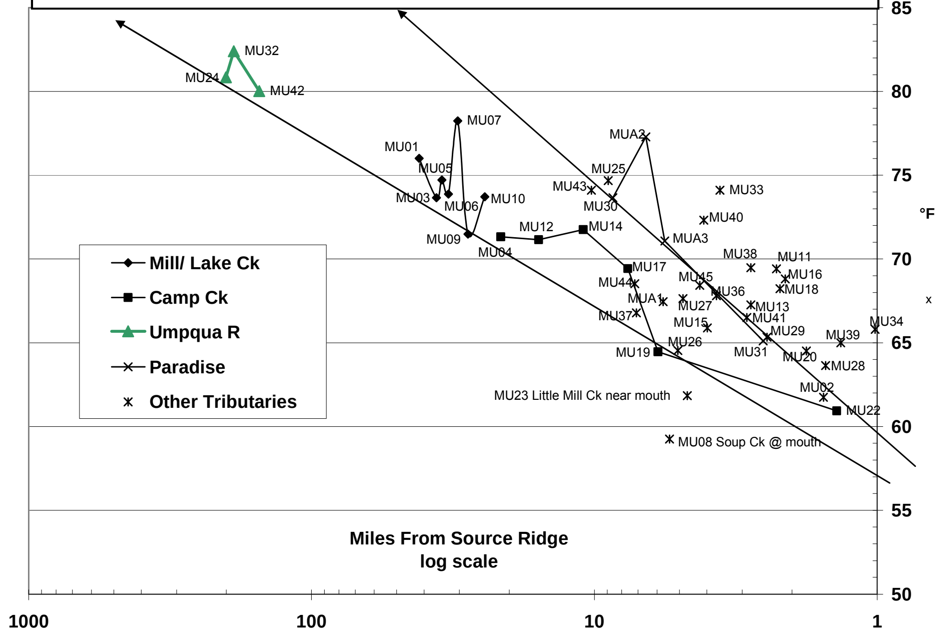
Umpqua Basin Temperature Characterization Studies

In 1998 a project was started to identify the stream temperature characteristics in the Umpqua Basin by systematically collecting a large amount of synoptic time-series data from streams within the subwatersheds of the basin. For four years, about 100 data loggers were deployed during the summer season between two subwatersheds to obtain representative temperature data at sites located from the headwaters to the mouth of each subwatershed. The emphasis was on maximum summer temperatures and the data was processed to display some of the distribution characteristics including the temporal and spatial variability of the daily maximum temperature statistic.   The report Stream Temperature in the Umpqua Basin (Reference 3) contains a summary of this work.

One result of this work was data related to the special distribution of specific temperature data parameters. Chart 1 shows the distribution of the August 8, 2000 maximum temperature value for locations on the Lower Umpqua and associated tributaries as a function of the distance to their respective source points. These results are consistent with the concept that stream temperatures tend to increase in the downstream direction. It was also noted that the limited data in the Lower Umpqua River displayed considerable variability. This was attributed to the fact that placement of data loggers in the large river is generally limited to a few sites along the edge that will remain submerged and are accessible. The physical conditions of these sites are quite variable and contribute to the variability in the temperature data.

It was also noted that the water temperature in the lower river can exceed 80°F during a portion of its diurnal cycle. This is a serious issue since this portion of the river is a conduit for migratory fish for the entire basin.

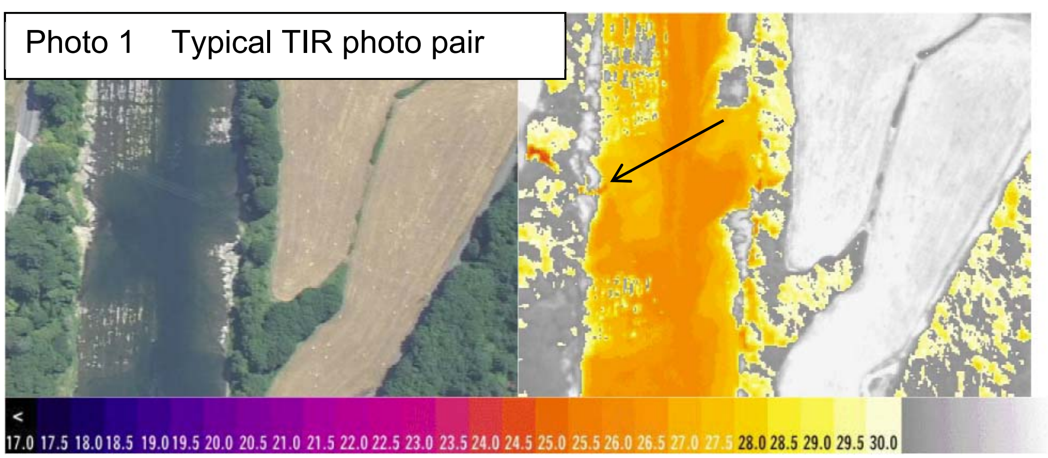
Chart 1 Maximum Temperature on 8/8/2000 as a Function of Distance From Source



2002 TIR Data

In the summer of 2002, Oregon DEQ contracted with Watershed Sciences, LLC of Corvallis to conduct airborne thermal infrared (TIR) remote sensing surveys in the Umpqua Basin[2]. An extensive set of images with an area of approximately 1200 by 1400 feet were taken along the river route at approximately 700 foot intervals. A software application was provided to conveniently view these images along with the locations superimposed on a color ortho-photo of the project area using ESRI GIS version 3.2. Photo 1 shows a typical photo pair from the Watershed Sciences data file. [Note the small thermal influence of Paradise Creek as indicated by the arrow.]
In general, the TIR data confirmed that the water surface temperature of the river edges were typically warmer and more variable while the surface water temperature of the central thalweg was fairly uniform and cooler. Exceptions occurred at the mouth of some of the tributaries that displayed a small cool zone associated with the outflow from the tributary that was typically located on the edge of the river channel.

Photo 1 Typical TIR photo pair



In addition to supplying image pairs at over 17,000 locations, Watershed Sciences also specifically sampled the center portion of the channel for selected sites as shown in Photo 2 that was excerpted from the Watershed Sciences document. The radiant temperature (pixel value) was queried from each "X" point and the maximum, median, and minimum value was generated for each sample. Some of these data were plotted as a longitudinal profile for a section of Lower Umpqua.

Photo 2 TIR color video image pair showing how temperatures are sampled from the TIR images. The black *X's* on the TIR image show typical sampling locations near the center of the stream channel.

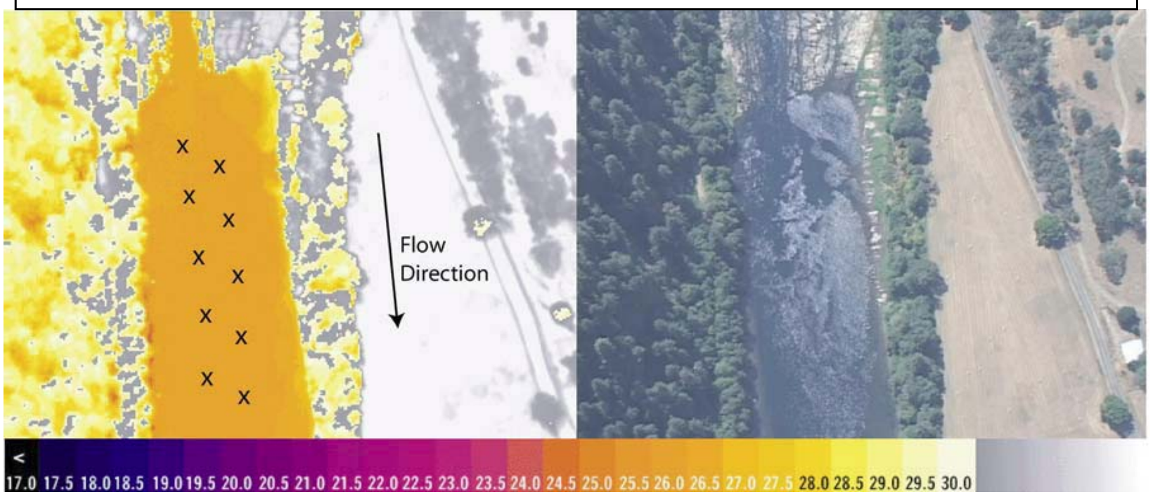


Chart 2 shows the maximum, minimum, and median sampled values for the project area. Note that the flight time through the project area was less than 26 minutes and adjustments for diurnal heating were not made in this case since typical thalweg heating rates are about 0.3°C/hr. Also, note that the River Miles indicated in Chart 2 is based on the TIR flight data and is offset somewhat from the River Miles that appear on the USGS quad maps.

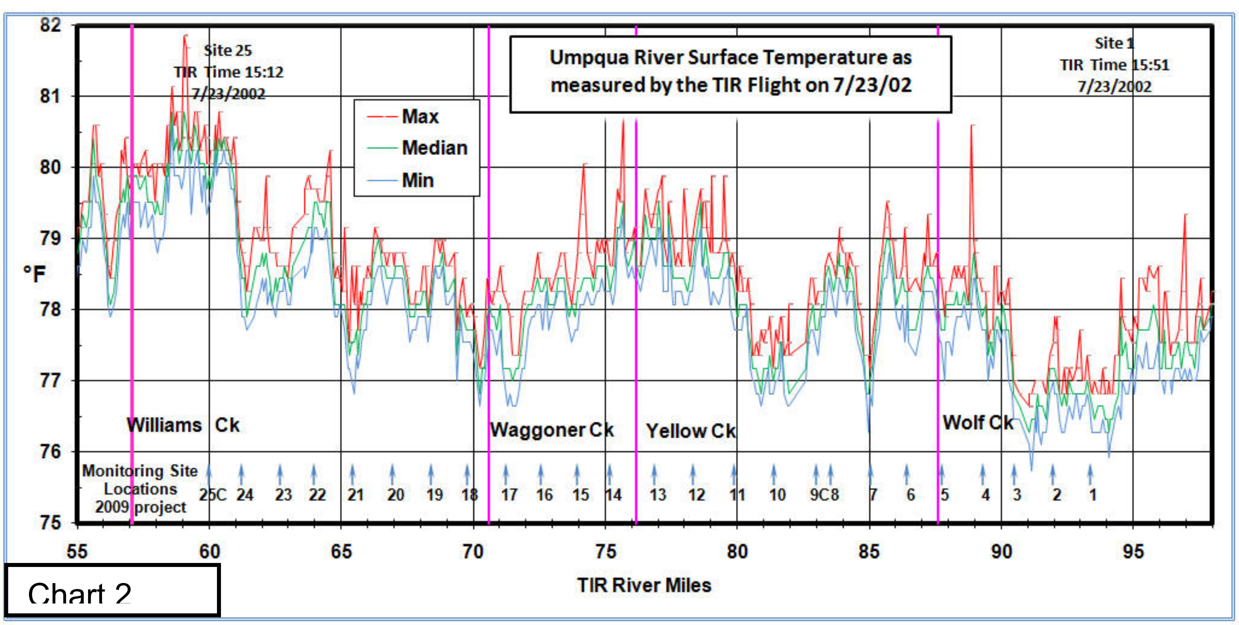


Chart 2

While the TIR project provided excellent information on the spatial distribution of the surface temperature of the river, questions remained regarding subsurface influences and the dynamic temporal distribution patterns. Particular interest was focused on the source of the variability that appears in the data and the possibility of cool "refugia" zones.

In 2008 the Partnership for the Umpqua Rivers Watershed Council (PUR) conducted water quality sampling on about 24 Umpqua River miles between Mill Creek and Elkton. Intensive bottom sampling using temperature probes did not detect significant cold-water inflow. Also, several data loggers were deployed along the edges of the river as well as at the mouth of several tributaries. This work confirmed the edge effects that were apparent in the TIR data. In some shallow areas the edge temperature was noticeably higher than the main channel. However, the small edge zone associated with the mouths of small tributaries or seep zones could be noticeably cooler. The results of this work are reported on the 2008 Report (Reference 2).

2009 Project Description

Objective of 2009 Study:

To quantify the dynamic response of the thalweg temperature of the river within a temporal and spatial context and relate the results to site specific physical characteristics of the river.

The remaining challenge was to quantify the dynamic response of the thalweg temperature within a temporal and spatial context. There is a scarcity of synoptic time-series temperature data from the thalweg of large rivers due to the obvious challenges of deploying and retrieving a set of data loggers from deep flowing water. In the summer of 2009 PUR initiated a study to address this challenge by deploying 33 temperature dataloggers at 25 sites over 33 miles of the Umpqua River between the James Wood and the Big K boat landings (Map 1). The TIR chart (Chart 2) and the map show the location of the monitoring points. Four additional loggers were deployed at two sites to obtain cross section data (indicated by the red slash lines on the map). Pictures of all of the deployment locations are available in Appendix E Site Photos.

Methodology

Site selection: An attempt was made to space at a uniform distance while trying to get representative samples over the range of channel conditions variability. The samples are somewhat biased in that white water and high use areas were avoided.

Deployment: The data loggers were weighted using cement blocks as shown in Photo 3. In deep areas floats were attached to increase visibility but were adjusted to remain below the surface to reduce contact with recreational boaters and tubers.

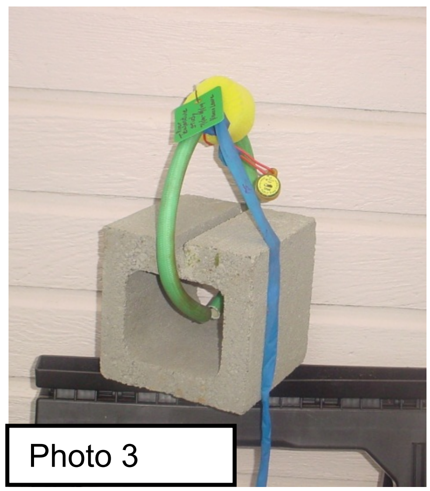
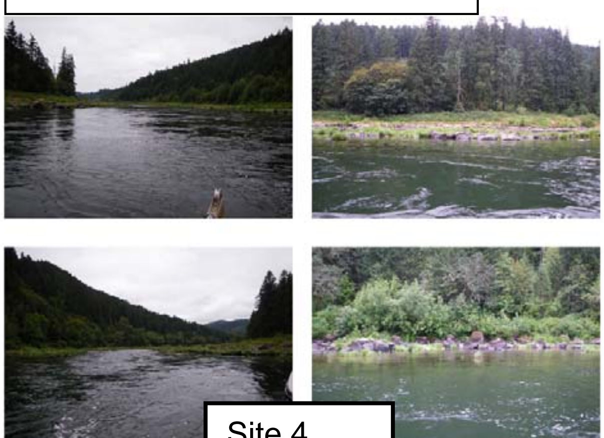


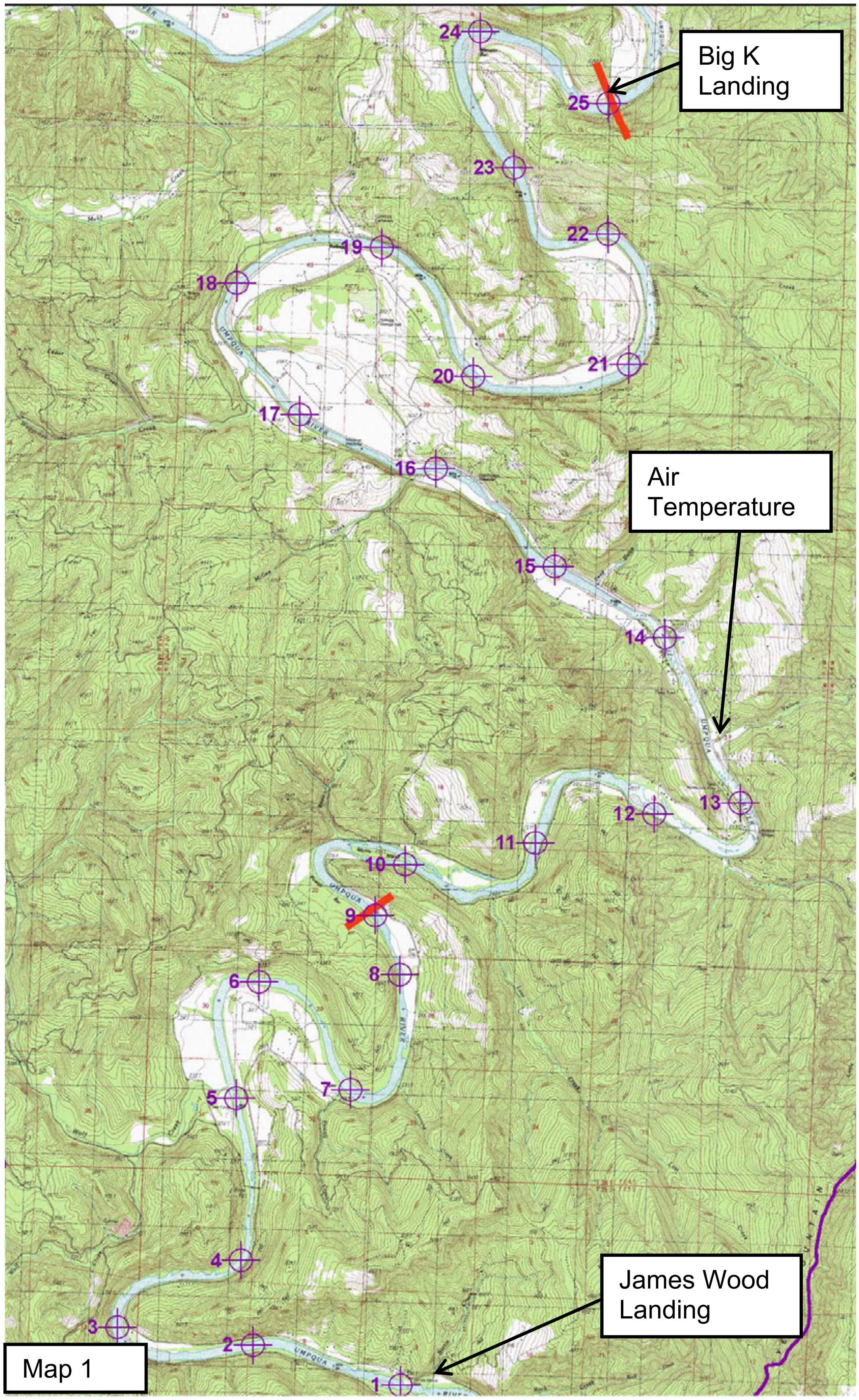
Photo 3

Typical Deployment Photos



Site 4

Site 5


24
25
Big K
Landing
23
22
19
18
21
20
17
16
Air
Temperature
15
14
13
12
11
10
9
8
6
7
5
4
3
2
1
James Wood
Landing
Map 1

A drift boat with motor was used for deployment and redundant GPS readings were taken to establish the location of the deployed units. A set of photos in each direction were taken for each site. It was found that the parallax between near and distance objects in the photos was very helpful for relocating the deployment location.

Air temperature was recorded by simply placing a data logger in a shaded tree located at Yellow Creek Park, near the midpoint of the project (Photo 4).

Photo 4

Retrieval: One pass was made with the drift boat and most of the units were retrieved using a hooked pole. For eight of the locations we were assisted by Alan Bunce who retrieved them by snorkel diving in the river – in some cases in swift current and depths up to 25 feet. We were unable to locate two of the 33 deployed units (Sites 21 and 22).

GIS Work

GIS mapping data were collected to obtain information on the physical characteristics and thermal properties of each site (Photo 5). A complete set of GIS comparison photos for all of the sites is located in Appendix D Site Data.

Five upstream sample points were set at 100 ft intervals at each site. The TIR grid files containing the temperature information were georeferenced to fit the matching ortho-photo and the temperature data was classified to a fixed temperature range of 22 to 30°C to provide higher color contrast in the thermal imagery. Note: The blank areas in the colored grid rectangles represent temperatures greater than 30°C.

The TIR temperature was obtained at each of the six points and the mean value calculated to represent the thermal conditions in the thalweg area immediately upstream. This step was taken to enable a direct comparison the median temperature data that was supplied by Watershed Sciences that used a more general sampling grid that was not necessarily specific to the thalweg (See Chart 3).

Average stream width was calculated from cross sections taken at the site and the upstream points ((green lines in Photo 5). Also, incident solar radiation was calculated for each point using the ESRI Radiation Tool.

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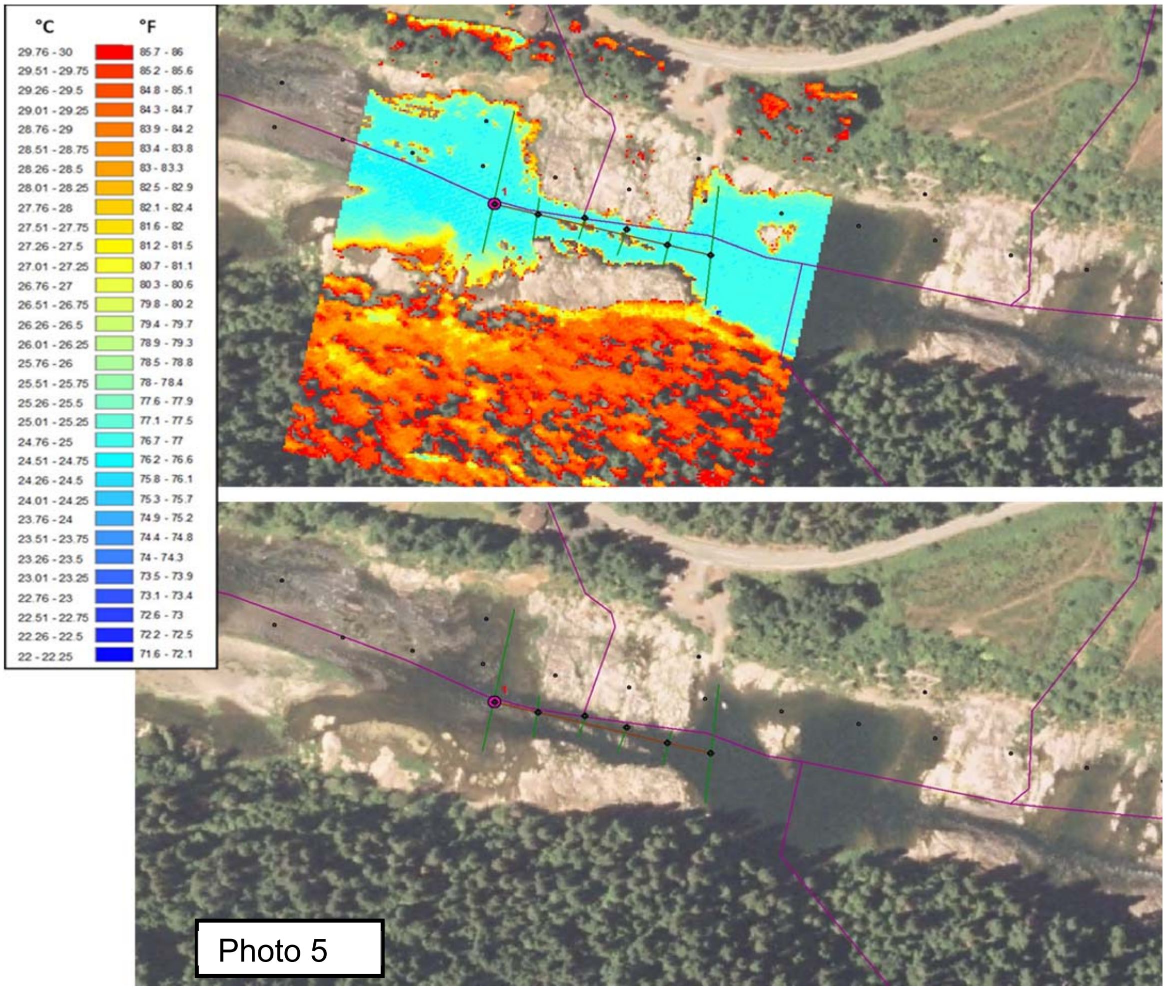


°C °F
29.76 - 30 85.7 - 86
29.51 - 29.75 85.2 - 85.6
29.26 - 29.5 84.8 - 85.1
29.01 - 29.25 84.3 - 84.7
28.76 - 29 83.9 - 84.2
28.51 - 28.75 83.4 - 83.8
28.26 - 28.5 83 - 83.3
28.01 - 28.25 82.5 - 82.9
27.76 - 28 82.1 - 82.4
27.51 - 27.75 81.6 - 82
27.26 - 27.5 81.2 - 81.5
27.01 - 27.25 80.7 - 81.1
26.76 - 27 80.3 - 80.6
26.51 - 26.75 79.8 - 80.2
26.26 - 26.5 79.4 - 79.7
26.01 - 26.25 78.9 - 79.3
25.76 - 26 78.5 - 78.8
25.51 - 25.75 78 - 78.4
25.26 - 25.5 77.6 - 77.9
25.01 - 25.25 77.1 - 77.5
24.76 - 25 76.7 - 77
24.51 - 24.75 76.2 - 76.6
24.26 - 24.5 75.8 - 76.1
24.01 - 24.25 75.3 - 75.7
23.76 - 24 74.9 - 75.2
23.51 - 23.75 74.4 - 74.8
23.26 - 23.5 74 - 74.3
23.01 - 23.25 73.5 - 73.9
22.76 - 23 73.1 - 73.4
22.51 - 22.75 72.6 - 73
22.26 - 22.5 72.2 - 72.5
22 - 22.25 71.6 - 72.1

Photo 5

Results

Time-series data

The primary output of this project was the collection of synoptic time-series data, collected at 30-minute intervals, from the river thalweg. Out of 25 units deployed, 23 were successfully retrieved. Five additional dataloggers were used to sample cross sections at two sites and one unit was used to sample air temperature.

Chart TS 1 shows examples of the data for the entire study period for three of the sites. Appendix B Time Series Data displays charts for all of the sites. At this chart scale the similarity of response to the seasonal conditions is striking. The charts also show the mean daily temperature (plotted at noon).

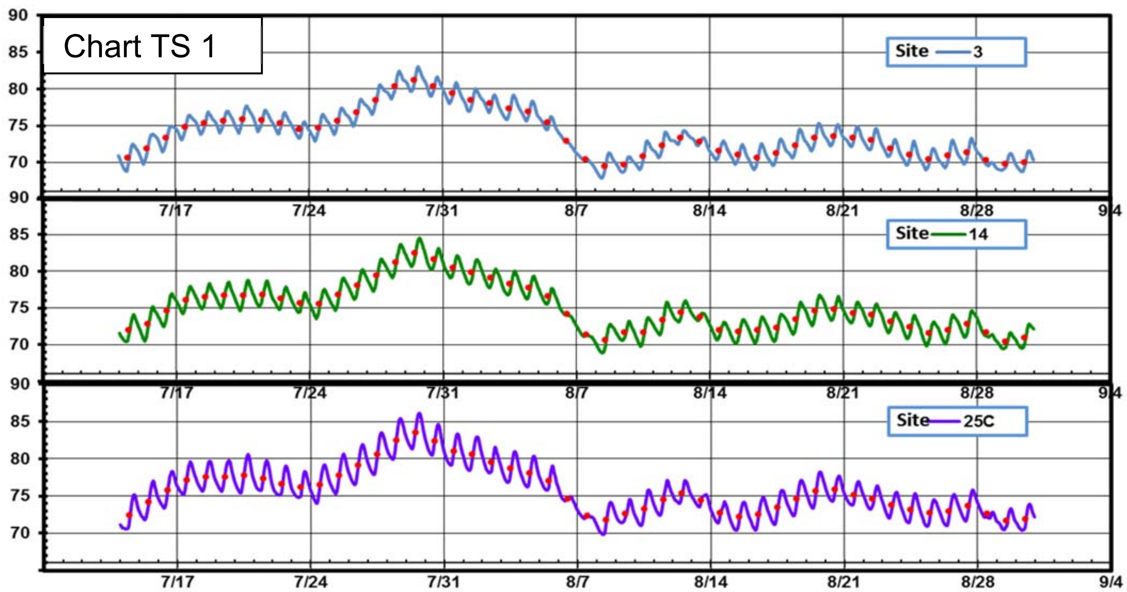


Chart TS2 better illustrates the range of temperature variability between the sites. The blue vertical line denotes the time 15:30 and intersects the data information that would be obtained from a typical TIR flight.

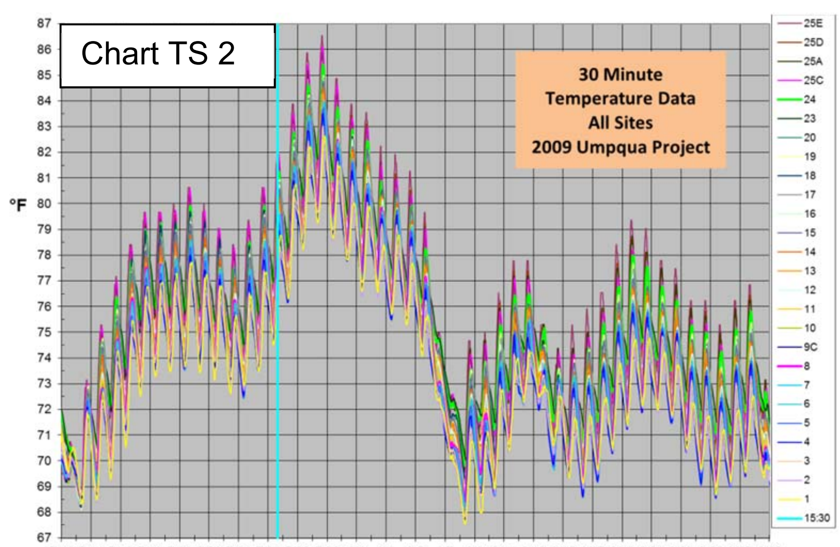


Chart TS 3 compares the air temperature data with two representative water temperature sites.

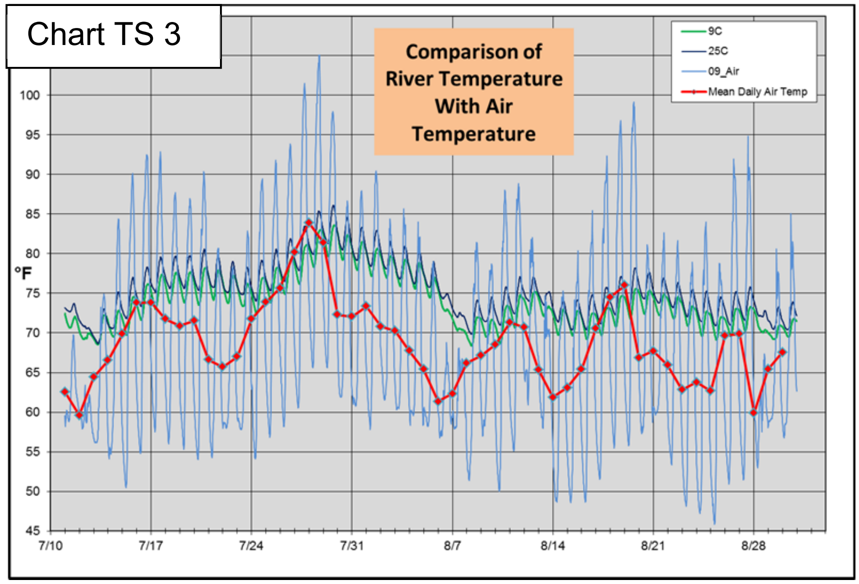


Chart TS 3

Chart TS 4 shows the phase relationships and the response characteristics of the individual sites. It is apparent that heating starts after sunrise, obtains a maximum rate near noon, and reaches maximum temperature in late afternoon. Note that the phase relationship between sites may vary by several hours and that the "15:30" line will intersect each site curve at a somewhat different point in its heating cycle implying that the intersecting value will not necessarily represent the same position on the heating curve for every site

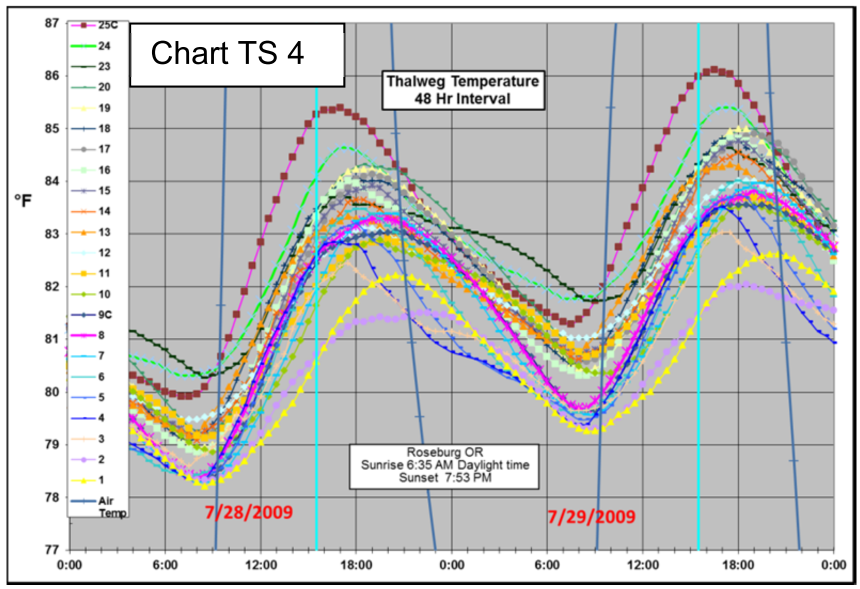


Chart TS 4

Chart TS 5 shows the data from the two sites with cross-section data. Note the difference in magnitude and phase for some of these points.

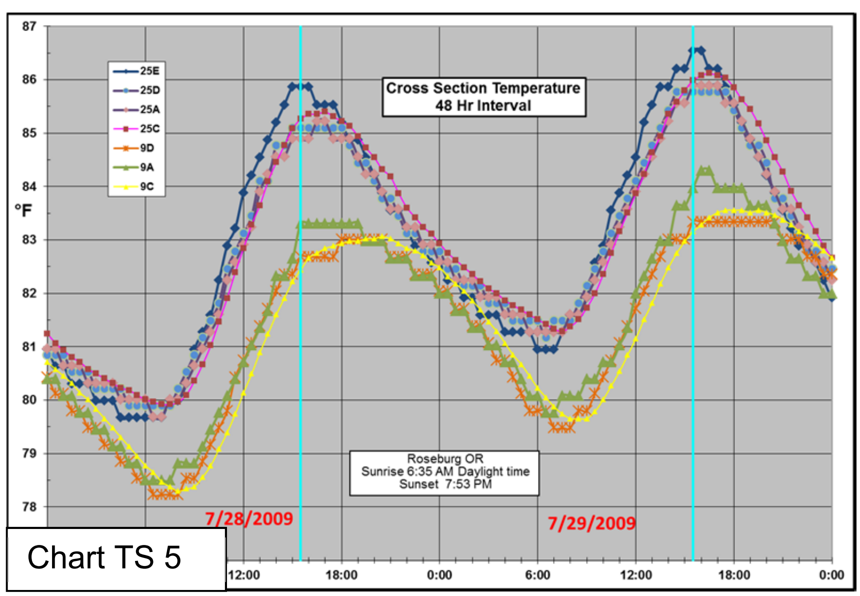
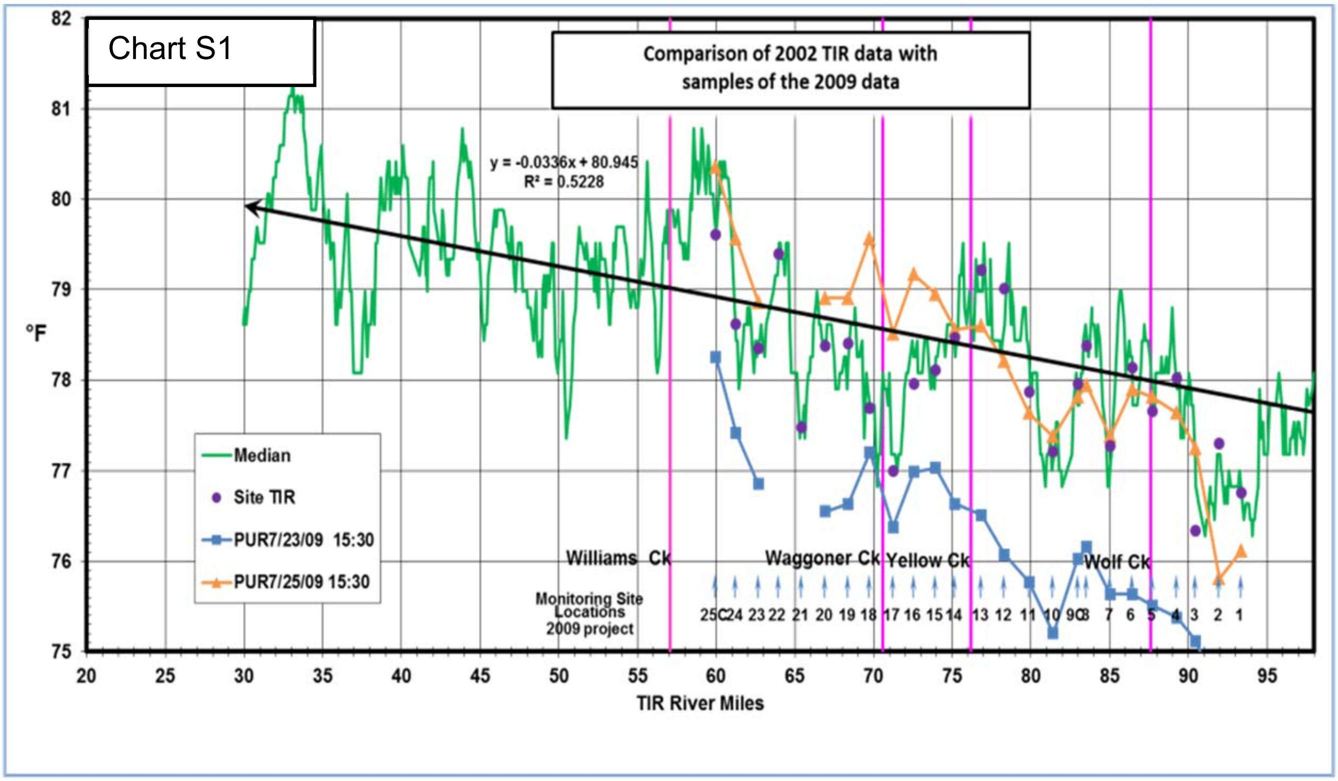


Chart TS 5

Spatial Distribution

Comparison of GRID data sampling

One objective of the study was to compare the median temperature results sampled by Watershed Sciences from the TIR GRID data with the thalweg-specific PUR GRID sampling. The results of this comparison are shown in Chart S1 (labels Median and Site TIR). Note that the results are in good agreement.



A linear regression line was run on the TIR Median data to establish a reference line to adjust for the downstream heating effect. Two examples from the 2009 temperature data for the 15:30 time period are also shown. The 7/23/09 data corresponds to the 7/23/02 date of the TIR flight. It is apparent conditions on 7/25/09 more nearly matched the prevailing weather conditions on the day of the 2002 flight.

3D Charts

Synoptic time-series data provides an opportunity to view the spatial and temporal response simultaneously.

Chart S2 provides a visualization of the synoptic time-series data over a two-day interval. It illustrates the dynamic pattern of the river temperature and shows variability between sites that is similar to the variability shown in the TIR data.

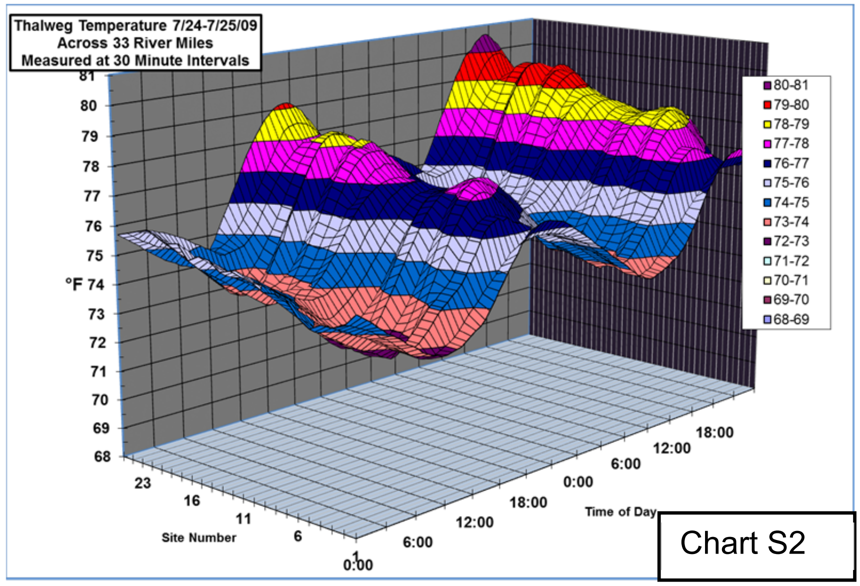
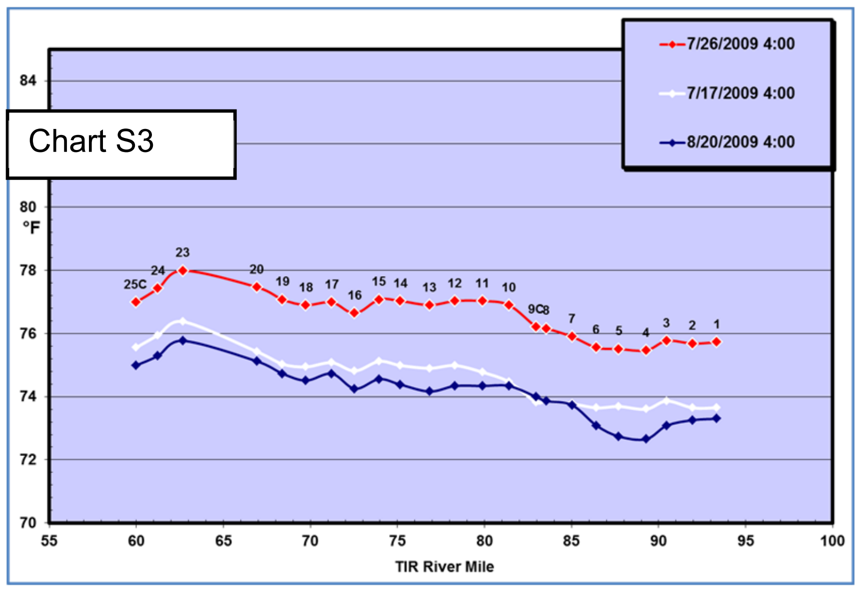


Chart S3 shows a typical spatial profile plot of temperatures measured at all of the sites at 4:00 AM on three different days. A set of these plots was generated for each 30-minute interval over a four day period with respective start dates of 7/17, 7/26 and 8/20.



These charts can be viewed as a slideshow in the Power Point file available at the Yoncalla.net website. They can also be viewed as a movie on the internet at: http://www.youtube.com/watch?v=O5KMoSH6Y3k .

Since the flight took place between 15:00 and 16:00 in 2002, the TIR median temperature data were added to all of the charts for that time interval for comparison. For example, Chart S4 shows the data for 4:00 PM with the 2002 TIR data added. The charts within this time interval can be easily identified by the gold colored background.

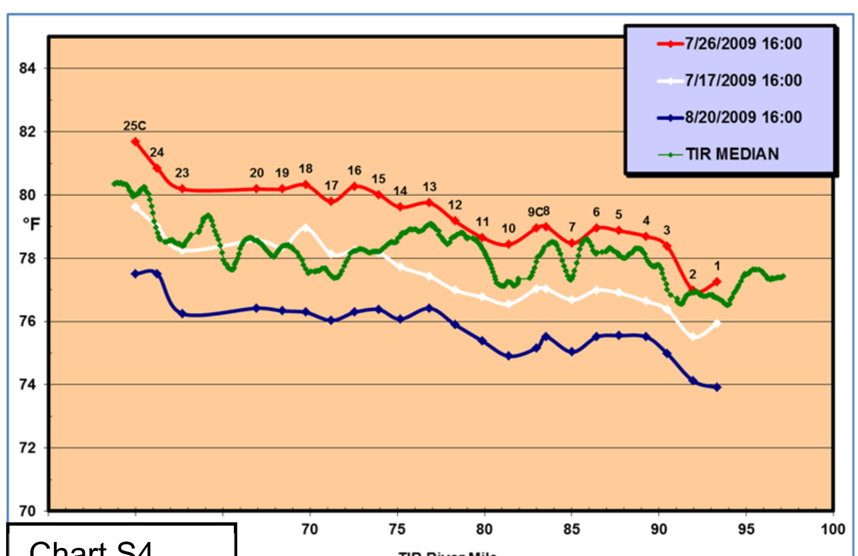


Table 1 Site Data

Site Number	TIR River Mile	Site Depth Feet	River Azimuth Upstream	River Azimuth range 0-180	Ave Site TIR °F	Average Zone Width Feet	Width At Site (Ft)	Solar Radiation (WH/m²) calculated for 7/23 00:00-16:00	Solar Radiation (WH/m²) calculated for 7/23 15:00-16:00	PUR7/23/09 15:30 °F	PUR7/25/09 15:30 °F	Deviation Site TIR from Median Reg	Relative Zone Velocity*	Relative Site Velocity*
1	93.4	5.6	104.9	104.9	76.8	165.7	365.1	4975.2	404.0	74.6	76.1	-1.05	1.45	0.66
2	92.0	6.0	79.7	79.7	77.3	364.4	368.8	4923.5	401.6	74.5	75.8	-0.56	0.62	0.61
3	90.5	4.0	154.5	154.5	76.3	269.6	245.4	4961.8	403.0	75.1	77.2	-1.57	1.25	1.38
4	89.3	10.0	221.8	41.8	78.0	131.4	165.8	4910.3	395.7	75.4	77.6	0.07	1.03	0.81
5	87.7	10.4	166.1	166.1	77.7	221.9	266.7	5009.2	411.4	75.5	77.8	-0.34	0.58	0.49
6	86.4	14.6	277.0	97.0	78.1	148.3	263.5	4982.9	404.7	75.6	77.9	0.10	0.62	0.35
7	85.0	10.0	322.2	142.2	77.3	299.7	282.5	5000.4	406.3	75.6	77.4	-0.82	0.45	0.48
8	83.6	21.0	175.2	175.2	78.4	198.3	197.9	4941.8	400.9	76.2	77.9	0.24	0.32	0.32
9	83.0	7.6	141.9	141.9	78.0	252.7	255.8	5004.8	413.9	76.0	77.8	-0.20	0.70	0.69
10	81.4	11.6	279.3	99.3	77.2	124.9	113.3	4938.4	396.9	75.2	77.4	-1.00	0.93	1.03
11	79.9	7.8	194.1	14.1	77.9	360.2	349.6	4927.8	401.3	75.8	77.6	-0.39	0.48	0.50
12	78.3	11.8	291.2	111.2	79.0	116.3	98.1	4513.3	328.7	76.1	78.2	0.70	0.98	1.17
13	76.9	12.1	158.2	158.2	79.2	140.2	153.3	4930.1	389.9	76.5	78.6	0.86	0.80	0.73
14	75.2	4.9	155.9	155.9	78.5	349.5	355.9	4991.9	406.0	76.6	78.6	0.05	0.79	0.77
15	73.9	4.0	117.8	117.8	78.1	408.7	405.5	4962.3	404.9	77.0	79.0	-0.35	0.83	0.83
16	72.6	7.7	109.1	109.1	78.0	321.3	333.4	4868.4	394.5	77.0	79.2	-0.55	0.55	0.53
17	71.2	6.4	122.7	122.7	77.0	381.0	392.6	5012.1	409.7	76.4	78.5	-1.55	0.55	0.54
18	69.8	7.0	217.8	37.8	77.7	275.0	291.3	5036.7	391.4	77.2	79.6	-0.91	0.70	0.66
19	68.4	21.0	282.5	102.5	78.4	275.2	346.7	5006.8	409.6	76.6	78.9	-0.24	0.23	0.19
20	66.9	15.4	321.5	141.5	78.4	158.0	210.5	4975.0	399.1	76.6	78.9	-0.32	0.55	0.42
21	65.4	5.3	233.4	53.4	77.5	339.9	293.6	4965.5	403.0			-1.27	0.75	0.87
22	64.0	9.0	118.7	118.7	79.4	196.1	323.0	4964.1	403.1			0.60	0.77	0.46
23	62.7	12.0	147.4	147.4	78.4	276.2	252.2	4893.4	409.3	76.9	78.9	-0.49	0.41	0.45
24	61.2	3.6	267.6	87.6	78.6	284.5	259.4	4952.0	400.8	77.4	79.6	-0.27	1.32	1.45
25	60.0	6.3	241.4	61.4	79.6	333.9	297.8	4928.8	399.6	78.3	80.4	0.68	0.64	0.72
	Maximum Value			Minimum Value									*flow: 1350 cfs	

Site Data

Information for each site was compiled from the field notes and from GIS analysis as shown in Table 1. Maximum and Minimum values are highlighted. Dataloggers for sites 21 and 22 were not found

Description of table parameters

- Site Number — PUR site reference (See Map 1 for locations).
- TIR River Mile — Distance measurements established by Watershed Sciences for the 2002 TIR Flight to reference the location of their data points. These values are different than the river mile marking on the USGS Quad maps.
- Site Depth — Depth at the deployment point. It is typically in the deepest point in the cross section. However, it is not necessarily representative of the upstream conditions.
- River Azimuth — Local river orientation based on a straight 500 foot line extending upstream from the deployment point. The values were converted to a 180 degree basis to consolidate the data.
- Ave Site TIR °F — This is the average temperature extracted from the six points that were sampled in the upstream influence zone. The data came from the TIR GRID files and corresponds to the sampling that Watershed Sciences used to develop the temperature data that they reported (See photo 2 and Chart S1).

- Average Zone Width — Average of the six cross section widths taken at each site. Widths measured from GIS ortho-photos. They represent summer conditions but not necessarily the exact conditions during the study.
- Width at Site — Used to compare relative flow velocities between the site and the influence area.
- Solar Radiation — Average results from the six sample points using the ESRI Radiation tool.
- PUR Temperature Data — two samples of the 2009 time-series data collected for the study. The 15:30 sample time corresponds roughly to the time of the 2002 TIR flight.
- Deviation of Site TIR from Median Reg — Difference between the site TIR values from the TIR median temperature regression line as shown in Chart S1. This value serves as an index of the relative temperature of each site after adjustment for the downstream heating effect.
- Relative Zone Velocity — A estimate of the average velocity in the upstream zone based on the average width, site depth and a prevailing flow of 1350 cfs.
- Relative Site Velocity — Similar to the above. These values provide an indication of the dwell time in the site area.

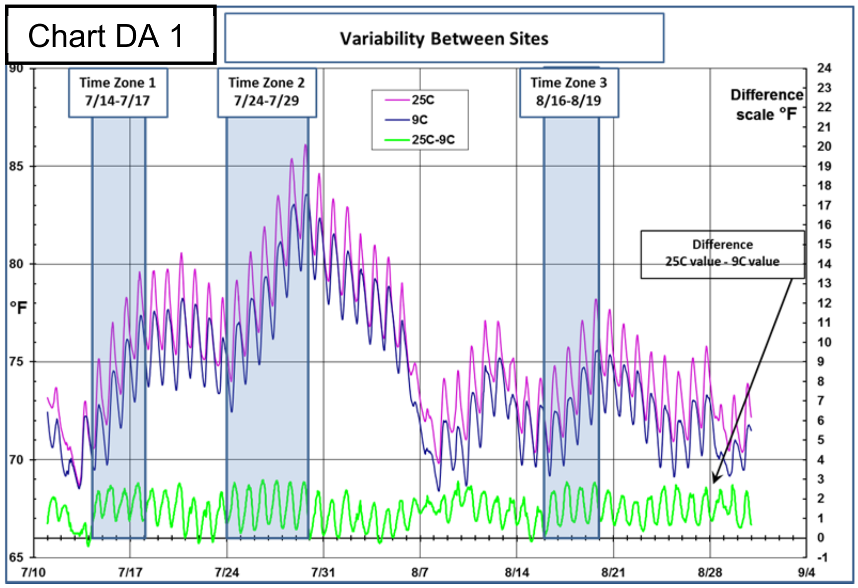
Data Analysis

Over 75,000 temperature readings were collected in the river in the summer of 2009 at twenty three locations. This section contains some attempts at analysis that may be of interest but is by no means exhaustive.

Differences Between Sites

While there is noticeable similarity in the thermal response of the sites as seen in Chart TS 1, the differences between sites is of particular interest.

Chart DA1 shows the seasonal data for two representative series and the difference (green line) between them. Note that this transformation reduces the variability from twenty °F to less than four °F.



Three time zones from within the study period were identified as being associated with the most uniform difference patterns. These time periods are associated with clear sky and warm conditions that are common during western Oregon summers. During these periods all of the sites are more likely to experience similar thermal conditions and tend to respond in unison with a fixed increase in daily values. Conversely, during cloudy or cooling conditions individual sites may not experience similar conditions throughout the day.

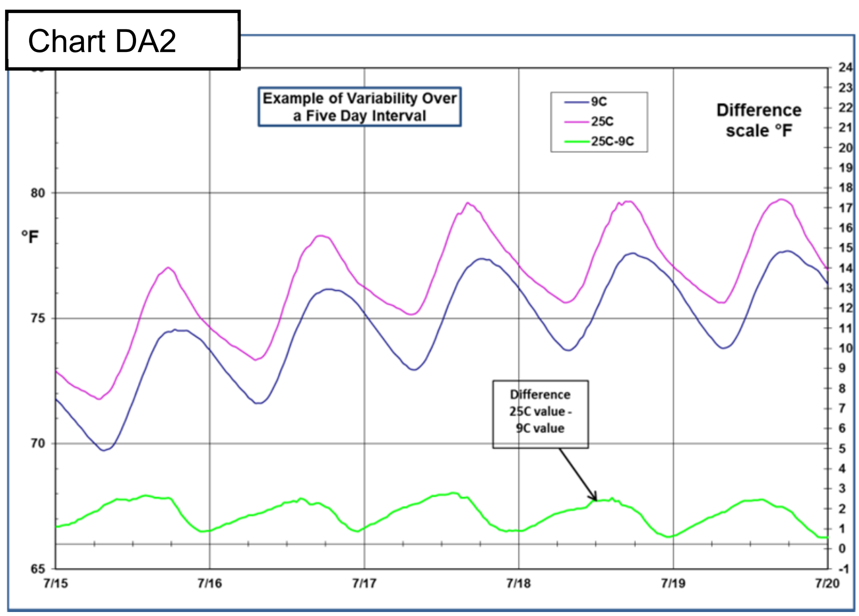
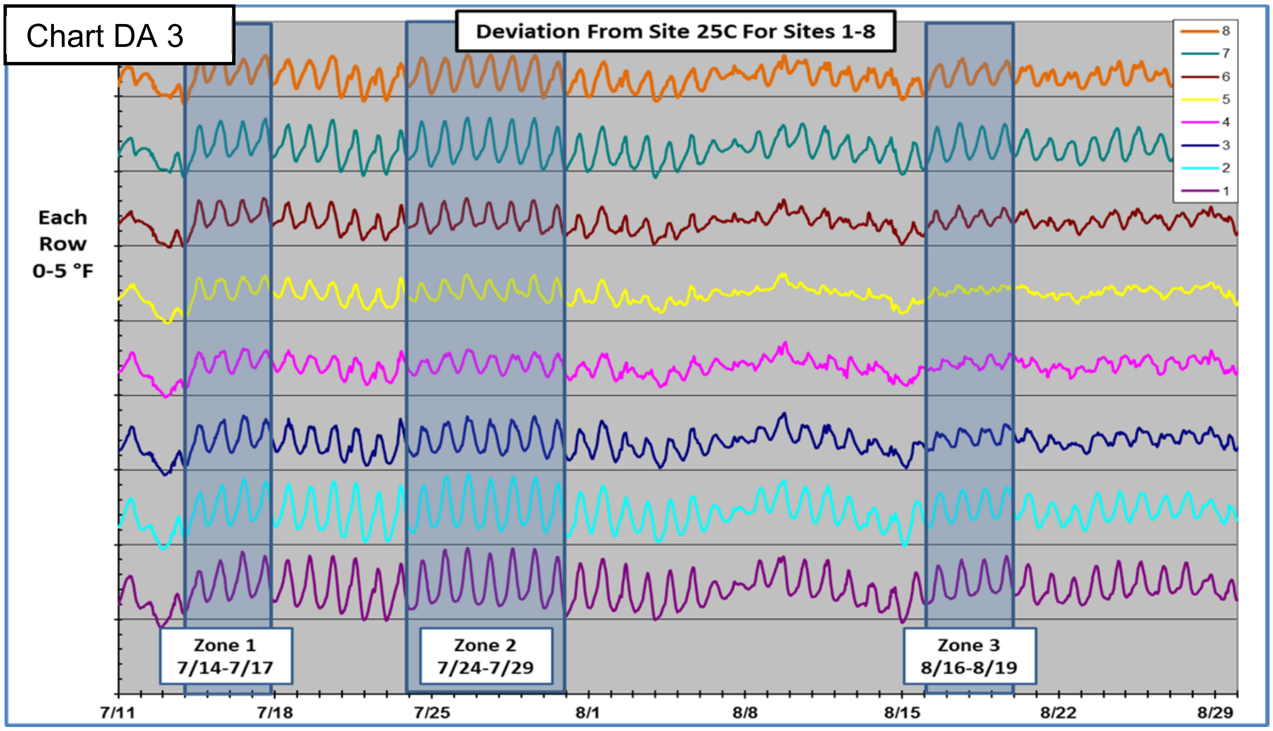


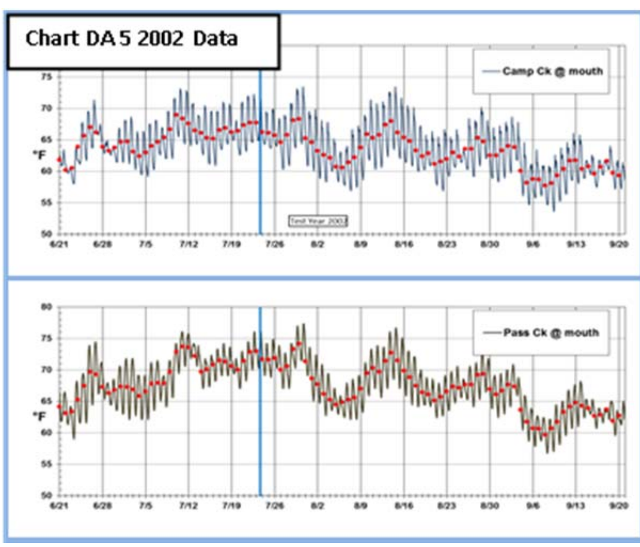
Chart DA 2 shows the relative phase relationships in more detail. It is interesting to note that the minimum occurs near midnight at the inflection point of the cooing portion of the 25C curve.

Chart DA 3 shows representative difference data for the first seven sites. Appendix B Time Series Data / Differences has data for all of the sites. Comparisons of the within-zone patterns show more similarity, indicating relative uniformity of the prevailing thermal inputs.



Compare 2002 & 2009 conditions

Since the uniformity of the thermal response of the river temperature pattern is affected by the prevailing climate conditions it is of interest to compare conditions at the time of the 2002 TIR flight with the 2009 conditions. PUR has been monitoring summer stream temperature at five locations in the lower Umpqua Basin since the year 2000 and these data provide the means to help compare seasonal patterns and weather influences for a specific date.



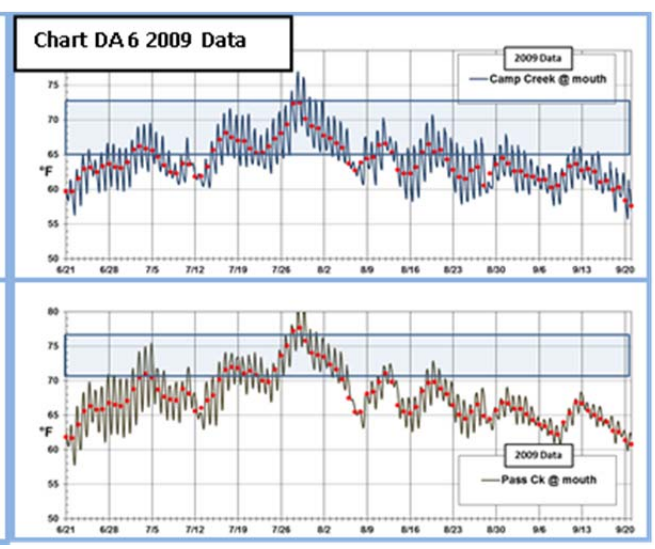
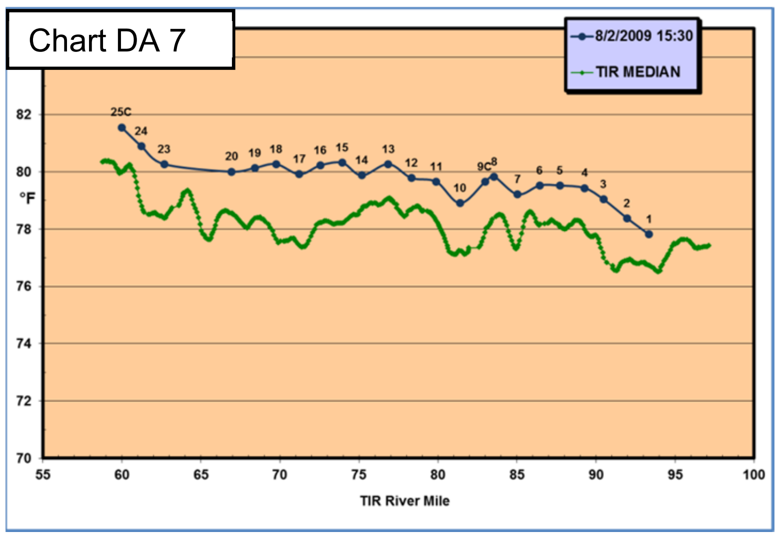


Chart pair DA 5 shows the 2002 temperature pattern for two streams in the general vicinity of the project; Camp Ck @ mouth and Pass Ck @ mouth. The vertical blue line denotes 15:30, the time of the TIR flight on 7/23. It appears that the prevailing weather condition at that time was experiencing a slight cooling trend with Camp Ck temperatures in the range between 65°F and 73°F and Pass Ck with a range of 71°F and 77°F.

Chart pair DA 6 shows the corresponding 2009 data for the reference streams with 2002 range highlighted. It appears that conditions around 8/2 would be a reasonable match for the 2002 TIR conditions.

Chart DA 7 compares the 2002 TIR median temperature data provided by Watershed Sciences with the 2009 PUR data as measured at 15:30 on 8/2/09. Even though there is a displacement difference of about 1°F the slope and shape of the curves agree quite well. Note: Chart S4 for 7/17/09 16:00 also shows a good match.

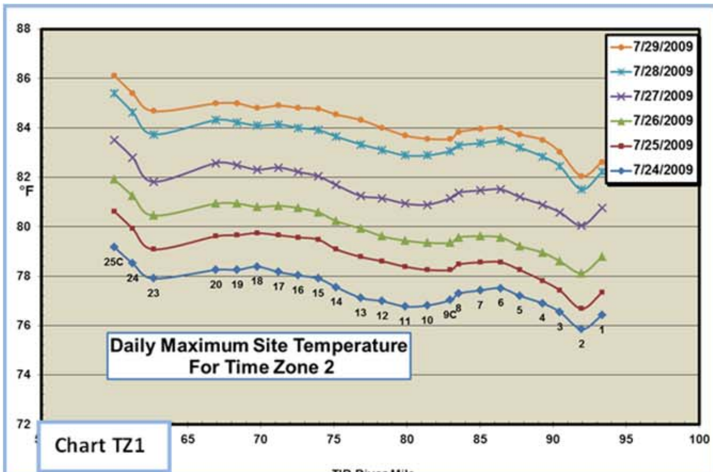


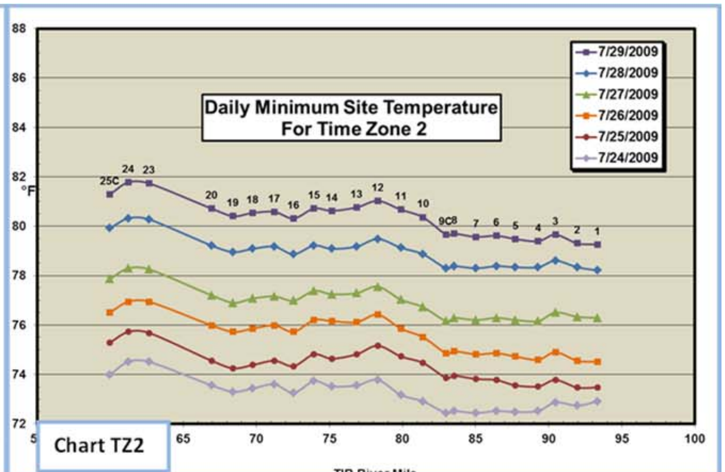
Time Zone Data Statistics

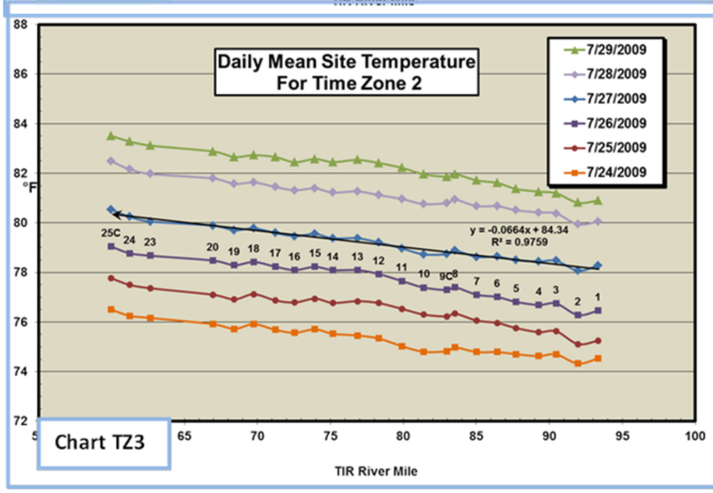
Max, min, mean, ΔT

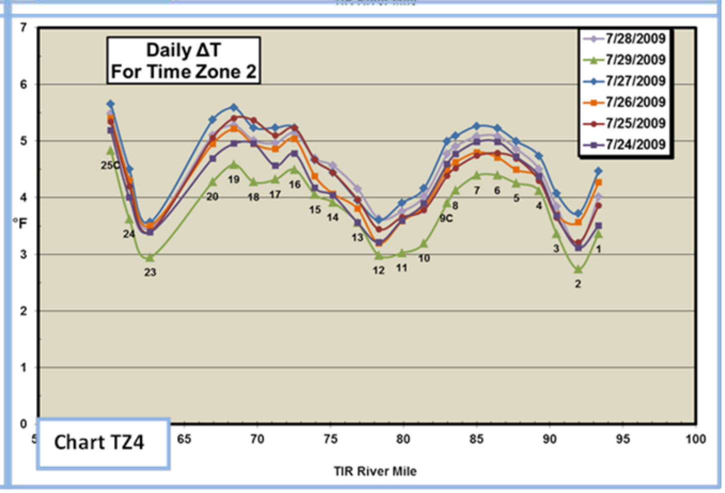
Since stream temperature data is typically complex, various statistics are commonly used to quantify the components of particular interest. The daily maximum, minimum, mean and difference between them, ΔT are probably the most common.

Charts TZ 1-4 show the plots for these statistics for each day in time zone 2. Charts for all of the time zones are in Appendix C Spatial Distribution. Under ideal uniformly distributed and steady heating conditions all of the sites would respond in a similar manner resulting in a set of equally spaced parallel curves. The departure from this ideal illustrates the extent of the error for this type of analysis.

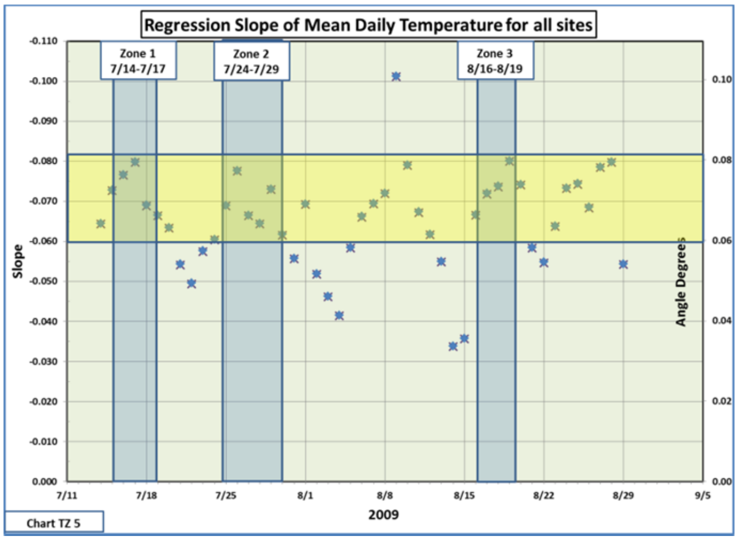


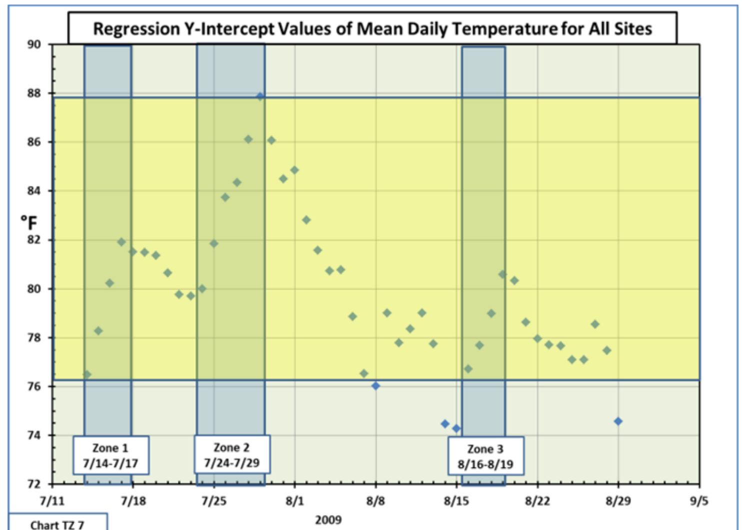


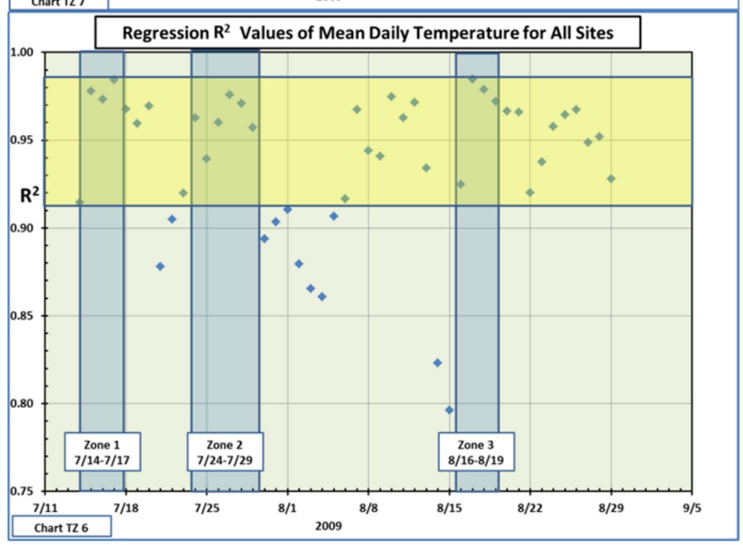




Note that the mean value plots consistently show a more linear pattern indicating that the maximum and minimum deviations tend to cancel. The implication is that sites that absorb more heat during the day may radiate more heat during the night. This effect is particularly noticeable at sites 1 and 25c on the max-min charts. The ΔT curves are less uniform because the error deviations associated with the maximum and minimum values are additive.







Daily Mean Regression Statistics

The linear nature of the spatial distribution of the mean daily temperature makes it is a useful indicator of the rate of downstream heating in the river in °F/mile.

Linear regression information was calculated for all of the daily mean data from the project. Charts TZ 5 – 7 shows how the corresponding slope, Y-intercept and R^2 values varied over the summer season. It appears that use of the time zones was particularly effective in reducing variability in the slope data.

Downstream Heating

A distinctive characteristic of summer stream temperature data is the tendency to increase in the downstream direction. This effect has been consistently observed in other Umpqua studies (Stream Temperature In the Umpqua Basis –Ref 3) and the slope of the heating line has been shown to be fairly constant. When shown on a larger scale it is apparent that this line is not strictly linear but is an exponential curve (See Chart 1) however it can be treated as linear for short distances.

On the spatial scale, downstream warming occurs because flowing water is not exposed to prevailing thermal conditions for as long as the surrounding environment. Surface water initially emerges from the ground at about 52°F and becomes warmer as it moves downstream at the rate of the order of 15 miles per day with the exposure time being directly related to the distance traveled.

On the temporal scale, daily temperature statistics at a given location tend to increase because, in the summer, the net incoming heat flux during the day exceeds the energy lost during the night resulting in a net increase in temperature. This effect can be obscured by varying weather conditions but is very apparent during periods of uniform heating as shown in the time zone charts. It appears from Charts TZ 1-4 that the daily offset for each curve is approximately 1.2°F/day.

Since both the spatial and temporal effects are related to exposure time, the downstream spatial temperature change resulting from one day exposure should be of the same order as the between-day temporal increase at a site. The two effects can be compared directly from the data.

Table 2 Comparison of temporal and spatial daily heating rates.

Statistic	Flow	Temporal	Spatial			
		Site 1	Velocity*		Slope	Increase °F
	CFS	Daily Increase °F	Feet/sec	Miles/Day	°F/mile	1 day travel
max	1530	1.82	1.22	20.03	0.0795	1.59
average	1255	1.23	1.00	16.42	0.0703	1.15
min	1110	0.57	0.89	14.53	0.0602	0.88
			*1250 sqft cross section			

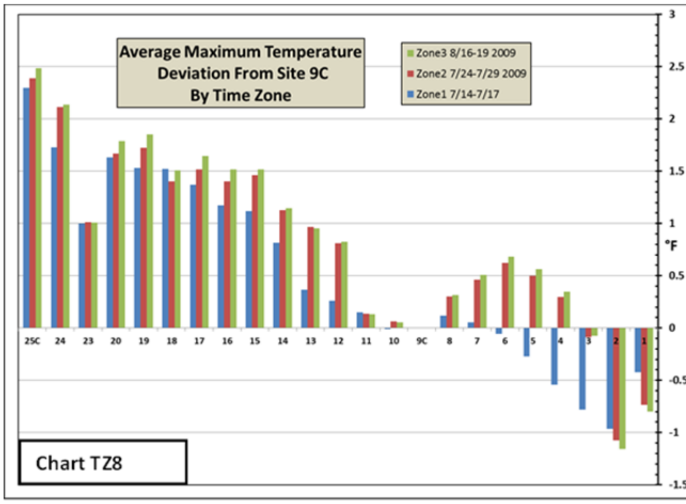
In Table 2 the range of daily temperature increases for uniform climate conditions for site one was obtained from the three time zone periods to determine the daily temporal effect.

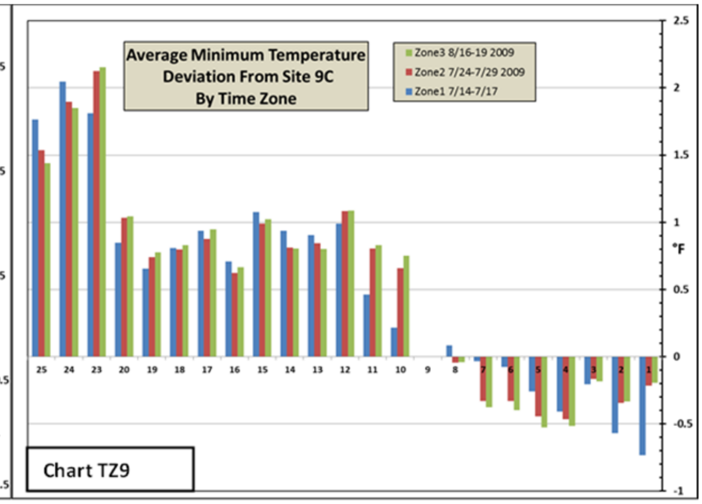
The spatial heating effect was determined from calculations of the distance traveled in one day and the observed heating rate in °F/mile. Average flow velocity was calculated using stream flow data from the Elkton gage (USGS 14321000) for the 2009 study period and an average cross section area of 1250 ft^2 that was estimated using the depth and data from the study. The heating rate was calculated using the daily mean regression slope values from the three time zone periods. Even though these calculations involve some approximations it appears that the results are consistent with the concept.

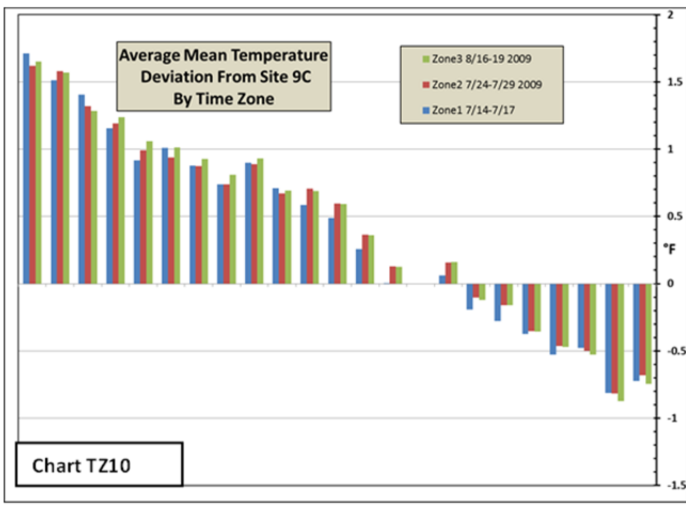
Variability between the three time zones

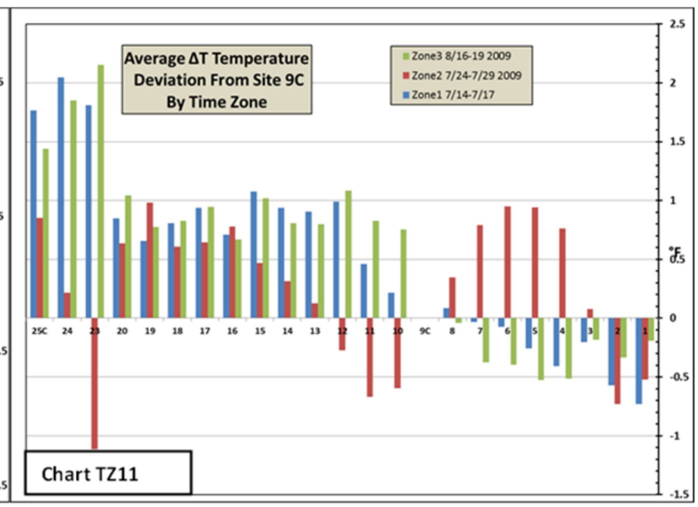
The time zone data suggests that the differences between sites are relatively constant. However, differences in the solar path and in prevailing flow conditions can introduce additional variability between time zones.

Charts TZ 8-11 compare the average deviation of the temperature statistics values from site 9C for each time zone. For the max-min statistics, zones two and three compare very well with differences in the order of 0.1°F. The reason for the larger error with some of the sites in time zone one is not immediately apparent. In any case, most sites match within 0.5°F.







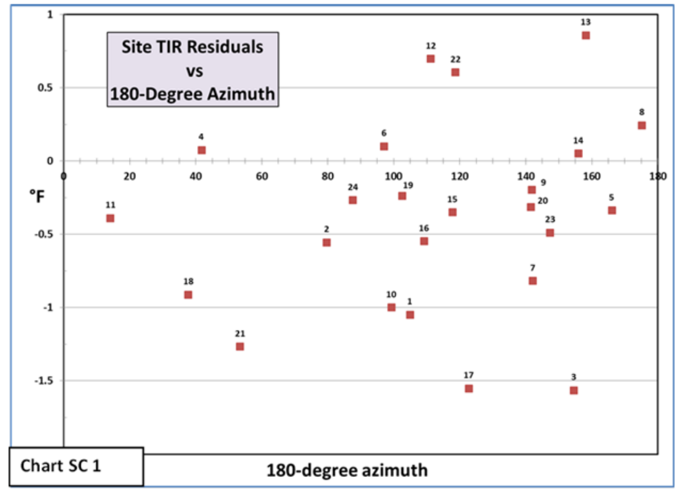


The results for the mean value statistics agree very well for all sites. Apparently the deviations tend to cancel when mean values are used. Conversely, the errors appear to accumulate when the %ΔT values are used.

Larger charts are available in Appendix C Spatial Distribution / Time Zone Differences.

Influence of Site Conditions

The temperature variability that remains after the data is filtered for uniform climate conditions and adjusted for downstream heating can be attributed to differences in the physical characteristics of the site and the associated upstream influence zone.



The deviation of the PUR sampled Site TIR values from the regression line in Chart S1 provide a relative index of the sites independent of downstream heating. Several physical site parameters were compared with the deviation values.

River Azimuth and Solar Radiation

Azimuth data was developed for each site by measuring a line that was projected through the five hundred foot influence zone immediately upstream from the deployment point. The residual TIR departures from the regression line on Chart S1 were compared with the river azimuth and cumulative radiation to check for a correlation.

Since the gradient of the river is small, it was assumed that the flow direction was irrelevant with respect to solar heating so the azimuth data was reduced to a 180 degree basis. In other words, a segment with a flow azimuth of 35 degrees was assumed to receive essentially the same amount of solar radiation as a segment with a 215 degree azimuth.

Chart SC 1 does not show any obvious pattern. It was thought that river sections with a NE/SW (45°) orientation would be warmer due to more direct exposure to the afternoon sun. It is interesting to note that the majority of the sites are in the SE/NW sector with more direct exposure from the mid-morning sun.

Cumulative solar radiation was calculated for the six points at each site for July 23, the day of the TIR flight, using the ESRI spatial analyst radiation model. Charts SC 2 and SC 3 show the average results at each site for a 16 hour interval (00:00 to 16:00) and a one hour interval (15:00 to 16:00) respectively. It is interesting that site 12 consistently received noticeably less radiation – apparently due to local topographic effects. However, no other discernible pattern is apparent.

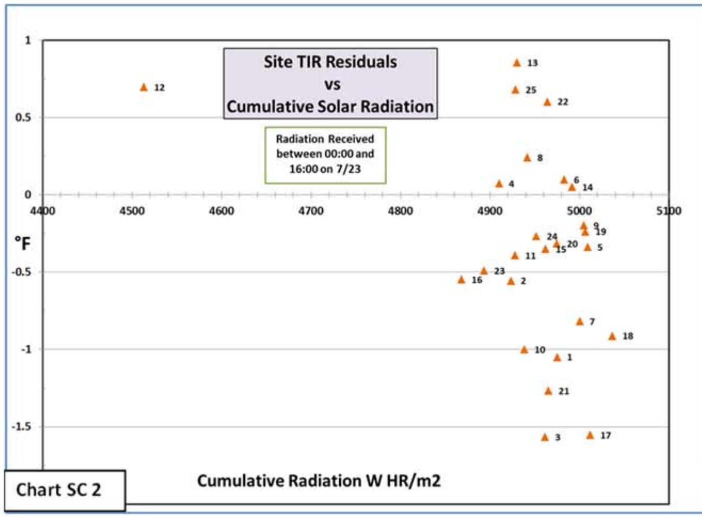


Chart SC 2

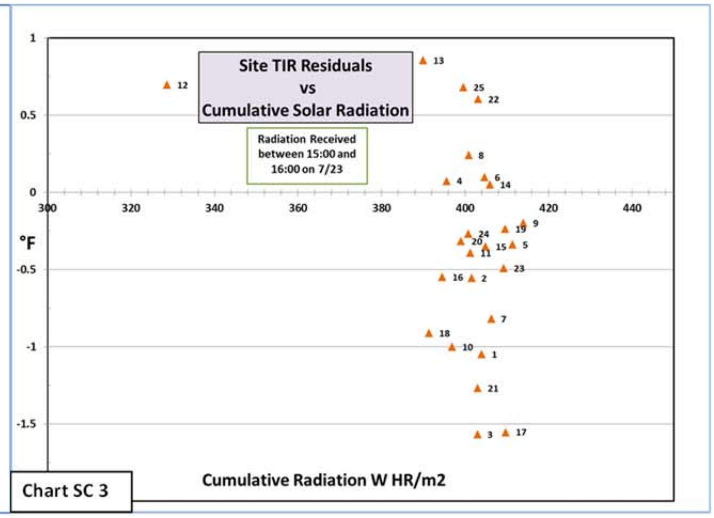


Chart SC 3

Influence of Depth and Volume

The thermal response of a liquid depends upon the amount of liquid being heated and for an input flux per unit area, depth is directly related to volume. Depth measurements taken at the deployment point were used as an approximation of the characteristic depth of the influence zone. (Note: this is not a particularly accurate estimate of zone depth conditions.)

Chart SC 4 does not show correlation between depth and relative heating of the sites. However, the two deeper sites appear to have less deviation. This result is consistent with the observation that the river edges tend to have more temperature variability; from shallow water heating or from cooling effects due to shade or tributary inflow.

In Chart SC 5 a relative estimate of the volume of water associated with the site was

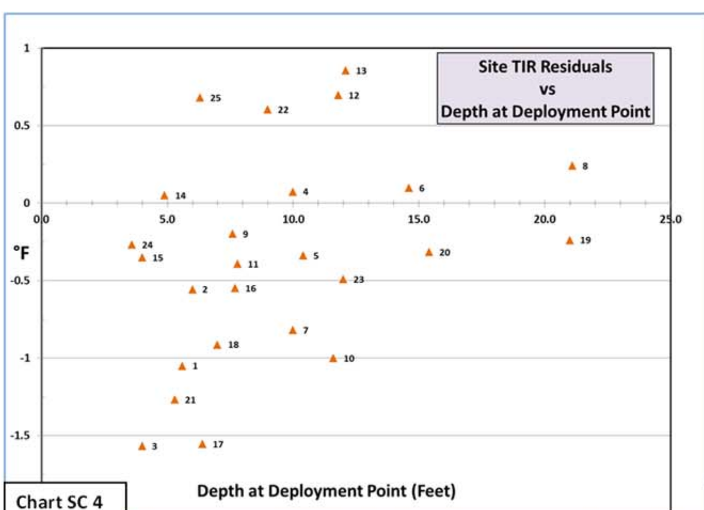


Chart SC 4

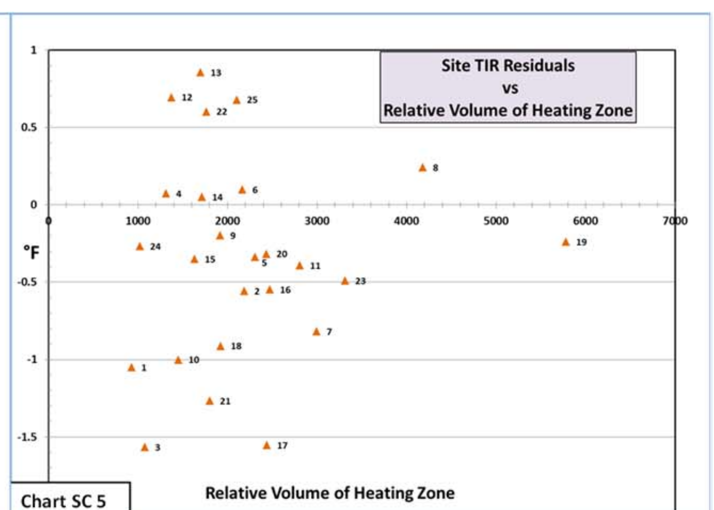


Chart SC 5

made using the product of the depth and the average width of the influence zone. While the data distribution shifted somewhat the general pattern is similar.

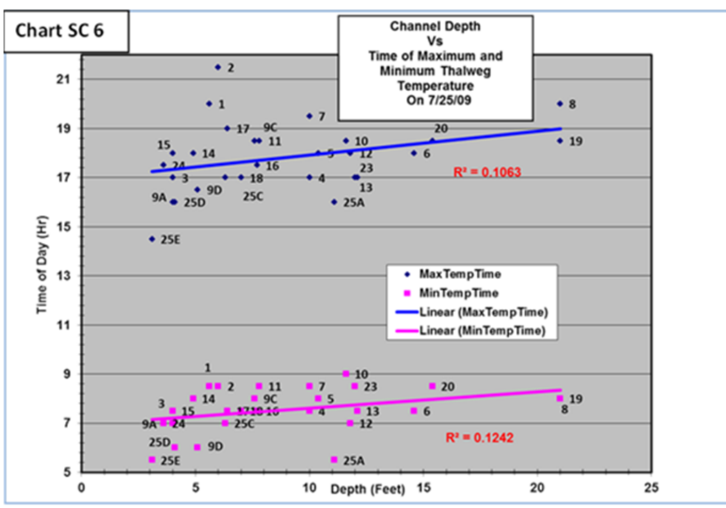
Heating Rates and Heating Interval

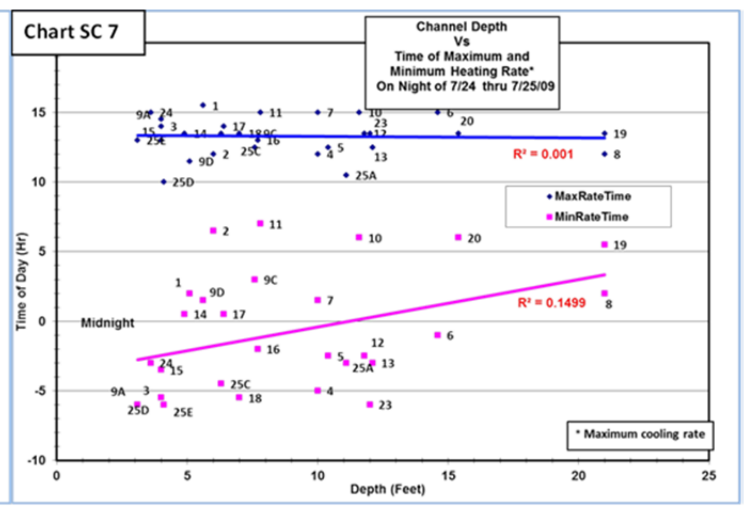
The 2009 time-series data provides an opportunity to look at the timing of the daily statistics as well as the daily heating rates at the individual sites. The phase shifts between the sites that are apparent in Chart TS 4 indicate that sites respond to the thermal environment at different rates.

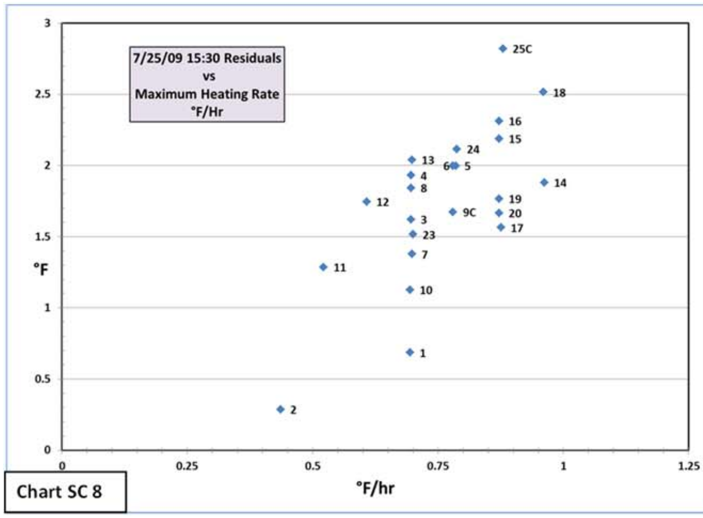
Chart SC 6 shows the differences in timing of the maximum and minimum values for a specified date. There appears to be a slight correlation with depth with deeper sites responding later. Chart SC 7 indicates that the time of maximum heating is relatively constant at about 1 PM while the maximum rate of cooling appears to occur later in the deeper water.

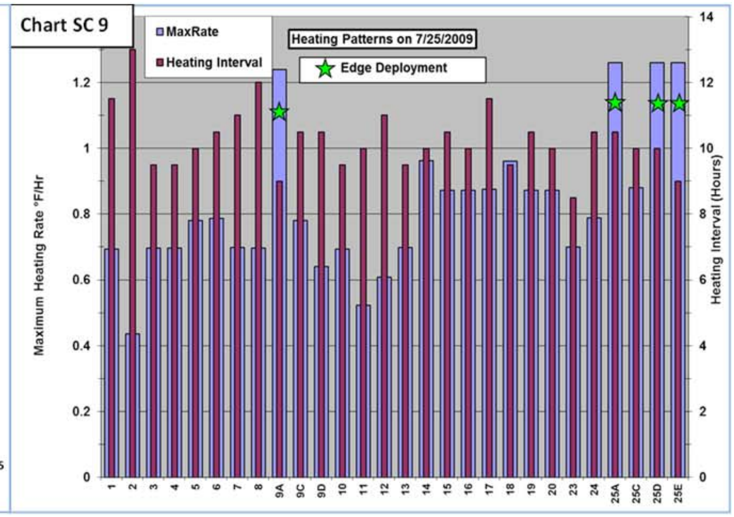
Chart SC 8 shows the deviations of the site temperatures at 15:30 on 7/25/09 from the 7/25 daily mean regression line. All of the deviations are positive because the temperature at 15:30 is near the daily maximum. The warmer sites are associated with higher heating rates.

SC 9 displays values for two descriptive parameters, (1) the maximum daily heating rate °F / hour and (2) the time (hours) between the daily minimum and maximum temperature value (heating interval). Note that some of the units from the cross section sites show high rates due to shallow water.









Some Conclusions

Water quality data can be highly variable both spatially and temporally and data from point grab samples may not accurately represent the full range of variability within the data. The 2002 airborne thermal infrared (TIR) survey contracted by ODEQ and implemented by Watershed Sciences of Corvallis provided an immense amount of information on the spatial scale representing conditions at essentially one point in time. These data showed a surprising amount of variability in the two degree Fahrenheit range that did not seem to have an obvious explanation (See Chart 2). The time-series data from this project confirmed the presence of this variability and, combined with the TIR data provides an excellent spatial-temporal view on the summer season thermal response of the Umpqua River.

A key result from this study is that the river temperature appears to be strongly influenced by its immediate thermal environment and that variation in the environment (both spatial and temporal) result in corresponding changes in temperature. This effect is in contrast the commonly expressed notion that the river simply increases in temperature as it flows downstream – that “cooling” cannot occur at downstream points.

On the spatial scale this effect is apparent by the variability shown in the TIR profile and the cause of this variability is of particular interest. A preliminary analysis of the temperature relationship with several physical site parameters did not show significant correlations. However, many of the warm areas seemed to have a strong association with exposed bedrock. The primary influence zone appears to quite local, within the range of a few hundred feet.

On the temporal scale the immediate local response to the thermal environment is also apparent from examining the time-series data. The commonality of the diurnal variation between sites is well known and corresponds well with instantaneous solar position (see chart TS 4). Likewise, the time-series charts in Appendix B show that the river responds to changes in seasonal climate pattern in a similar manner throughout its length.

The relatively uniform summer climate in western Oregon provides an opportunity to compare the thermal response at the different sites. The data shows that, on a typical warming day the temperature of the river will increase about 1.2°F / day. Likewise, after traveling an additional day through the system, the temperature will have increased a similar amount (see Table 2, Page 20). Of particular interest were the mean daily temperature profiles that showed a good regression correlation with distance. These results can be useful for modeling the temperature of the river.

This study and the 2008 study did not detect areas of significant cold water upwelling. However, the TIR imagery shows occasional cooler areas along the edges typically associated with riparian shade and cold water tributary inflow. Trees along NE facing banks seemed to be particularly effective and managing these areas for shade could help provide thermal refugia for the fish. Likewise, maintaining shade near the mouth of the cooler tributaries and assuring a good pool at the outflow should be considered.

The relationship of the immediate environment on river temperature suggests that historically the river responded in a similar way to similar conditions such as presence of bedrock and riparian shade. However, the absence of large wood jams in the river represents a major change in conditions that will probably never be restored. These jams undoubtedly were very beneficial to cold-water fish by providing additional shade and cover.

There is an immense amount of information contained in the data from this project that could be developed with further analysis. Specific data is available upon request.

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2. Smith, K., Water Temperature Variability on the Lower Umpqua River - 2008 Study, Umpqua Basin Watershed Council.
3. Smith, K., Water Temperature Stream Temperature in the Umpqua Basin - Characteristics and Management Implications. 2003 Umpqua Basin Watershed Council
4. *Aerial Surveys in the Umpqua River Basin*. 2003, Watershed Sciences, LLC: Corvallis.