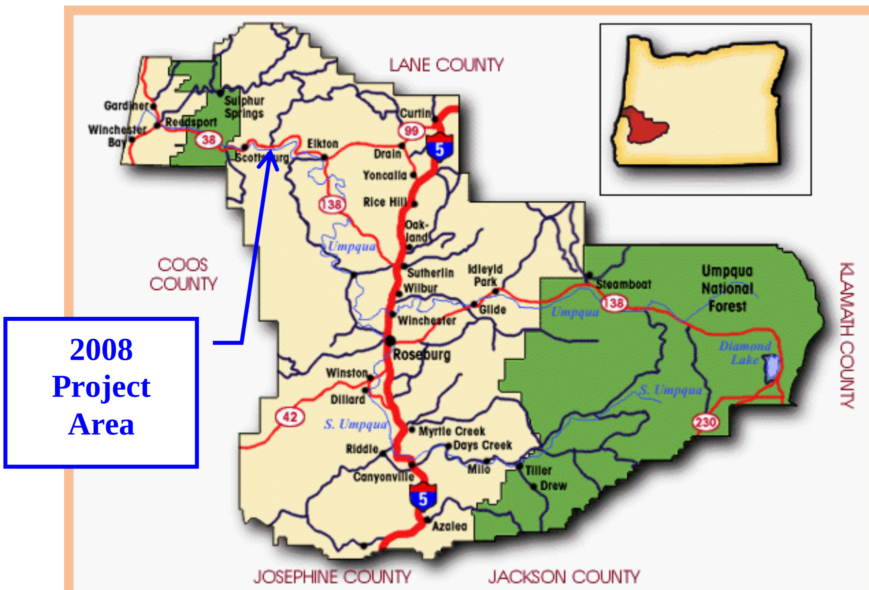
Partnership for the Umpqua Rivers

Your Watershed Council

Water Temperature Variability on the Lower Umpqua River

December, 2010



InSight Consultants

PO Box 362
Yoncalla, OR 97499

Phone: 541-849-2724
www.yoncalla.net

Table of Contents

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 is included in the following supplemental Appendices:

A. Background – 2008 Lower Umpqua River
Contains supplemental information relevant to the topic.

B. Field Notes – 2008 Lower Umpqua River
Contains data from 2008 work and associated site information.

C. Work Notes – 2008 Lower Umpqua River
Contains details on the field work and the data analysis used for this report.

Key references are also available that include the Watershed Characterization Reports for the Umpqua Basin

Acknowledgments

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 contents of this document do 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.

Special thanks goes to Sandy Lyon of the PUR Watershed Council for her grant administration and project coordination work as well as her, and her son Kris', invaluable help on the River. 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.
Thanks also to:

- Ryan Michie of ODEQ for providing the TIR Grid files.
- Christian Torgersen USGS FRESC Cascadia Field Station for his interest and useful suggestions.
- Holly Truemper of ODFW – Roseburg for the updated information on fish use in the Lower Umpqua.
- Hydrologist Denise Dammann for the 2008 Camp Creek temperature data.

River Temperature Variability on the Lower Umpqua River

By Kent Smith, Hydrologist, Insight Consultants
Review Draft April 2008

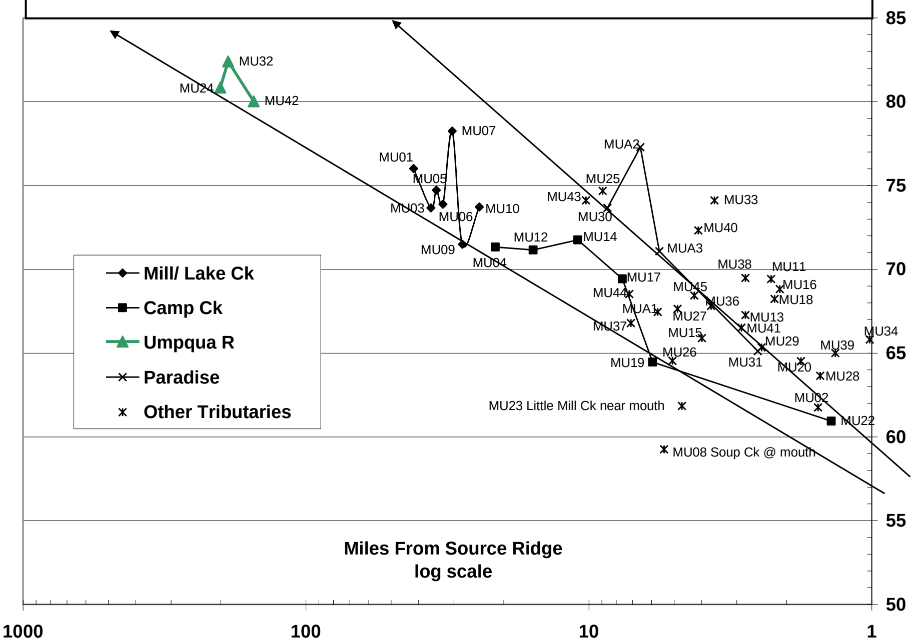
Background – Previous Work

Umpqua Basin Temperature Characterization Studies

The Umpqua River Basin is a major coastal fishery resource in Oregon and water temperature is a key management issue (See Appendix A / Geographic Setting, Fish Utilization and Management Issues). To help address this issue a project was started in 1998 to identify the stream temperature characteristics in the Umpqua Basin by systematically collecting a large amount of synoptic time-series data from the subwatersheds of the basin. For four years, about 50 data loggers were deployed each year in two subwatersheds to obtain representative data at sites located from the headwaters to the subwatershed mouth. 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.

Chart 1[1] shows the distribution of the August 8, 2000 maximum temperature value for locations on the Lower Umpqua and associated tributaries as a function

Chart 1 8/8/00 Maximum Temperature as a Function of Distance From Source



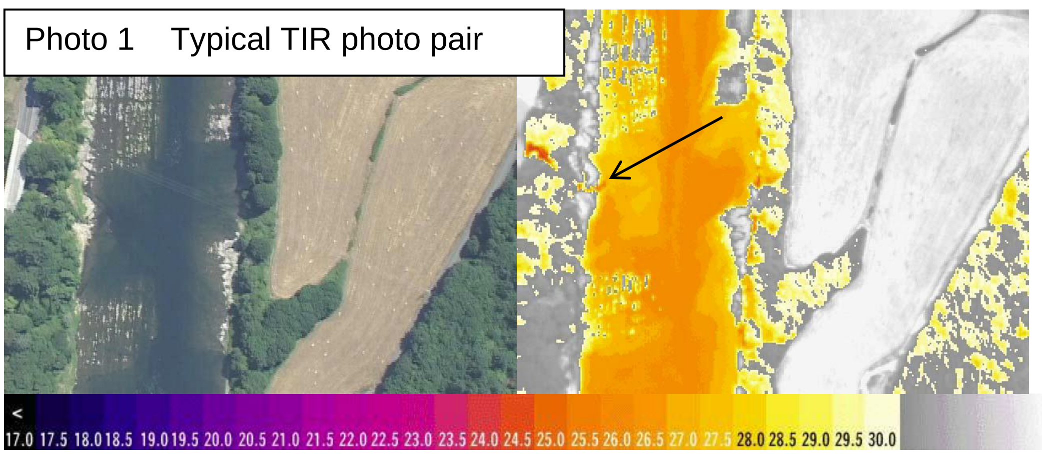
of the distance to their respective source points. These results are consistent with the concept that stream temperatures tend to increase in the downstream direction. It was also noted that the limited data in the Lower Umpqua River displayed considerable variability. This was attributed to the fact 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.

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 orthophoto 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.]

Photo 1   Typical TIR photo pair



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.

In addition to supplying image pairs for over 17,000 sites, Watershed Sciences also specifically sampled the thalweg 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.

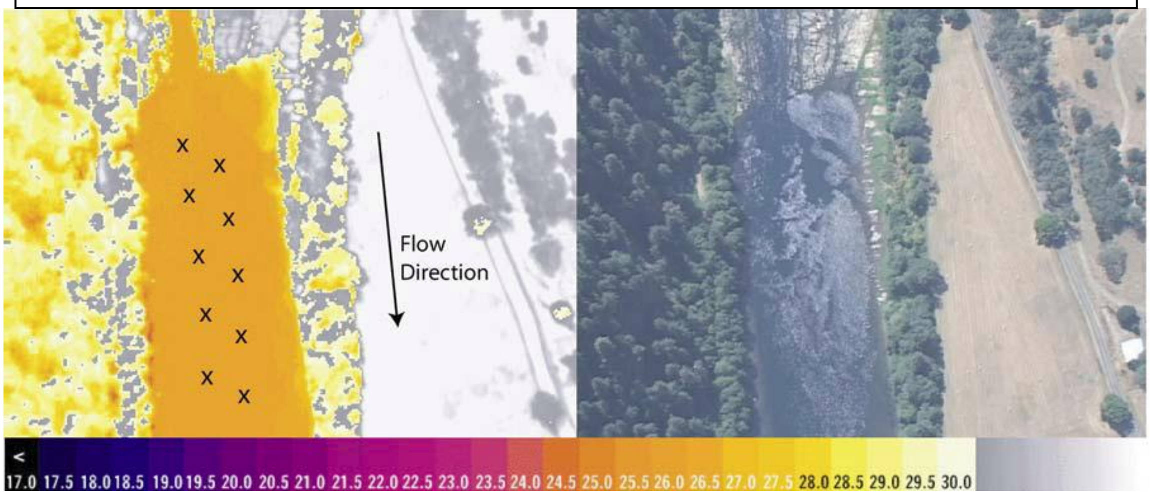


Chart 2

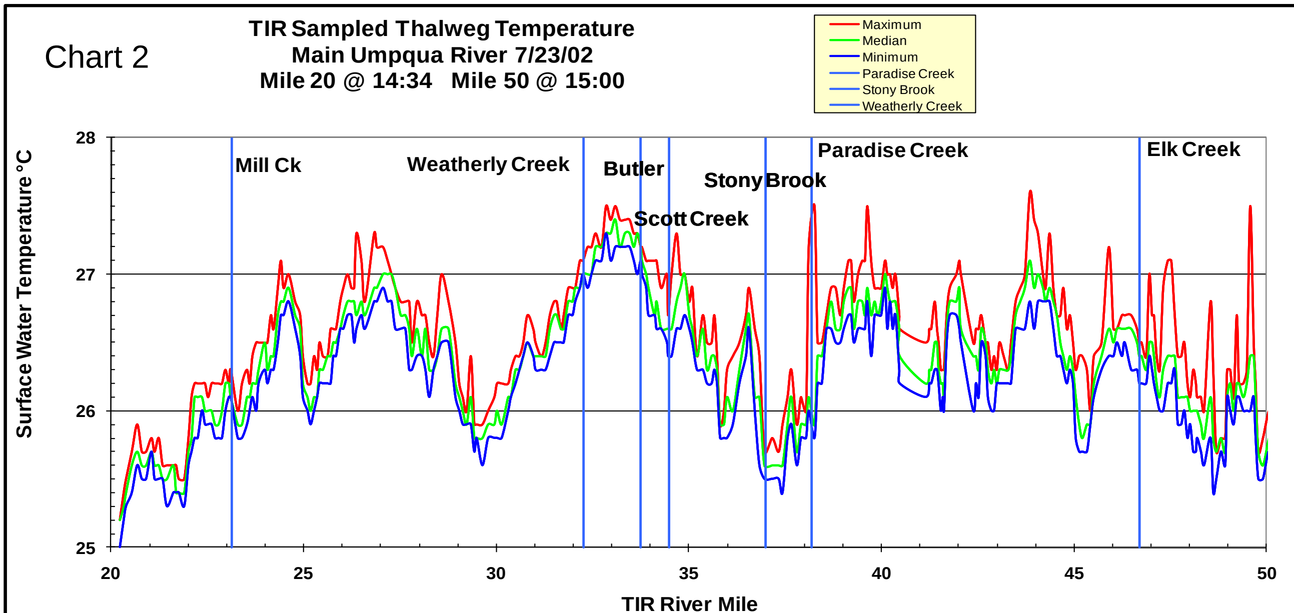


Chart 2 shows the maximum, minimum, and median sampled values for the project area. Note that the flight time through the project area was less than 26 minutes and adjustments for diurnal heating were not made in this case since typical thalweg heating rates are about 0.3°C/hr. Also, note that the River 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.

Another product of the TIR project was the associated Grid Files that enabled the extraction of the observed temperature value at the pixel level and a direct comparison with the 2008 data.

2008 Study - Background

A main objective of the 2008 work on the Lower Umpqua was to learn more about the availability of thermal refugia in the portion of the river between Elkton and Scottsburg. At first glance, there does not appear to be much refugia available. The river channel configuration is quite simplified and appears to offer little refuge in the form of springbrooks and alcoves. The influence of cold tributaries can be seen in the TIR photos but, typically, their effect is small.

However, the profile shown in Chart 2 suggests that something significant may be affecting the bulk river surface temperature in the thalweg region in certain sections of the river. For example, between RM 29 and RM 33 there appears to be a cooling effect of about 1.5 °C taking place. This type of effect was noted at several locations on the river profile by Watershed Sciences but they were unable to provide a definitive explanation (see page 10 of the Watershed Sciences report (Reference 2).

While a 1.5°C temperature change is not, in itself, a major benefit to cold-water fish when the river temperature is in the 27°C range, a cold water source sufficient to produce this change in a river flowing at about 1000 cfs could provide significant thermal refuge in the inflow zone. Groundwater inflow is often suggested as a possible explanation. Previous field work has shown that groundwater in the lower elevation regions of Umpqua Basin is approximately 54°F (12.2°C) which is also the mean annual temperature of the area. [See Appendix A / Groundwater Notes and Appendix C / Groundwater Influence.] Upwelling groundwater could deliver cold water to the river bottom interface river much like lava tubes deliver molten lava up to floor of the ocean where it is rapidly cooled. Also, like lava in the ocean, the water surface temperature would not necessarily indicate the thermal conditions on the bottom. The TIR photos detect only surface temperature since water is opaque to the infra-red radiation associated with these temperatures. [See Appendix A / Radiant Heating Basics] Consequently, it is possible that there may be areas on the river bottom with water temperature in the range of 13°C (55.4°F) that were not detected by the TIR photos.

For example, on Chart 2 in the Weatherly Ck region between RM 29.7 and RM 33.5 there is a 1.6 °C (2.9 °F) drop in surface temperature. The rate of decrease is fairly constant over the interval suggesting that, if increased cold water inflow is responsible, it is not present at the end points but is distributed uniformly between the end points and should be detectable by bottom sampling.

Appendix C: Work Notes has details for a simple calculation to estimate the quantity of groundwater inflow would be needed to cause the observed effect. A simple mixing formula was used:

$$T1Q1+T2Q2=T3(Q1+Q2)$$

Where:

T1	Initial river temperature	27.4 °C
T2	Groundwater temperature	12.2 °C
T3	Temperature after mixing	25.8 °C
Q1	Nominal river flow (CFS)	1050 CFS
Q2	Required Groundwater inflow	

Solving for Q2 yields a groundwater inflow of 124 CFS which represents a flow contribution of over 10% or a longitudinal contribution of 32.4 cfs /mile.

Since the vertical temperature gradient at the river bottom interface would be very steep, the cooling effect would probably not reach the surface where it would be detected by the TIR instruments (which only measure the surface temperature of the water). However, water upwelling at the rate calculated should be detectable by a temperature probe that measures directly at the water-river bed interface. [Note: the cold zone may of the order of one or two inches thick and direct contact with the bottom may be needed for detection. A boundary layer thickness calculation is possible but is outside of the scope of this project.]

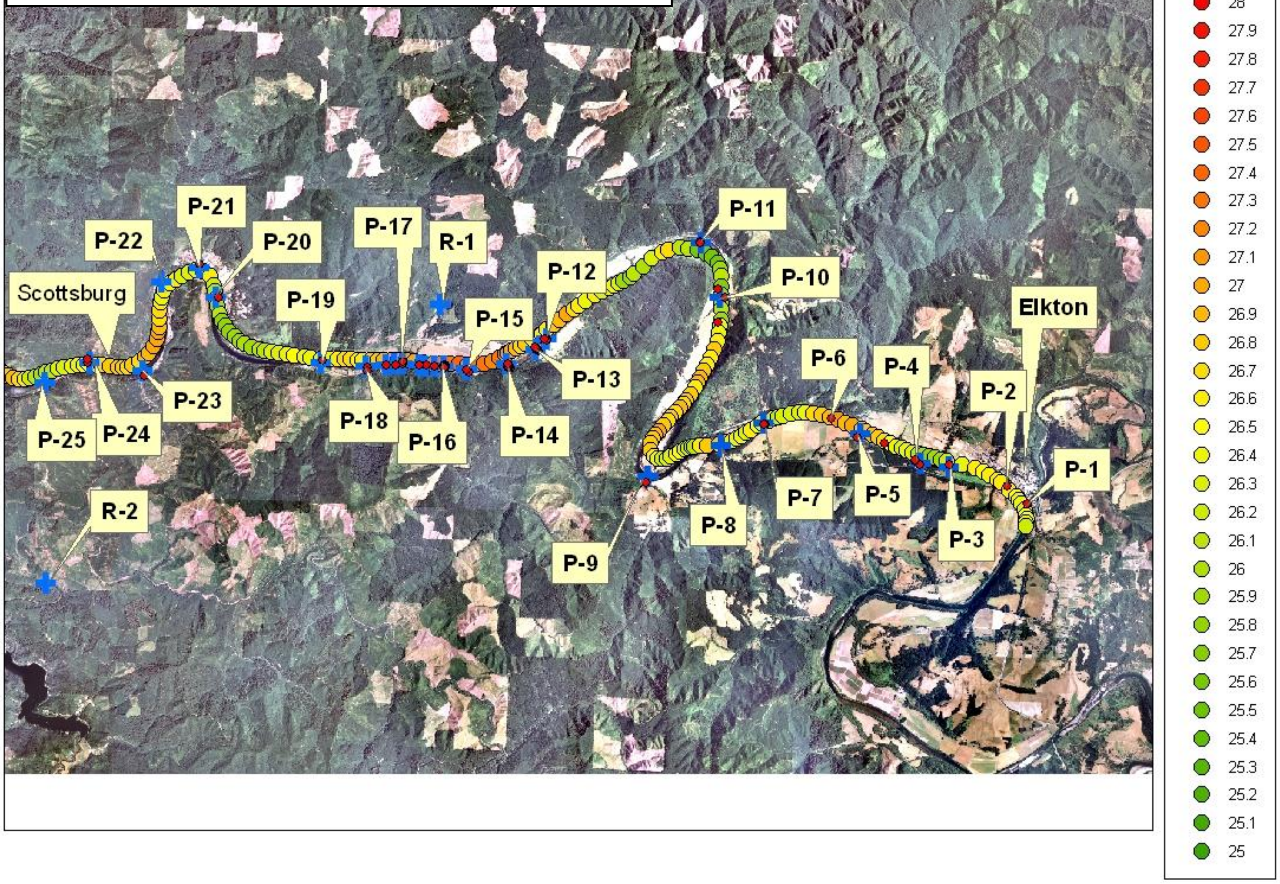
To test for this inflow, a direct measurement approached was used to sample the temperature of the river bottom to try to detect any emergent cold water. [Note: This result could also be tested by careful discharge measurements to determine the amount of flow gained in this reach. However, resources were not available to make the necessary measurements and a positive result would not necessarily help locate the source of the inflow.]

2008 Study – Sampling Results

Photo 3 shows the major sample points as well as the median temperature data (as colored dots) obtained from the Watershed Sciences TIR flight in 2002.

Information for the specific sites and a table of all measurements taken are in Appendix B: Field Notes. Information on the analysis process and chart development is shown in Appendix C: Work Notes.

Photo 3 Sample Sites 2008 Project



Cross-Channel Bottom Temperature Variability

The 2002 TIR study provides an excellent view of the surface water temperature distribution across the river channel at a specific moment on July 23, 2002. Cross-channel point samples were collected at sites P-13 and P-14 on 8/26/08 to compare the TIR results with the river bottom temperature.

Cross-Channel Variability at Site P-13 (See Appendix B for site details)

At site P-13 a series of grab samples were taken over a period of time (9:26 AM to 10:28 AM). Since the sample interval was relatively brief, no attempt was made to correct for diurnal temperature changes. Photo 4 shows the cross-channel sample points and Photo 5 shows the corresponding TIR grid file of the 2002 data with an additional inserted file that was limited to the water surface in the vicinity of the sampling. GIS software was used to generate a line of points across the grid to sample individual pixel temperature values to enable a comparison with the 2008 field measurements. {Note: a different color scale was used for each of the two TIR photos to better contrast the temperature gradients.}

Photo 4 Sample points at Site P-13

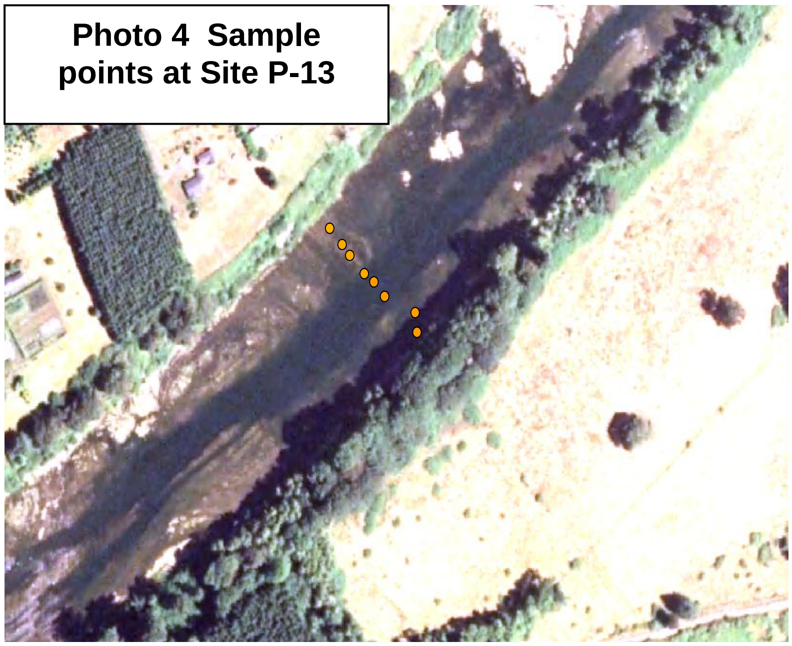
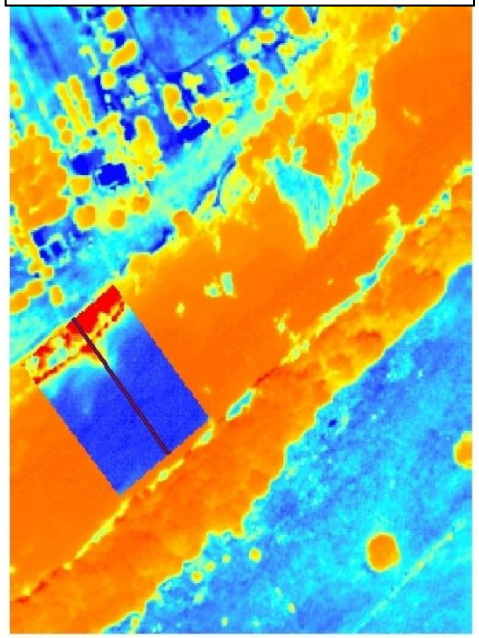


Photo 5 TIR Grid



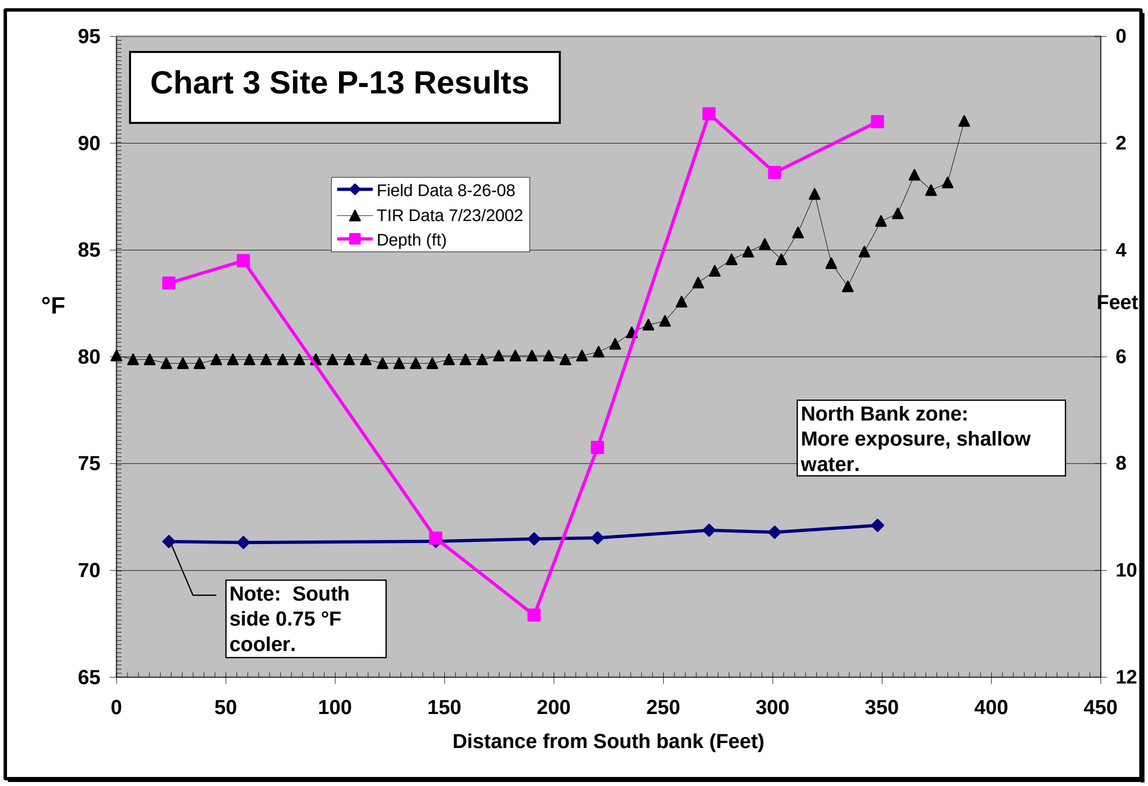


Chart 3 compares the results from the 2008 field study with the line of points sampled on the 2002 grid data. Since the data were collected on different days and different times, the nominal temperatures are not expected to match but a similar pattern could be expected. In this case it is apparent that the nominal surface water temperature recorded by the 2002 TIR flight was about 9 °F warmer than the bottom river temperatures measured on 8-26-08[1]. However, both show a similar warming pattern toward the north bank which is more exposed and has shallower water and it is reasonable to conclude that both measurement methods are producing similar results. The difference in temperatures is due to conditions on 7/23/02 being much warmer. It is of interest to note that the range of values is higher on the warmer day which, intuitively, would be as expected.

Since no temperatures in the 55°F to 65°F range were measured on the river bottom on 8/26/08, it is apparent that no cold water upwelling was detected in the area.

Cross-Channel Variability at Site P-14(See Appendix B for site details)

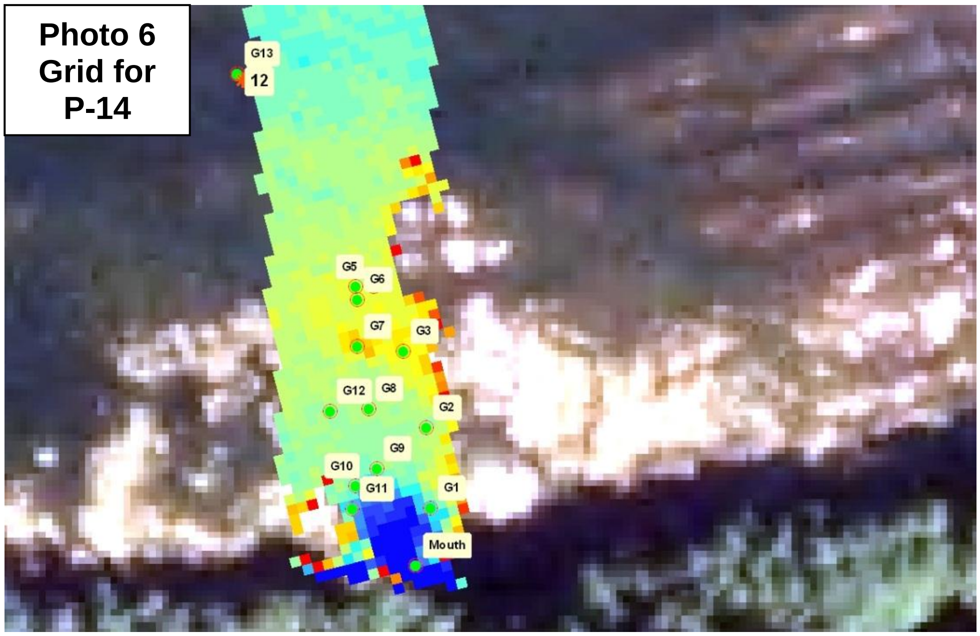
Site P-14 -Butler Creek Zone- is of particular interest because the pool associated with Butler Creek is a known cool-water location. Photo 5 shows a small alcove at the mouth of Butler Creek that is surrounded with a bedrock formation. (Note: There is more exposed bedrock in the photo than was present during the 2008 testing.)

Photo 5 Site P-14 Butler Ck area

[1] Surface water temperature was spot checked and found to be similar to the bottom temperature. This finding is consistent with previous work (See XXX). An emphasis was placed on bottom temperature sampling to detect effects from upwelling groundwater.

Photo 6 shows the 2002 TIR Grid surface water temperature data georeferenced onto the ortho photo. The relatively small cool pool area in the river is a typical of effect of small tributaries. It is also apparent that the water is warmer in the vicinity of the shallow water that is associated with the exposed rock formation. In general, the river edge of the river is warmer in midday due to the shallower water and exposed rock. The numbered points locate where point samples were taken to measure the bottom temperature. These points were also entered into GIS to enable the extraction of the surface water temperature from the 2002 TIR data.

Photo 6 Grid for P-14



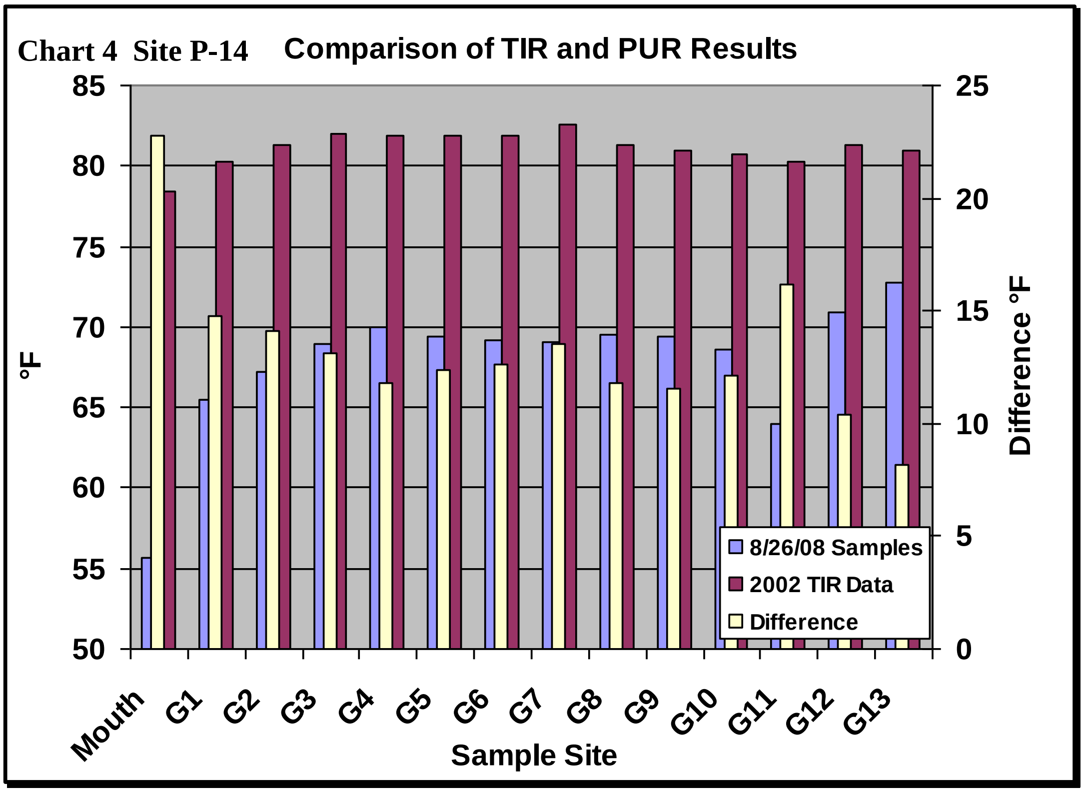


Chart 4 compares the 2008 field work results with the 2002 TIR data. The observed temperature difference, expected for dissimilar conditions, is fairly uniform; suggesting that both data collection methods are producing similar information. The disparity for the “mouth” measurement is not surprising given the resolution of the TIR data and the steep temperature gradient at that location. It is apparent that the two points were not exactly matched. Again, it is significant that no sign of cold-water upwelling was observed on the river bottom. The only cold water was observed at the mouth of Butler Creek.

Point Samples – Longitudinal Data

July 17 & 18, 2008 Work

On July 17 & 18, 2008 point sample temperature measurements were taken in the project area with the objective of locating possible upwelling sites in the thalweg region of the river. This section contains a summary of the results of that work. Details of the work and analysis are located in Appendix C: 7/18 & 19 Work.

Photo 3 shows the locations of the sample sites as well as the median values of the 2002 TIR sampling. The colors of the small circles represent the relative temperature, with green being the coolest and orange being the warmest.

Since the samples were taken over a period of several hours on the two days, some adjustment for the diurnal change was needed. Each day, a reference data logger was placed in the river at each end of the study reach to record the diurnal response for the day. The rate of heating was derived from the data and used to “normalize” all of the sample data to a fixed time (12:00 noon on 7/1//08). Chart 5 shows an example of the timing of the sampled field data and the corresponding reference loggers’ data.

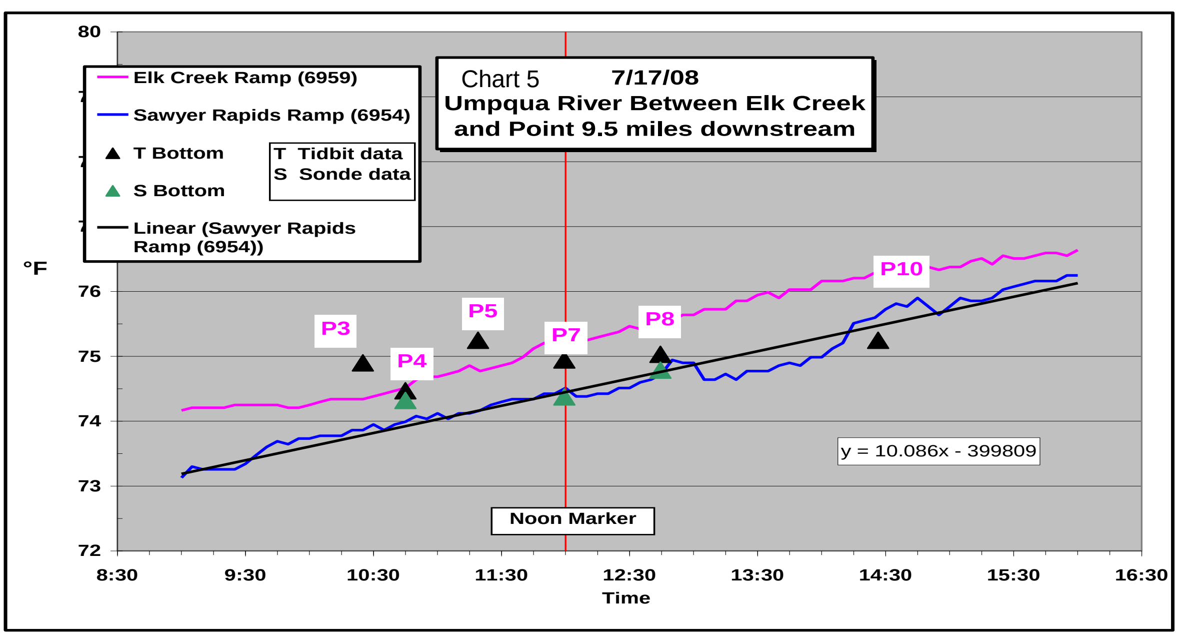
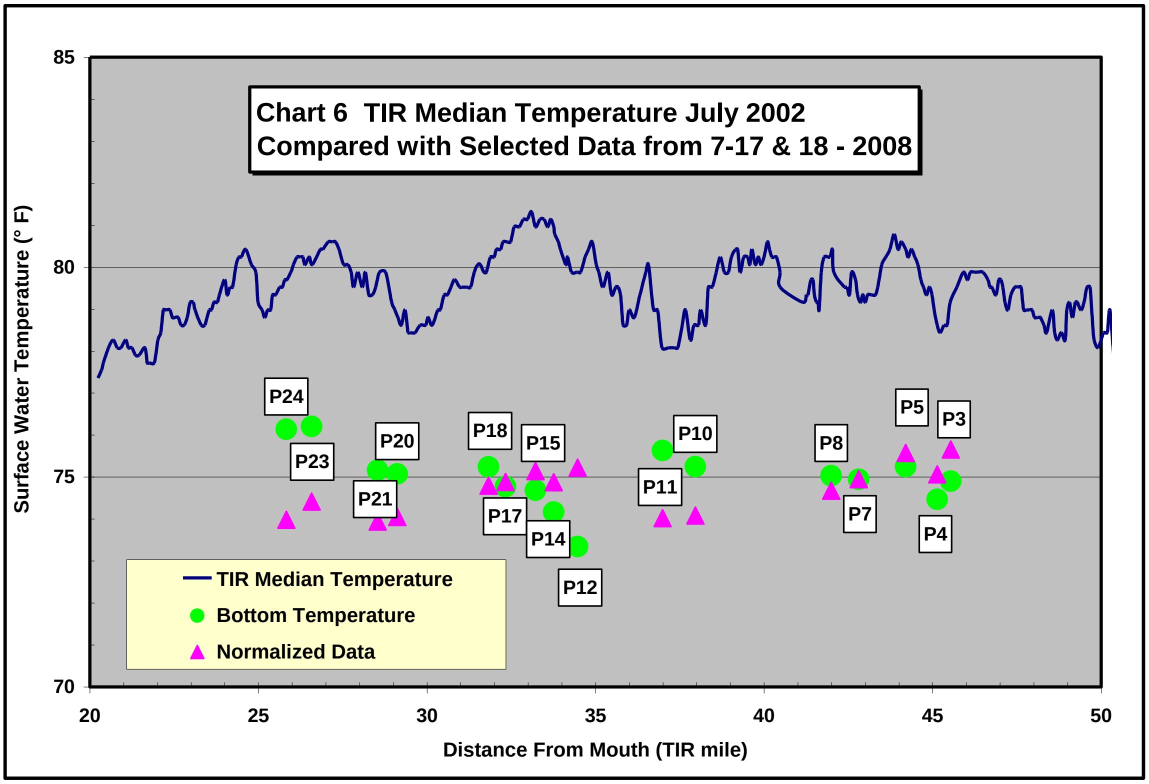


Chart 6 compares the measured data and the normalized data with the TIR median temperature from the 2002 flight. In general, the normalized data shows a similar pattern as the TIR data and one could conclude that, after allowing for the difference in prevailing temperature conditions, they are providing essentially the same information. For the purpose of this study, the most important observation is that none of the measured point sites showed any indication of upwelling water from the river bottom that would account for the observed TIR cooling / warming pattern.

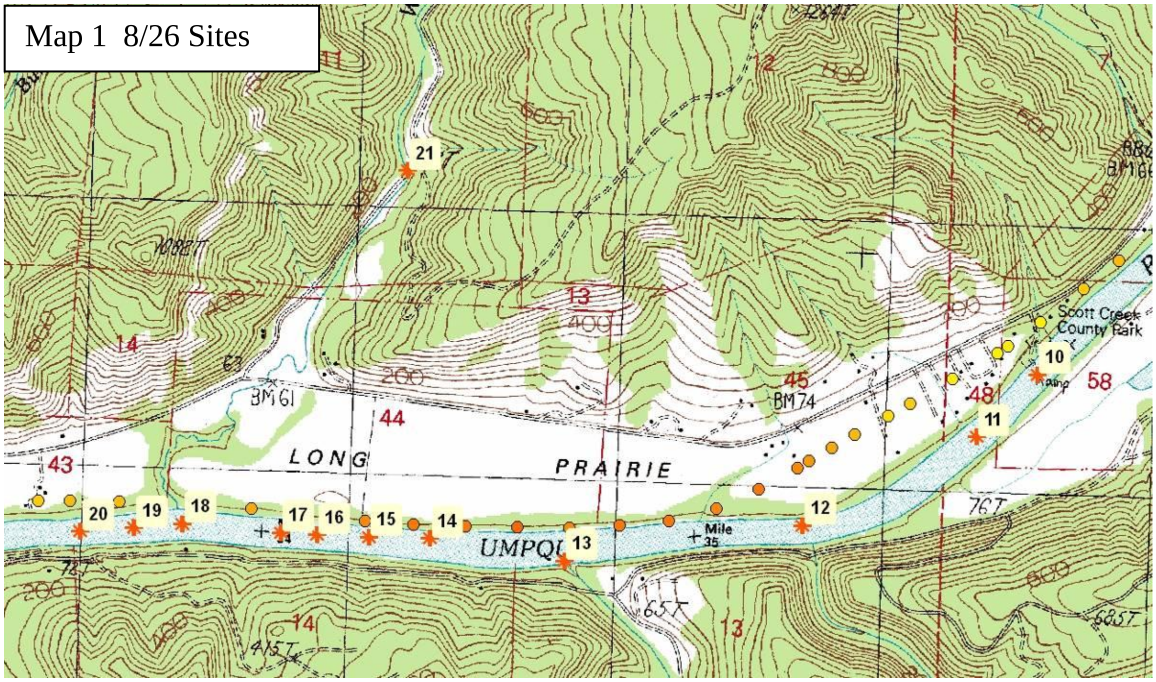


August 26, 2008 Work

The objective of the 8/26 work was to concentrate the sampling in the area of interest near Weatherly Creek in an attempt to detect any indication of coldwater upwelling that could account for the variability observed in the TIR profile data. On 8/26/08 a longitudinal profile was sampled as shown on Map 1. The Cross reference table shows the overlap with Photo 3.

Chart 7 shows the time series plot of the sample data along with diurnal data from a data logger at the Scott Ck Boat Ramp and the resultant “normalized” data. Chart 8 shows the data plotted against the river distance as well as measured depth (on right axis).

Sample Point Cross Reference	
Map 1	**Photo 3**
10	P-12
11	P-13
12	P-14
13	P-15
21	R-1


Map 1 8/26 Sites
21
Scott Creek County Park
10
11
12
13
14
15
16
17
18
19
20
LONG
PRAIRIE
UMPQU
BM61
BM74
Mile 35

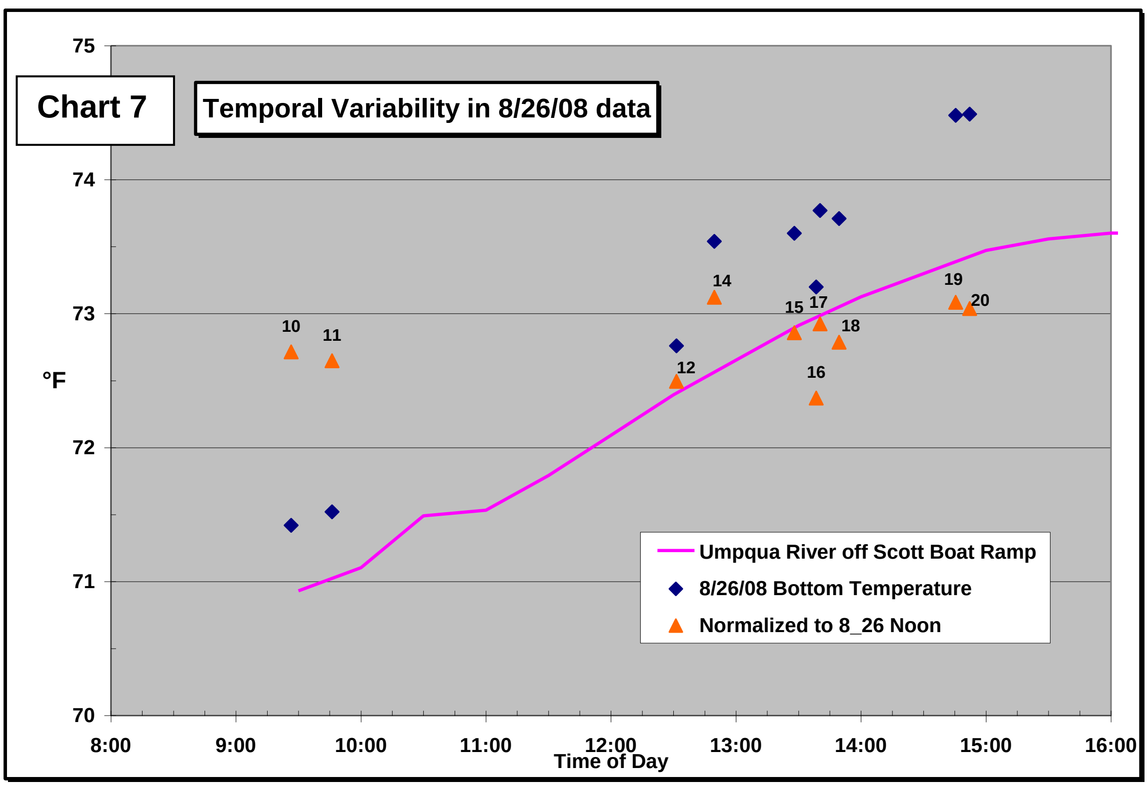
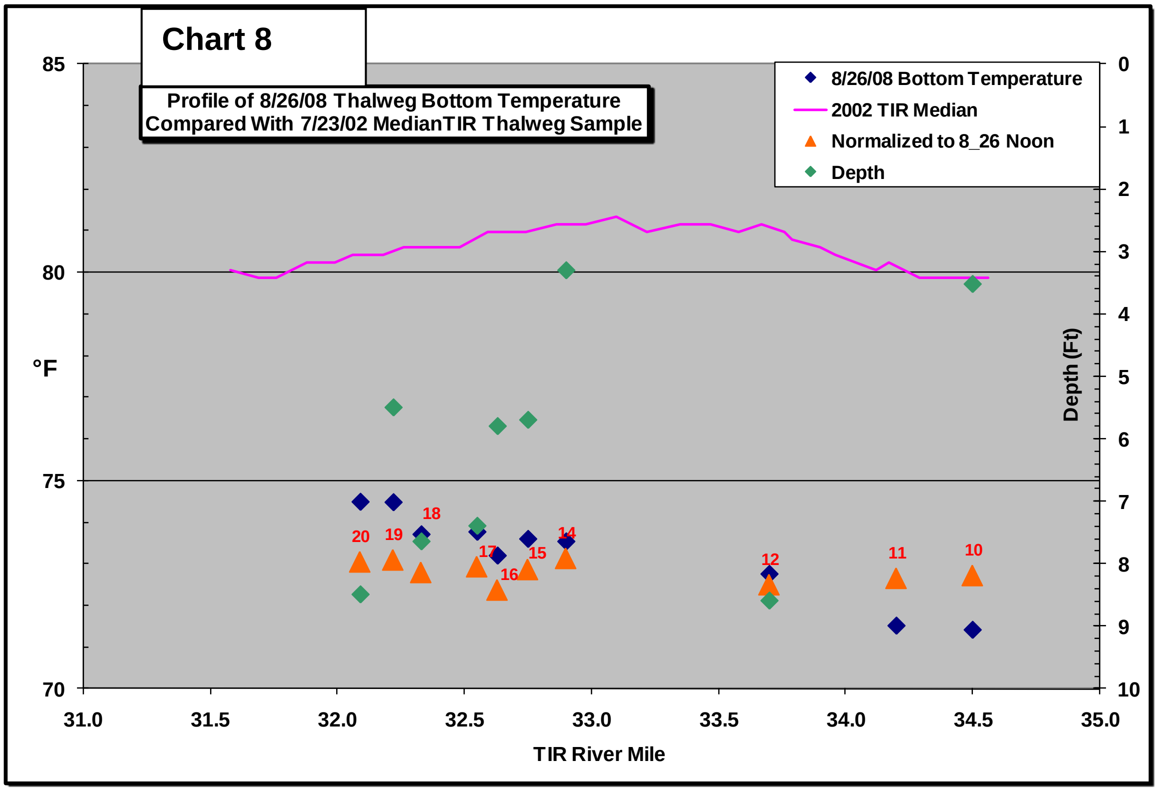


Chart 7
Temporal Variability in 8/26/08 data
°F
75
74
73
72
71
70
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
Time of Day
10
11
12
14
15
16
17
18
19
20
Umpqua River off Scott Boat Ramp
8/26/08 Bottom Temperature
Normalized to 8_26 Noon



The results of this work are similar to those of 7/17 & 7/18. The normalized data pattern is not distinctly different from the TIR data and no indication of coldwater upwelling was observed. If coldwater upwelling was the cause of the observed TIR variability, a relatively large inflow would be expected to be found in the study area. That no cold-water upwelling was detected suggests that coldwater inflow may not be the cause of the variability in the TIR data profile within this project area.

Time Series Data Cross Section Variability

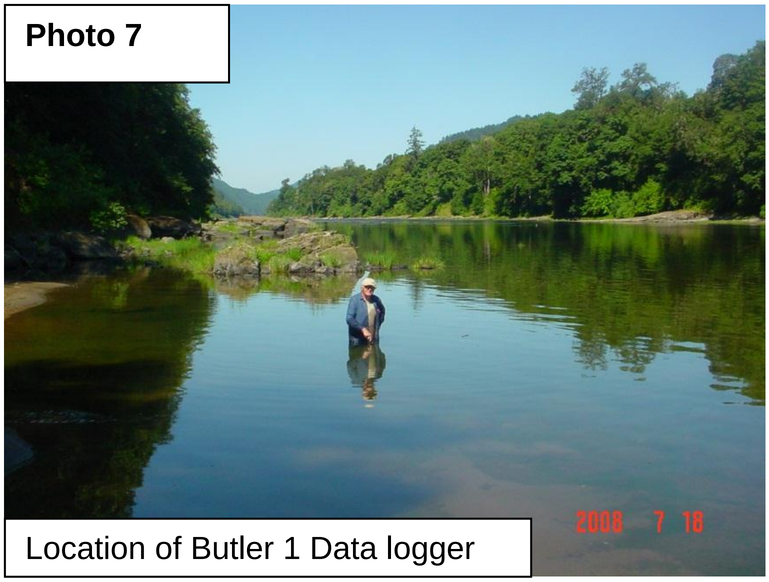
Several Onset Tidbit data loggers were deployed during the project. The units in the river provided a glimpse of the dynamic thermal patterns in the river and a possible explanation for the variability in the TIR data.

Partial River Cross Section near Butler Creek (Site P-14)

Three data loggers were deployed at site P-14: In Butler Creek below the culvert; Butler 1 near sample point G 12; and Butler 2 near sample point G 5 (See Photo 6}. Photo7 shows the deployment location for “Butler 1.” (Note the calm conditions in the backwater pool.)

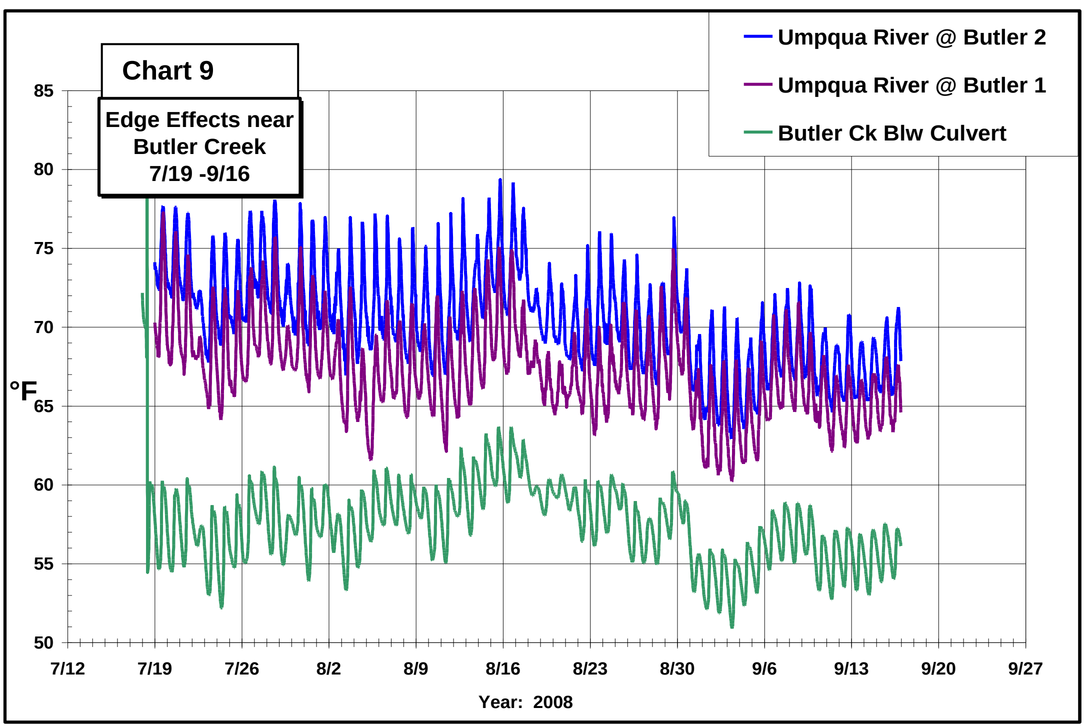
Chart 9 shows the response for the period of record and Chart 10 shows a detailed response for a three-day period with the blue-shaded central portion showing the 9/13/08 response. Examination of Chart 10 indicates that the diurnal pattern of the respective time-series appears to be shifting to the right as the sampling moves outward toward the thalweg region. The response for Butler Creek is typical of small streams that are typically very responsive to the immediate condition of the local thermal environment. The phase shift is probably a function of the larger thermal mass, extended exposure and the upstream contribution associated with the larger open channel.

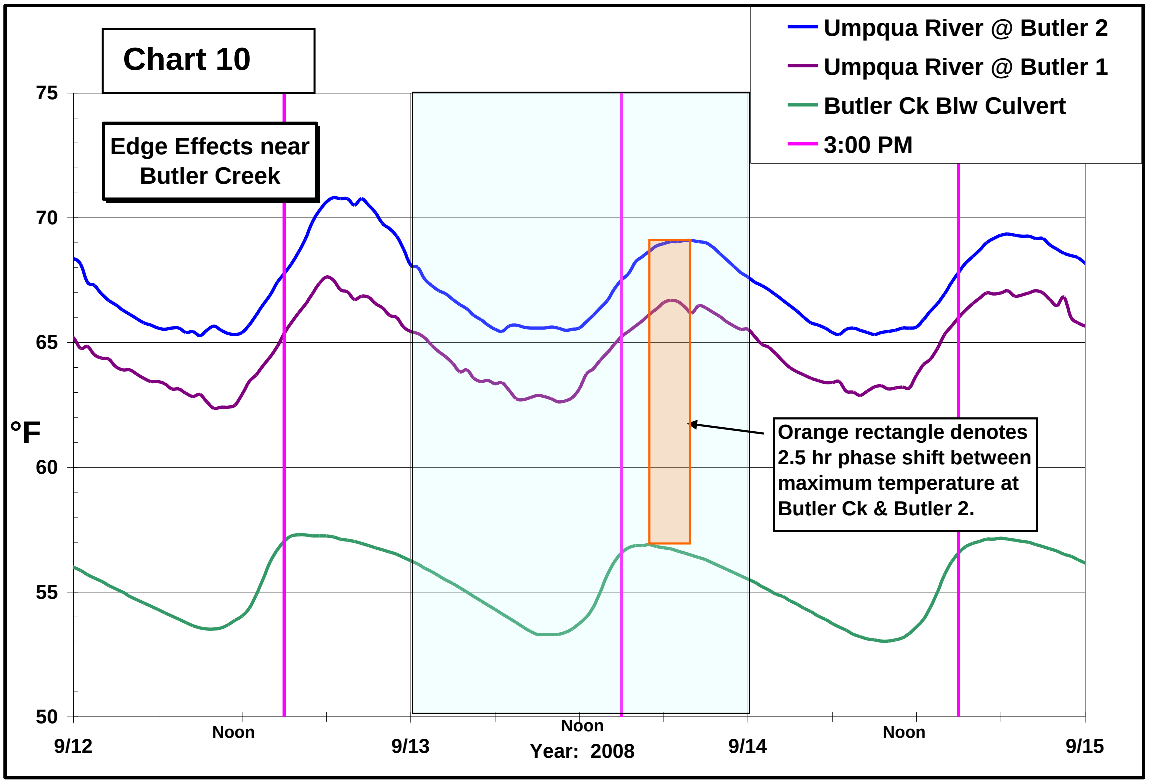
Photo 7



Location of Butler 1 Data logger

Examination of the 3 PM line indicates that the assumption that all points in the river reach "near maximum" in unison may not be valid to thalweg conditions and could introduce additional variability in a synoptic temperature profile. Table 9/13 shows the effect of the phase shift at 3 PM for the Site P-14 units. It is apparent that while the Butler Culvert unit is measuring the daily maximum temperature, the other units are more than 1°F from their respective maximum values. See Appendix C / Phase Shift for more detailed discussion on this topic





9/13/2008	Butler Creek	Ump @ Butler 1	Ump @ Butler 2
max	56.9	66.69	69.09
3:00:00 PM	56.56	65.23	67.5
min	53.3	62.66	65.44
ΔT °F	3.6	4.03	3.65
% ΔT	90.56%	63.77%	56.44%
Dev from Max	0.34	1.46	1.59
Difference	0	-1.12	-1.25

Partial River Cross Section near Stony Brook – Site P-11

Three data loggers were placed on the vicinity of Stony Brook, a small tributary that went dry later in the season. Photos 7a-9 show the respective data logger locations. Since Stony Brook went dry later in the season, data collected on 8/1/08 was selected for the relative comparison.

The water in Stony Brook was only two inches deep at the time of placement and the creek did go dry later in the season. The “alcove” unit was fastened to the log to monitor the temperature of the backwater pool. The river unit was placed about 60 feet from the alcove as shown in Photo 9. Obviously it is not in the central thalweg but circulation appeared to be good and the data should be fairly representative of the thalweg condition.


Photo 7a
Stony Brook Placement


Photo 8
Stony Brook Alcove


Photo 9
River Placement

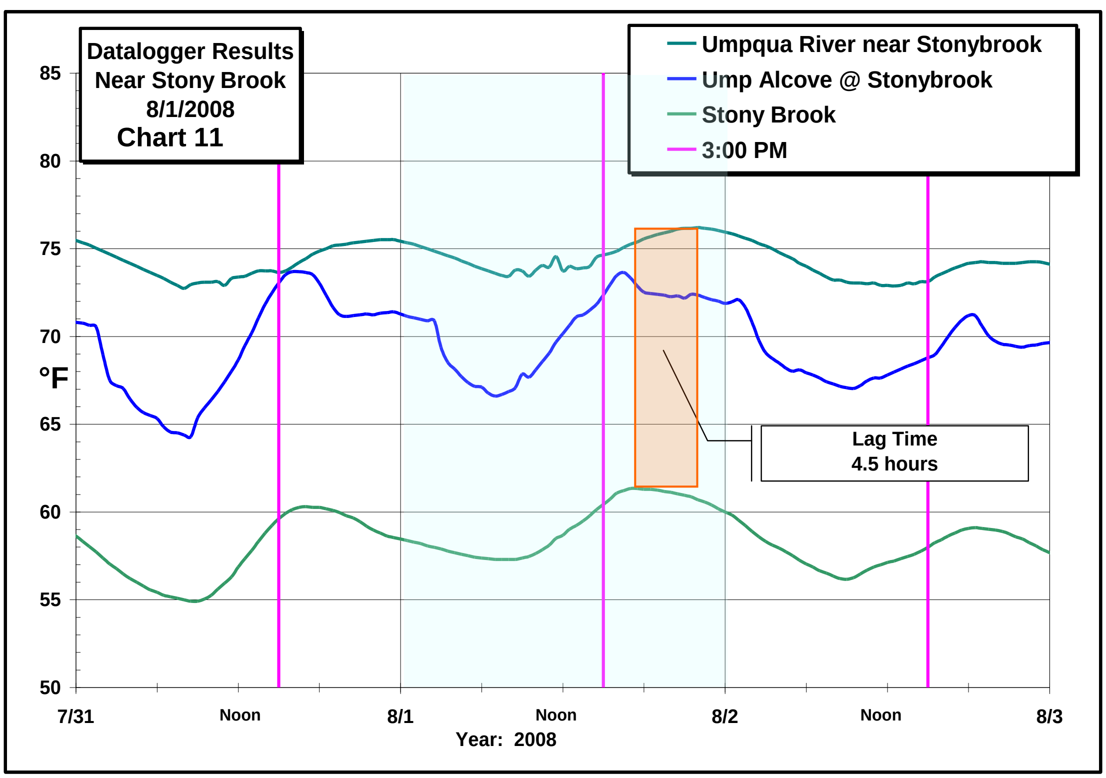

Datalogger Results
Near Stony Brook
8/1/2008
Chart 11
Umpqua River near Stonybrook
Ump Alcove @ Stonybrook
Stony Brook
3:00 PM
Lag Time
4.5 hours
85
80
75
70
°F
65
60
55
50
7/31
Noon
8/1
Noon
8/2
Noon
8/3
Year: 2008

Chart 11 and Table 8/1/2008 show that there is about a 4.5 hour phase shift in maximum values between the river and the tributary temperatures. This shift causes the river 3:00 PM observed value to be only 44% of its daily maximum while Stony Brook reached 78% of its daily maximum. The response of the alcove unit is more erratic, possibly due to topographic shading and/or eddy circulation effects.

8/1/2008	Stony Brook	Stony Brook Alcove	Ump @ Stony Brook
max	61.33	73.65	76.2
3:00:00 PM	60.43	72.35	74.64
min	57.29	66.6	73.43
ΔT °F	4.04	7.05	2.77
% ΔT	77.72%	81.56%	43.68%
Dev from Max	0.9	1.3	1.56
Difference	0	-0.4	-0.66

Time Series Data Longitudinal Variability

Photo 10 shows the data logger deployment near the Scott Ck Ramp (Site P-12). This unit and the Stony Brook (P-11) river unit both have good exposure to the thalweg zone of the river and they may provide a glimpse at the time-series response of the longitudinal thalweg profile.

Photo 10
Scott Ramp Site

Chart 12 shows detail for a representative day. The magenta line denotes the time at 3:00 PM, a typical time for sample the high daily temperatures. Note that on 9/13 the 3:00PM value for Scott Creek is noticeably closer to its daily maximum than that at Stony Brook.

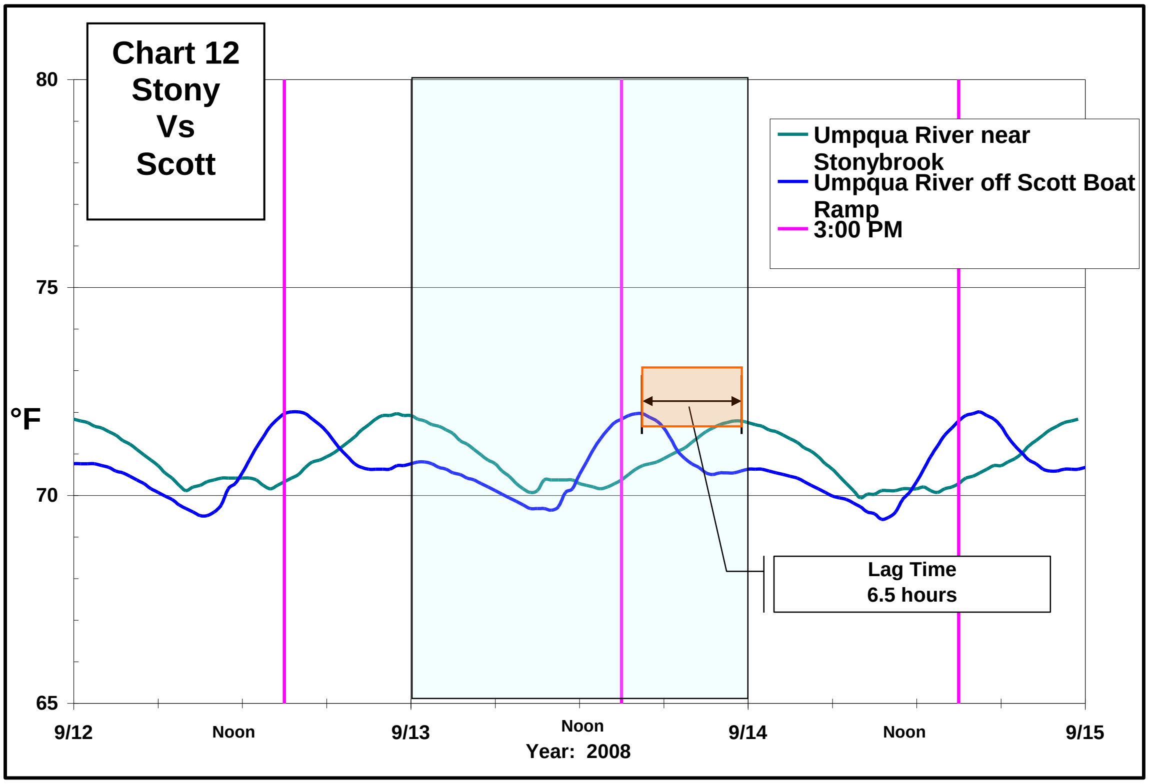
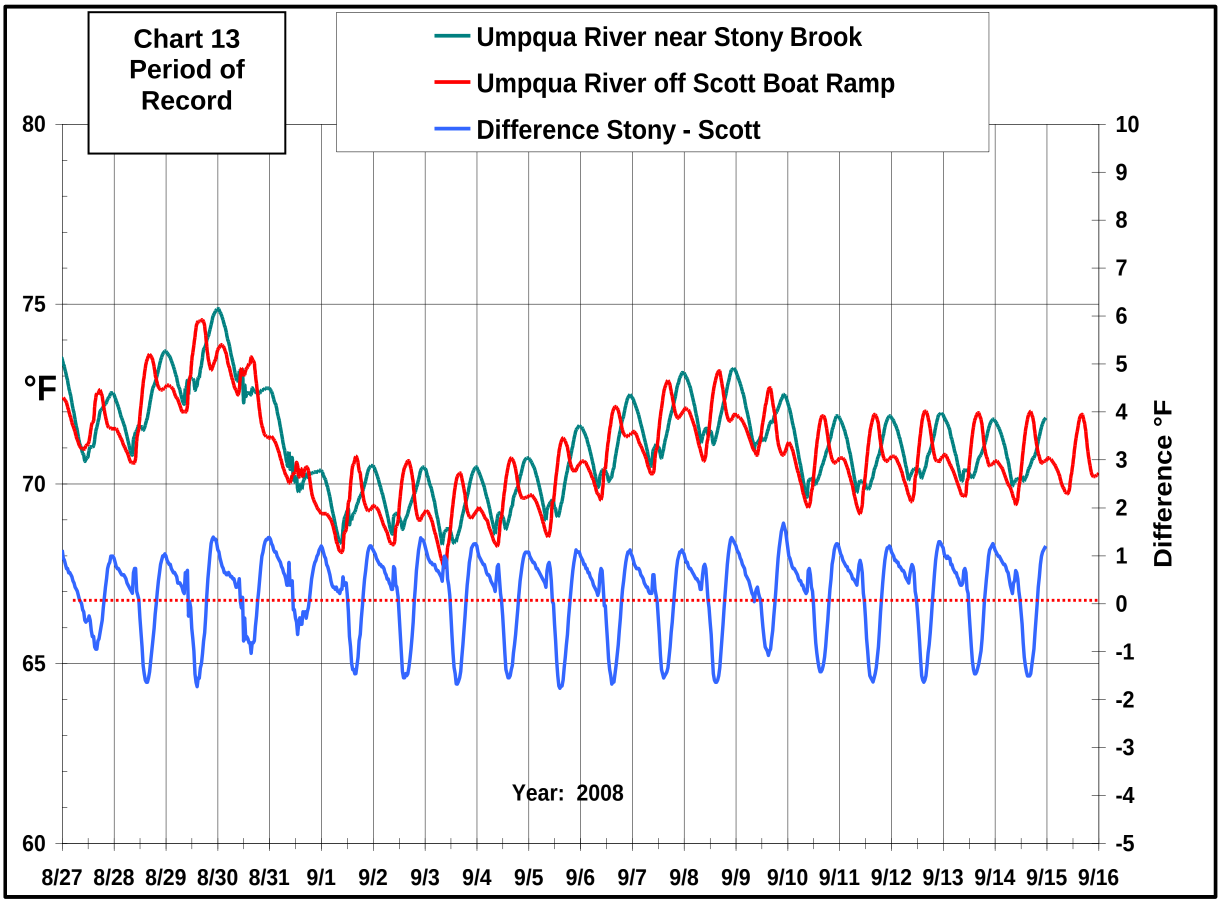


Table (9/13) shows values for 9/13/08. At 3:00 PM the Scott Ramp logger recorded 94% of its maximum value while the Stony Brook unit had reached only 17% of its maximum value. The corresponding temperature difference between the sites at this date and time is 1.29 °F. Examination of the 2002 TIR Median Temperature data in Photo 3 and Chart 2 shows the Stony Brook site about 1°C cooler which is close to the difference detected by the data loggers. [Note: On the 7/23/02 TIR flight, Scott Ck was sampled at 2:46 PM and Stony Brook was sampled at 2:48 PM.]

9/13/2008	Ump @Scott Ramp	Ump @ Stony Brook
max	71.96	71.79
3:00:00 PM	71.83	70.37
min	69.73	70.07
ΔT °F	2.23	1.72
% ΔT	94.17%	17.44%
Dev from Max	0.13	1.42
Difference	0	-1.29

Chart 13 shows the data for the period of record. The data logger at P-12 was deployed later in the season and consequently the data record is abbreviated. However, for the period of record, it is apparent that a consistent phase shift in data exists between the two sites. It is also worth noting that the response and amplitude of the two sites is similar suggesting a similar response to similar conditions as would be expected in the thalweg zone.

Chart 13 also shows the synoptic difference between the two sites and indicates that the phase pattern remained constant for the limited period of record with a period of 24-hours. It appears that the wave moves about 2.8 miles in 6.5 hours giving it a phase velocity of 0.43 mph and an effective wavelength of about 10 miles.



Tentative Conclusions:

This study suggests that it is unlikely that the sinusoidal variability observed in the TIR data was caused by significant cold-water upwelling since fairly extensive sampling in regions of expected upwelling did not show any sign of cold water inflow of the magnitude required to cause the observed effect. However, the limited time-series data suggests that the TIR variability pattern may be the result of an asynchronous response to daily solar input on different parts of the river. It also appears that this pattern is dynamic, with the diurnal extremes occurring at different times on different parts of the river. If this proves to be the case, an enterprising fish could possibly travel with the diurnal minimum as it moves up the river.

This study did not discover previously unknown cold-water refugia. It confirmed that the vertical water column is generally quite uniform in areas with even minimal flow. The water temperature along the edges is quite variable as shown in the TIR data. The net effect of the tributaries on the temperature of the main river is typically very small but may represent important thermal refugia points. This report indicated that significant cold-water upwelling could occur on the bottom of the river but would not necessarily be detected on the surface by a TIR flight. It is therefore possible that isolated points of cold-water upwelling do exist in the river – just not to the extent that would produce the observed TIR pattern. Locating these points may be problematic. It is expected that the temperature gradient on the bottom surface would be very steep – in the 1-2 inch range. Detection of this condition would probably require direct contact with the surface. Even though the cold zone may not be very thick, a fish could probably benefit greatly by "hunkering down" in cold the bottom sediment.

Additional time-series monitoring the thalweg of the Lower Umpqua is recommended to provide better information for the modeling and fish management efforts. Radio telemetry using fish transmitters may be the most efficient way to locate the elusive refugia areas in the Lower Umpqua.

References

1. Smith, K., *Lower Umpqua Watershed Temperature Study -Summer 2000*. 2000, Umpqua Basin Watershed Council.
2. *Aerial Surveys in the Umpqua River Basin*. 2003, Watershed Sciences, LLC: Corvallis.