Stream Temperature and Climate in the Calapooya Watershed

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An Umpqua Basin Watershed Council Water Quality Report

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Stream Temperature and Climate in the Calapooya Watershed

By Kent Smith
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12/15/2003

Summary:

This study is a continuation of a stream temperature characterization project for the Umpqua Basin that was started in 1997. This study complements conventional stream temperature data with local air and surface temperatures at thirteen locations in a 250 square mile watershed within the river basin to provide climate related information. These data are supplemented with thermal imagery from a 2002 study done by Oregon DEQ. Also temperature and evaporation rate information was obtained from a separate reference site.

The data confirms that mean summer temperature in the Umpqua Basin ranges from about 54 °F near the source point on the watershed divide to about 65°F and remains fairly constant at points beyond twenty miles from the divide. Areas with high peak daily temperature appear to be associated with exposed reaches. It also indicates that, under the late summer low-flow conditions typical of the area, the stream temperature is very dependent on the local thermal environment and is independent of temperature effects further upstream. Because of this, there appears to be ample opportunity to improve the local thermal environment (and corresponding stream temperatures) at many specific locations.

Objective

The objective of the study was to obtain a better understanding of the relationship between stream temperature and the local climate. Figure 1 shows the representative air temperature distribution for both a open area and a forested area (Satterlund 1972). Note that the temperature profile continually shifts between the two extreme values on a daily basis. In general, the earth surface becomes heated by solar radiation during the day and the heat is radiated back into space during the night via longwave radiation. In a forested setting, the canopy serves as the receiving surface and a

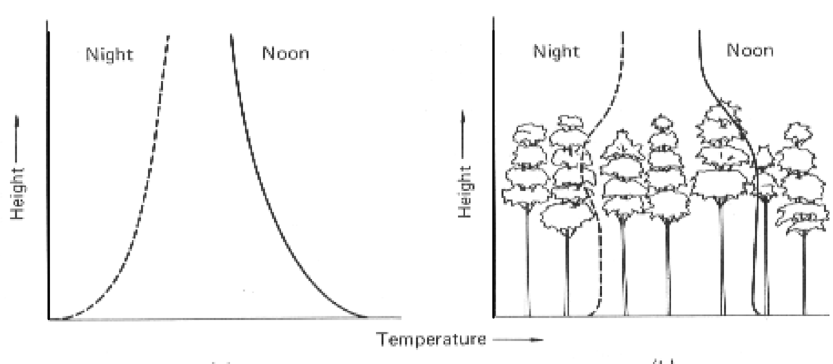
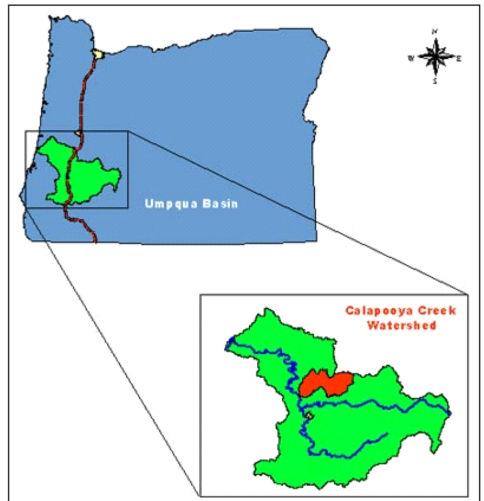


Figure 1 Temperature distribution (a) Open area, (b) Forested area.

modified thermal environment is created between the canopy and the ground.

A stream with surface flow will experience similar thermal fluxes. However, since water has distinctly different thermal properties and the water is flowing, the net response from the water surface is not exactly the same as a typical surface point. The data from this study will provide an opportunity to examine these differences and obtain a better understand of the relationship of the stream temperature to the local thermal environment.

Background:



Graphic Courtesy of UBWC

The Umpqua River Basin (5,000 square miles) is world-known as an important salmonid fishery and the summer stream temperature is considered to be a key factor influencing the habitat quality of the system. Since the larger streams tend to be warmer, the smaller streams and tributaries are of particular interest both for the quality of habitat and because of their sensitivity to management. The Calapooya Creek watershed (area 254 square miles) is a representative watershed of sufficient size to display spatial stream temperature patterns.

Climate conditions in the Umpqua River Basin

Climatic conditions in Southwestern Oregon are characterized by wet winters with moderate temperatures and dry and moderate summers that typically approach drought conditions. There are several implications of this climate regime that relate directly to summer stream temperature:

- The heavy rain precipitation (about 30 inches) during the winter causes relatively large streamflow that moves large amounts of sediment and forms large capacity channels and during the summer drought conditions the flow recedes gradually to a minimal base-flow condition. For example, the August flow at site Cal 3 (gage station 14320700, watershed area 210 sq miles) ranges from 2.6 to 28 cfs with a mean of 11 cfs (.052 csm). The average annual discharge, based on 19 years of record, is 486 cfs (Moffatt, Wellman et al. 1990) and the 2-yr storm flow is 11,700 cfs (Harris, Hubbard et al. 1979). A consequence of the disparity between the winter and summer flows is that the high winter flows create high capacity channels and consequently the summer flow occurs in channels with large pools and large gravel deposits. This condition leads reservoir-like flow conditions and a large proportion of hyporheic flow during the late-summer months; both of which can affect stream heating processes and aquatic habitat.

- The moderate temperatures in the area result in a mean annual temperature of about 52°F. Several researchers indicate that the emergent groundwater temperatures will be close to the mean annual water temperature. Emergent water temperature is important because it represents the lower achievable limit for the daily mean summer stream temperatures. It is interesting that areas with colder winters may have colder mean annual temperatures and subsequently colder summer stream temperatures.

- The dry summer conditions typically results in “brown hill” conditions with low soil moisture and low humidity. This sets the stage for a special climate condition called the "oasis effect" where exceptional evaporation takes place in wet areas due to the availability of large amounts of dry warm air from the surrounding arid areas(Oke 1987). The energy involved with this evaporation process can significantly affect the stream temperature.

- The late summer weather is quite uniform with relatively clear sky and gentle breezes throughout the central basin. Air temperature data from riparian locations throughout the watershed are very consistent. Stream temperature data from different locations show the same seasonal pattern. Since there is little or no precipitation, the corresponding streamflow patterns are also very regular. These conditions provide an opportunity to compare data under relatively homogeneous conditions.

Channel Conditions

Figure 2 shows the stream network for the Calapooya watershed. The active channel widths vary from about 1 meter to about 8 meters. The late summer wetted width ranges from zero to about 5 meters. Stream depths range from a few centimeters to about 0.5 meters.

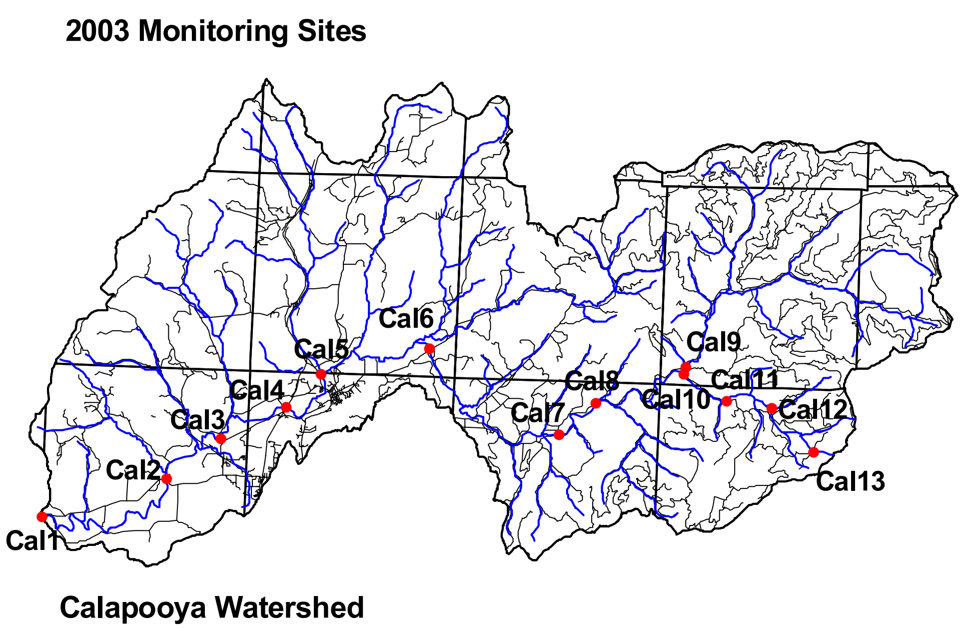


Figure 2 Streams, roads and monitoring site locations.

Study Design:

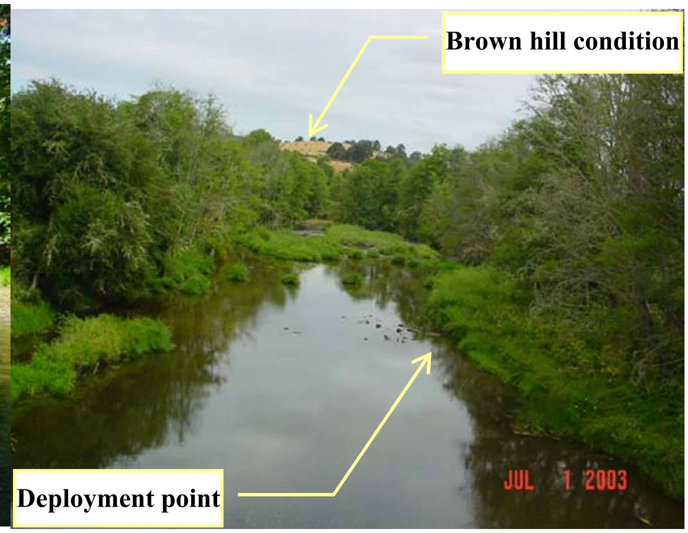
To meet the study objectives, thirteen monitoring sites were established between the mouth and the headwaters of the Calapooya watershed. At each site air temperature was measured in a shaded area in the adjacent riparian area with a vertical displacement of about six to eight feet above the water. Ground surface temperature was taken by inserting the data logger into the soil near the water edge with the thermistor tip flush with the surface. Stream water temperature was taken near the bottom of the channel in an area with good circulation. All of the temperature measurements were made at thirty-minute intervals.

TidbiT® data loggers manufactured by Onset Computer Corporation with a range from -5 °C to 37 °C were used to collect the temperature data. The mass of these thermistor units is about 0.5 ounce and the time constant in water is specified at three minutes. The ideal air temperature measuring device would have less mass and faster response. Consequently, these units may be underestimating the extreme values of the air temperature and will tend to damp out the expected high frequency variability. However, these units appeared to be well suited for measuring the surface and water temperature. A two-point calibration was performed on all of the units before deployment and after retrieval. All units were within 0.3°F of a reference thermometer.

Table 1 Monitoring site information

Site #	Site Location	Mouth Distance (Miles)	Divide Distance (Miles)	Elevation (Feet)
Cal 1	Calapooya @ mouth	0.0	44.3	315
Cal 2	Calapooya @ Cole Rd	6.9	37.4	355
Cal 3	Calapooya @ Rochester Bridge	9.9	34.4	385
Cal 4	Calapooya abv I-5 Bridge	12.7	31.6	390
Cal 5	Calapooya abv Cabin Ck	14.9	29.4	410
Cal 6	Calapooya @ Driver Rd Bridge	19.2	25.1	430
Cal 7	Calapooya @ Nonpareil	25.3	19.1	680
Cal 8	Calapooya @ gravel pit	27.1	17.3	730
Cal 9	Calapooya abv Hinkle Ck	31.0	13.4	815
Cal 10	Hinkle @ mouth	31.0	6.1	815
Cal 11	Lower Hinkle Ck	32.7	4.4	988
Cal 12	Hinkle blw Forks	34.2	2.9	1380
Cal 13	Upper Hinkle Ck	35.8	1.0	2056

Table 1 shows specific information about each site. The “divide distance” value is the distance from the site to the furthest upstream divide point. Since the divide point is different for the Hinkle Creek streams, the sum of the mouth distance and the divide distance is not always constant. The divide distance value is a useful index of channel size which is an important factor in defining the local thermal environment.



Picture 1 Site Cal 01 Calapooya Creek near mouth.

Picture 2 Site Cal 06 Calapooya Creek below Driver Valley Rd

Pictures 1 and 2 show representative monitoring site locations. More detailed pictures showing specific data logger locations are available upon request. In Picture 2 the "brown hill" condition of the dry hill in the background contrasts with the green of the riparian area.

Evaporation Rate and Shade Effects Study

To supplement the data from the Calapooya Creek watershed, a simple reference study was set up in Yoncalla, Oregon, located about 20 miles north of the watershed. In this study, air and surface temperature was measured in an open exposed area as well as a small wooded area in a manner similar to that used in the Calapooya study. In addition, two five-gallon pails, one shaded, and one exposed, were used to measure water temperature response and evaporation rates. Details of this study are available in Appendix 1.

Thermal Imagery Study

In August of 2002 a thermal imagery study sponsored by Oregon Department of Environmental Quality was completed by Watershed Sciences, LLC of Corvallis Oregon. A helicopter was used to take infrared and normal light photographs of the stream at about 300 ft intervals. These data were used to produce a detailed stream temperature profile of late afternoon stream temperature conditions in July 2002. Some of the spatial-extensive data from this study was used to complement the temporal-extensive data from the 2003 study.

Results

UBWC 2003 Study – Temporal data

The data loggers produce large quantities of data and there are many different ways to show the information. Some representative results are shown here. All of the data files for the thirteen sites are available upon request.

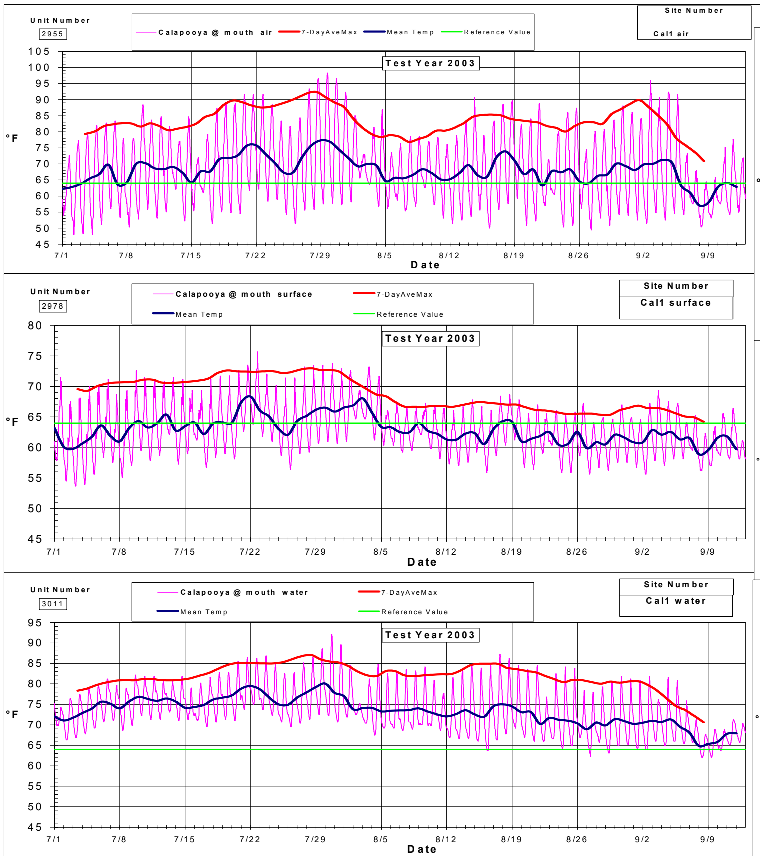


Figure 3 Site Cal 01 Calapooya @ mouth

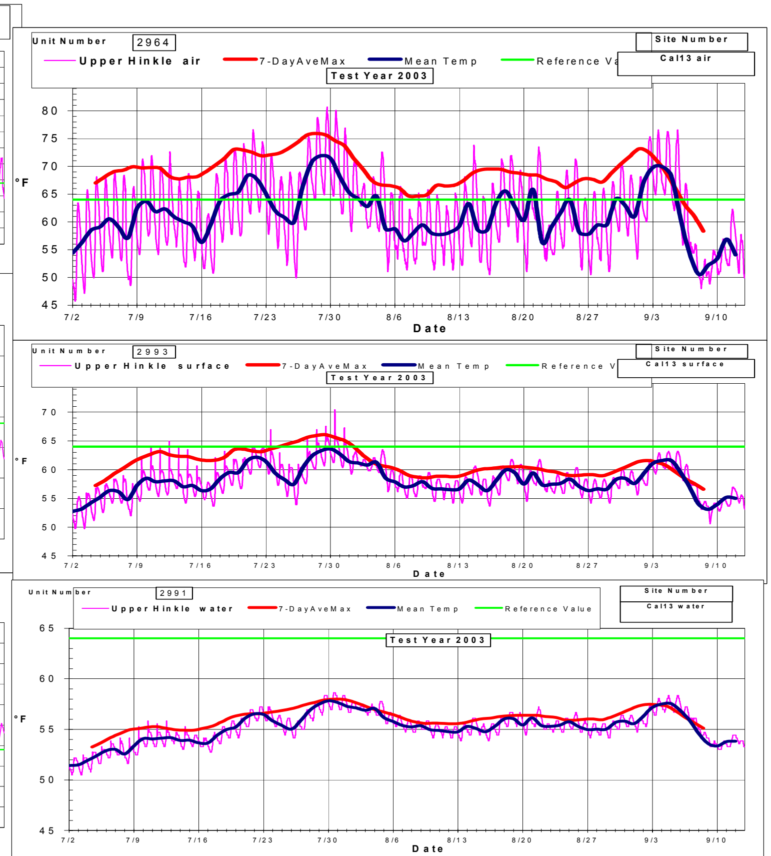
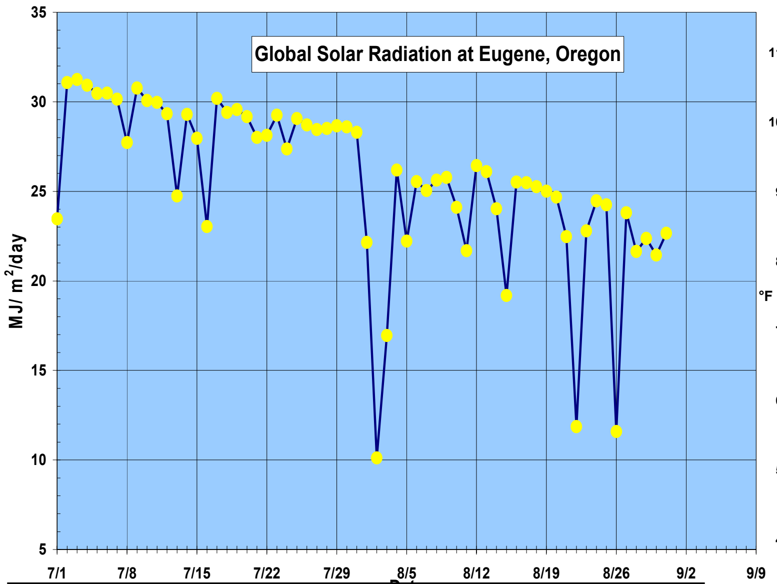


Figure 4 Site Cal 13 Upper Hinkle Ck

Figures 3 and 4 show the temporal variation of the air, surface and water temperature data for the sites located at each end of the study. The dark blue line traces the daily mean and the red line denotes the 7-day moving average of the daily maximum value. Note the diurnal fluctuations and the similarity of the seasonal pattern in all of the data.

Since the water and air units are measuring fluids, the effective sample volume is larger and they tend to represent a larger sample volume. In contrast, the surface unit is point specific and does not necessarily represent average conditions for the area. For example, changes in the solar path may have more effect on the surface unit than on the air and water units.

Figure 5 shows the daily global radiation as measured in Eugene, Oregon located about 60 miles north of the study area. The general downward trend is due to the seasonal change in solar declination. The corresponding temperature patterns do not decrease because the earth receives a surplus of heat in the spring and summer months. It is interesting to note that days with low solar input are associated with days with small diurnal variation and lower maximum temperatures for all of the temperature data in the study. This effect is particularly noticeable during the low radiation days on 8/2 and 8/22.



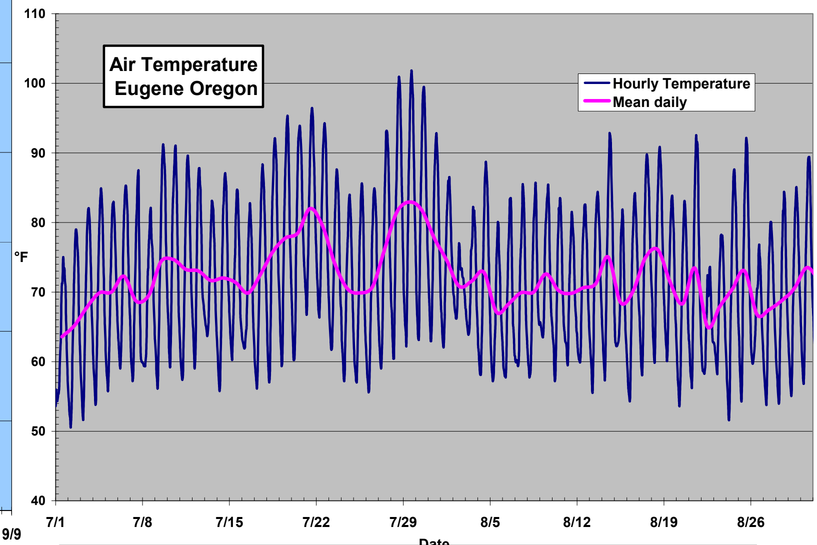


Figure 5 Global radiation @ Eugene, OR

Figure 6 Air temperature @ Eugene, OR

Figure 6 shows the air temperature as measured in Eugene, Oregon. Notice that the pattern mimics the air temperature data from the study sites. It appears that there is a component of the seasonal pattern that has fairly uniform diurnal variation but displays significant variation of the mean value. The probable source for this variation is the temperature of the prevailing air mass that is moving through the area. A good example of this effect occurs on 7/24 when an apparently cool air mass shifts the entire temperature pattern downward. Based on these observations, it appears that both the prevailing air mass temperature and the amount of direct solar radiation have a significant effect of the seasonal stream temperature pattern with the air mass effect causing a shift in the mean value with little change in amplitude and the radiation effect causing a change in the amplitude of the diurnal variation with less change in the mean temperature.

Yoncalla Reference Study

The objective of the reference study was to provide a non-riparian control environment

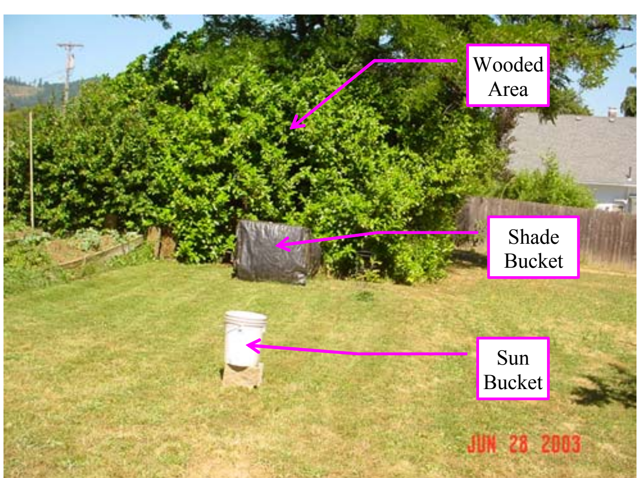


Figure 7 Yoncalla reference site

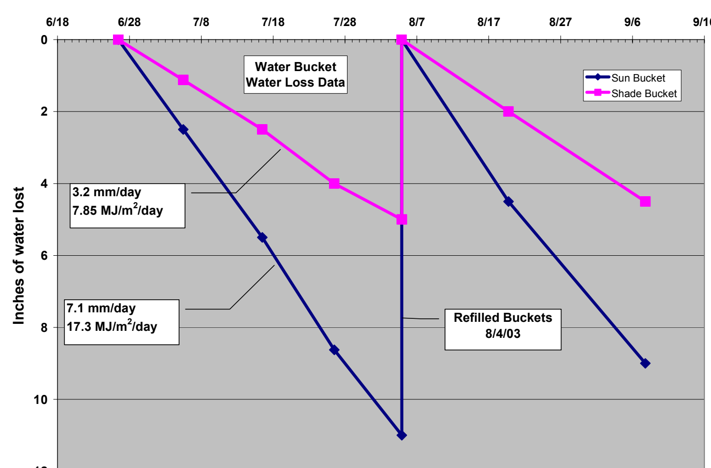


Figure 8 Evaporation losses – Summer 2003 in Yoncalla, Oregon

with no flow components for comparison with the 2003 Calapooya Study. Figure 7 shows the arrangement used for the study.

The daily evaporation rate was determined by simply measuring the water level in both exposed and shaded buckets and Figure 8 shows the results. The exposed bucket had an average daily rate of 7.1 mm/day and the shaded bucket had a corresponding rate of 3.2 mm/day. These rates represent daily latent heat loss of 17.3 $MJ/m^2/day$ and 7.85$MJ/m^2/day$ respectively (54% reduction for the shade area). It should be noted that the Hyslop Experimental Station in Corvallis collects daily evaporation rates from an evaporation pan and the average August 2003 rate observed was 7.14 mm/ day.

Seven temperature data loggers were used to record water, surface and air temperatures for the exposed, shaded and wooded conditions at the reference site. Charts and other results are available in Appendix A.

Energy budget and thermal equilibrium

Discussions of stream heating typically involve some type of energy balance analysis. While the overall process is quite complex, the results from this study does provide some information on the thermal flux components.

The heat flux components shown in Figure 9 can be described in many different forms. For a given section of channel with unit width the heat balance can be represented by the following equation:

$$Q^* = Q_H + Q_E + Q_G + \Delta Q_A + \Delta Q_S$$

Where:
Q^* net all-wave radiation flux
Q_H turbulent sensible heat flux
Q_E turbulent latent heat flux
Q_G sub-surface heat flux
ΔQ_A net advective heat
ΔQ_S change of heat storage in the water volume
(Oke 1987)

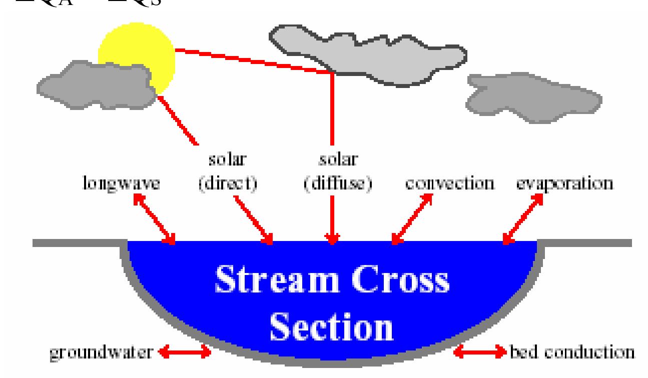


Figure 9 Stream heat flux components (Boyd and Sturdevant, 1997)

Note that, in this equation, all of the radiation components are grouped into one term (Q^*) and that the net advective heat includes all of the water-transported heat which includes surface, groundwater and hyporheic flow into and out of the volume of water. The sensible heat transfer (Q_H) refers to heat that moves directly between the air and the water. The latent heat Q_E is the heat transferred through evaporation and condensation. Heat transferred with precipitation was ignored since there wasn't any precipitation during the study.

Since Q^* is driven by the solar cycle, a daily diurnal cycle is established that is readily evident in the data. To discuss the flux components, it is helpful to define a steady-state condition the state where the daily input patterns remains constant from day to day and the daily output pattern is unchanged. Since then there is no net change in temperature from day to day, the change in the stored heat ΔQ_S is zero as measured on a daily basis. A recent paper from the St. Anthony Falls Laboratory (Bogan, Mohseni et al. 2003) refers to this condition as the equilibrium temperature and indicates that local physical conditions that affect shading and sheltering influence the equilibrium temperature of the stream at that location.

Generally most of the incoming heat from radiation Q* is balanced by the latent heat component Q_E.

Net radiation Q*

This component is the principal source of heat to a stream and is dominated by direct solar radiation as shown in Figure 9. Figure 1 shows how vegetation can shade the incoming radiation and influence the temperature of the ground or water below. The radiation component is well discussed in the literature relating to stream heating.

Evaporation flux Q_E

The evaporation flux Q_E is difficult to model accurately because the water surface, where evaporation occurs, has steep gradients with respect to wind effects, surface temperature, and water vapor pressure. This situation is particularly true in high moisture areas that are surrounded by relatively dry areas and the warm dry air can move into the moist area and accelerate the evaporation rate. This condition is called the "oasis effect" because it is commonly observed in desert areas. A direct consequence of this effect is that the day-time surface temperature will be cooler than the air temperature above the surface (inversion condition) as was observed at several of the monitoring sites. This condition causes the sensible heat flux Q_H to become negative since heat will flow from the air to the ground and the corresponding Bowen ratio (Q_H /Q_E) will be negative. The energy used for evaporation under this condition can exceed the net radiation energy. In extreme cases, the ratio of Q_E /Q* can exceed 2.5 while values greater than one are common (Oke 1987).

Advection

The advection component refers to all heat that is transported into and out of the volume by flowing water. The subcomponents are:

- Groundwater inflow- this flow continually adds to the surface flow along the entire length of all of the channels. Typically it is a small flow at any point and often enters below the surface of the stream. In general streams gain flow in the downstream direction, the contributing groundwater coming from an associated contribution area that can be quantified as the reciprocal of the drainage density. For example, a watershed with a drainage density of 10 stream miles per square mile would have stream contribution area of 0.1 sq miles per mile of stream or 528 square feet per foot of stream. Often the drainage density tends to be independent of scale and obviously that would also be the case for the contributing area. Consequently it can be assumed that the contributing area can be considered constant per unit length of channel through out the watershed. Of course, geologic differences will greatly affect this relationship. For example, alluvial filled valleys in the lower watershed may create high groundwater sources. The temperature of this inflow supply will generally be around 52 °F which is close to the mean annual temperature for the basin.

- Hyporheic flow- In portions of a channel part of the surface flow will pass through the permeable channel bottom or into the banks. This flow typically reenters the channel, thereby maintaining the continuity of the total flow. This process facilitates the exchange of heat with the adjacent soil material.

- Upstream contribution- Flow from upstream can bring in heated water that exceeds the equilibrium temperature of the local environment. Thermal processes and dispersion will act on this temperature difference until equilibrium is reached.

- Downstream contribution- The final temperature associated with the reach will become the upstream contribution for the next reach.

- Other situations such as water withdrawals and irrigation inflow will have similar influence on the net stream temperature.

Sensible heat flux Q_H

This transfer involves direct transfer between the air and the water interface and is driven by the relative temperature difference. When the water temperature is cooler than the air temperature, heat will flow from the air to the water. As noted above in the Q_E discussion, heat flow from the air to the water results in a negative Bowen ratio and the dominate water cooling process is usually the latent flux component. However, Figures 3 and 5 indicate that the prevailing bulk air temperature can have a significant affect on stream temperature and this change is primarily due to the combined effects of Q_E and Q_H.

Ground flux Q_G

This component is relatively small and it tends to balance out on a daily basis.

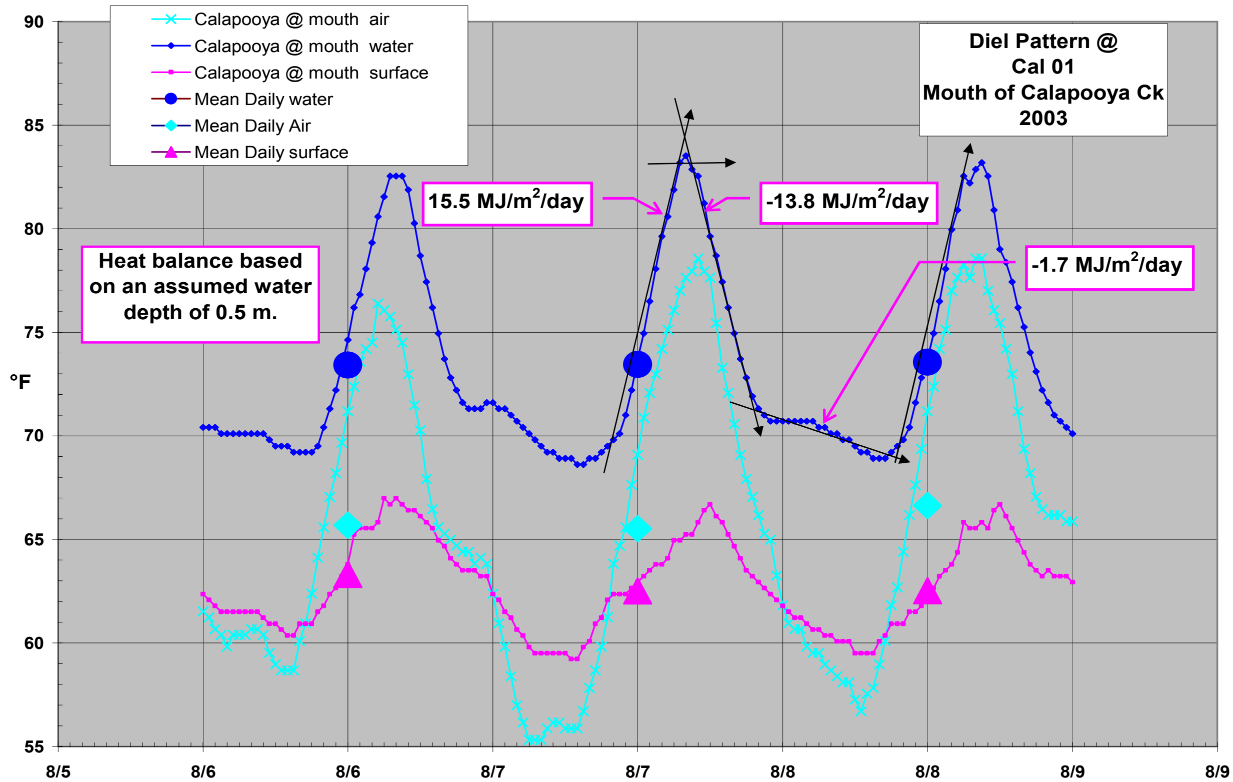


Figure 10 Site Cal 1 example heat balance

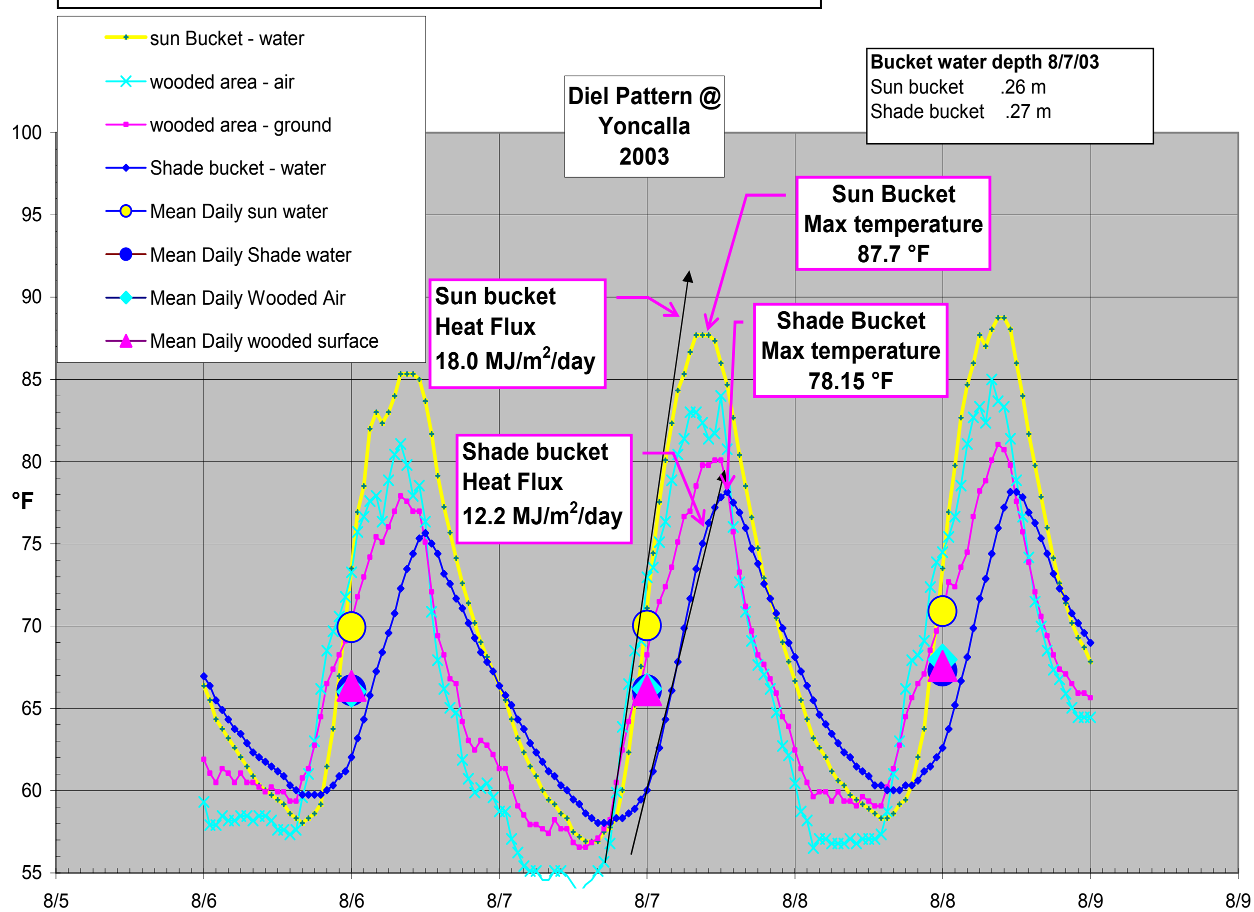


Figure 11 Energy balance at Yoncalla reference site

Daily energy balance

An indication of the relative size of the flux components can be obtained from the data collected from the 2003 study.

As an example, Figure 10 shows data for a three-day interval at site Cal 01 near the mouth of Calapooya Creek. The nearly uniform shape of the diurnal patterns indicates that near-equilibrium conditions exist. The energy flux calculations were based on an assume depth of 0.5 meters.

The following observations are of interest:

- At equilibrium, the incoming heat balances the outgoing heat
- The heating rate of 15.5 MJ/m^2/day is of the same order as the potential evaporation rate observed in the bucket studies (17.3 MJ/m^2/day). This indicates that the evaporative flux component can balance the effect of the net radiation component.
- The day-time and mean daily ground temperature is cooler than the corresponding air temperature. This condition is consistent with the oasis effect in a moist area and indicates a high evaporation effect.
- The water temperature curve closely tracks the air temperature. This suggests that local conditions dominate the net process.
- The water is more exposed to direct solar radiation than the ground and air measurement sites. This may account for the higher water temperature.

Figure 11 shows similar data from the Yoncalla reference study for the same time period. The energy flux calculations were based on the actual water depth.
Note the following:

- The similarity with the field data shown in Figure 10.
- The mean values of all of the shaded units are similar, indicating a common thermal environment. The higher mean value of the exposed bucket indicates a warmer thermal environment. This supports the interpretation the water temperature in Figure 10.
- The day-time surface temperature is near air temperature compared with the riparian data, probably due to lower moisture availability at the surface.
- The heat flux in the shaded bucket was about 30% less than the exposed bucket. This difference amounted to about a 9°F difference in the maximum daily temperature and is consistent with data from other shade buffer studies.

UBWC Study – Spatial distribution

It is generally accepted that stream temperatues tend to increase as the water moves further from the watershed divide. An objective of this study was to look at the spatial distribution of the corresponding environment as well as the stream temperature. To quantify the spatial pattern it is necessary to select a statistic to represent the temporal data from a monitoring site.

UBWC 2003 Study - Spatial Data

For the 2003 study, the August mean of the daily maximum, mean, and minimum were calculated for each site and the values were plotted against the distance from the watershed divide in Figure 12. Other statistics of interest can easily be calculated from the data that is available upon request. It should be noted that use of a single statistic is usally insufficient for stream habitat management planning.

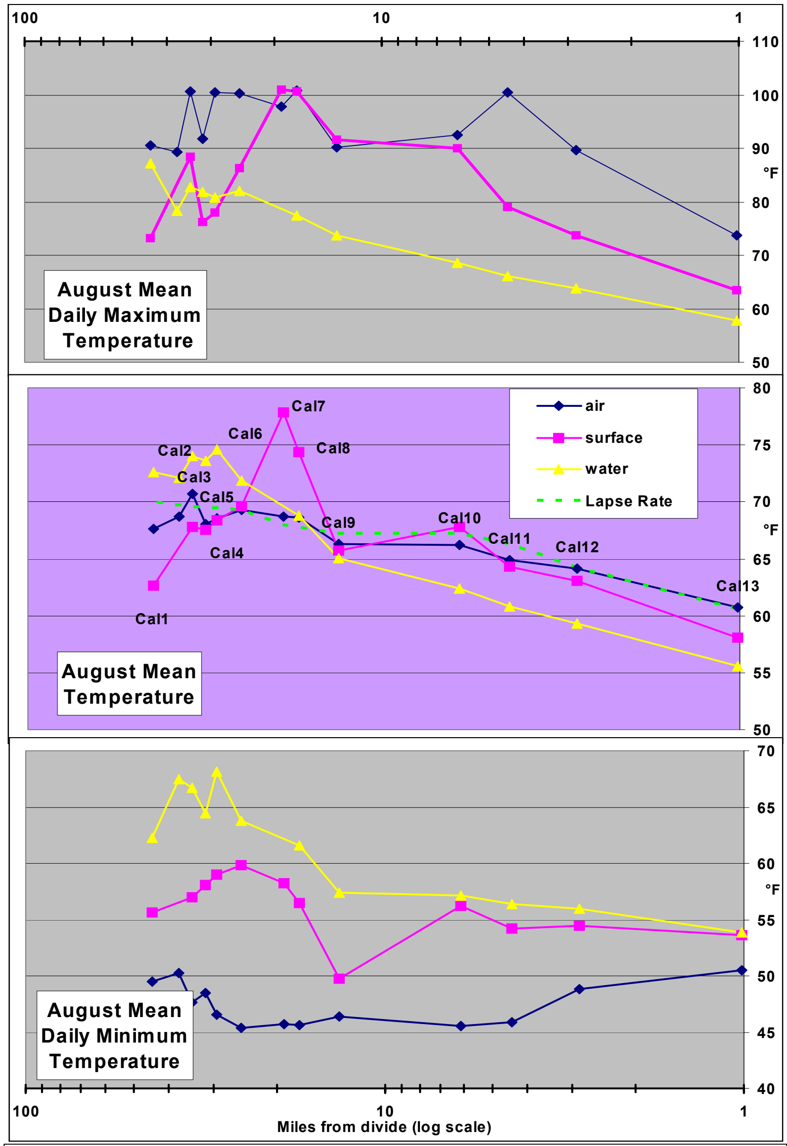


Figure 12 Calapooya Creek August 2003 mean temperatures for daily maximum, mean and minimum values.

A few comments about the data may aid interpretation.

1. The x-axis is log scale and represents the distance of the site from the furthest upstream point on the watershed divide. This measurement can be related to stream size and provides an opportunity for direct comparison between streams and tributaries that have different source points. Note that while sites Cal9 and Cal 10 are physically near each other (at the mouth of Hinkle Creek), they have different source points and hence are separated in the chart.

2. The stream temperature pattern shown is typical for other streams in the Umpqua Basin that has been discussed in detail in previous reports (see report Umpqua Stream Temperatures UBWC).

3. There is no surface temperature data for Cal2 and no water temperature data for Cal 6.

4. The dashed line in the center chart represents a dry adiabatic lapse rate of 5.4°F/1000 feet of elevation change. This value appears to account for much of the varability in the monthly mean air temperature value .

5. The relationship between air temperture and surface temperature is reverse from that shown in Figure 1. The high moisture content of the surface soil and the oasis effect may be contributing factors.

6. The thermal environments near the divide are thought to be dominated by the groundwater inflow and the shaded channels. As the water flows to the mouth, the channel becomes more exposed to solar radiation and the groundwater contribution becomes proportionately less. Typically there is a point about 20 miles from the divide where the increasing trend of the stream temperature stops.

7. The higher variability in the surface data is probably due to the sensitivity of the surface point to local conditions that was previously mentioned.

2002 Thermal Imagery Study - Spatial data

Figure 13 shows results from a study conducted in July of 2002 that used photo imagery to measure stream temperature during the warmest part of a day. This project was contracted by the Oregon DEQ and implemented by Watershed Sciences, LLC of Corvallis, Oregon. In this chart, the distances are measured from the mouth and the distance scale in not logarithmic. To assist in comparison of the data between the two studies, the locations of the UBWC 2003 study sites are shown on the distance axis. Note

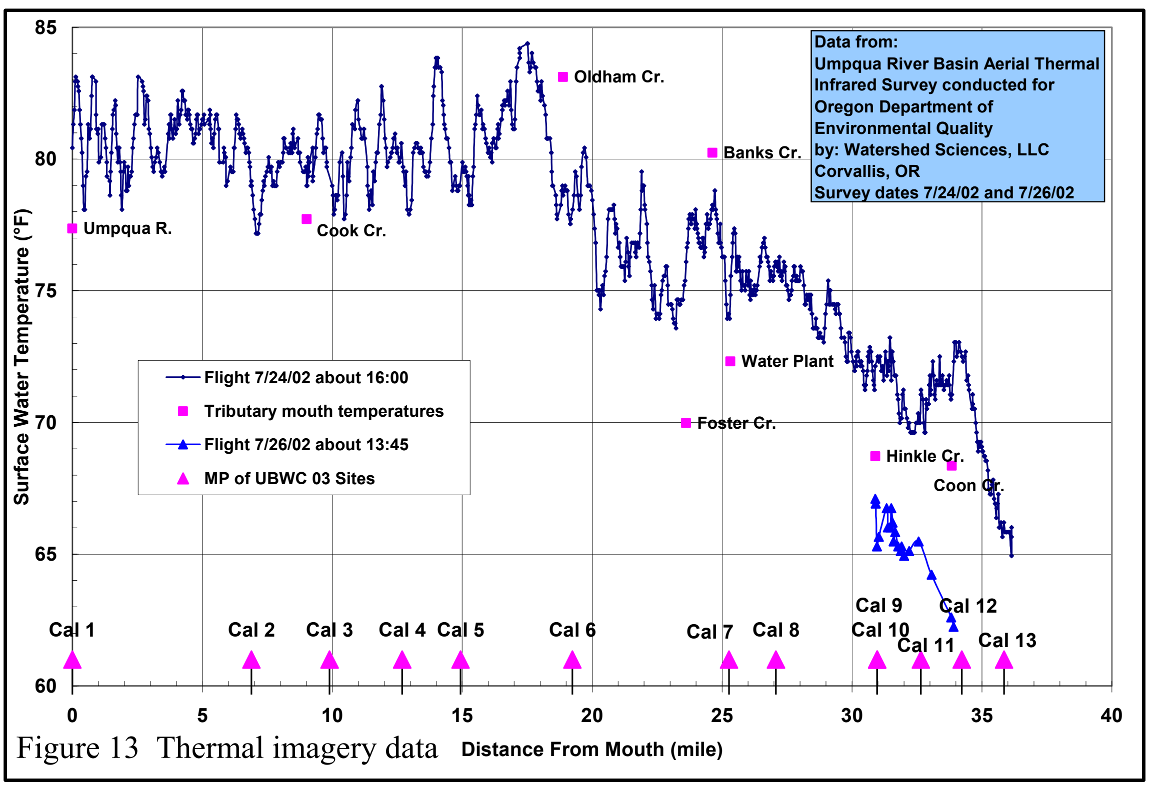


Figure 13 Thermal imagery data

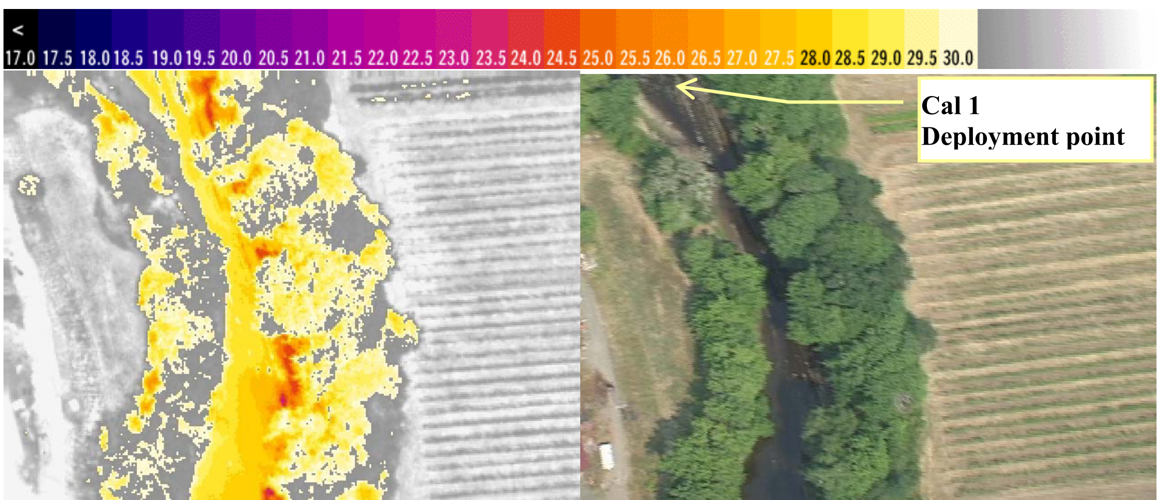
that the data collected on 7/26 is from Hinkle Creek and it corresponds to the data from sites Cal 10 through Cal 13 in the 2003 study.

The chart shows the surface stream temperature that was observed at the date and time indicated (near typical daily maximum temperature). The general shape of the curve is consistent the typical longitudinal profile pattern. The “noise” in the data suggests sensitivity to the local thermal environment.

Thermal Response to Variations in the Local Environment -Spatial Effects

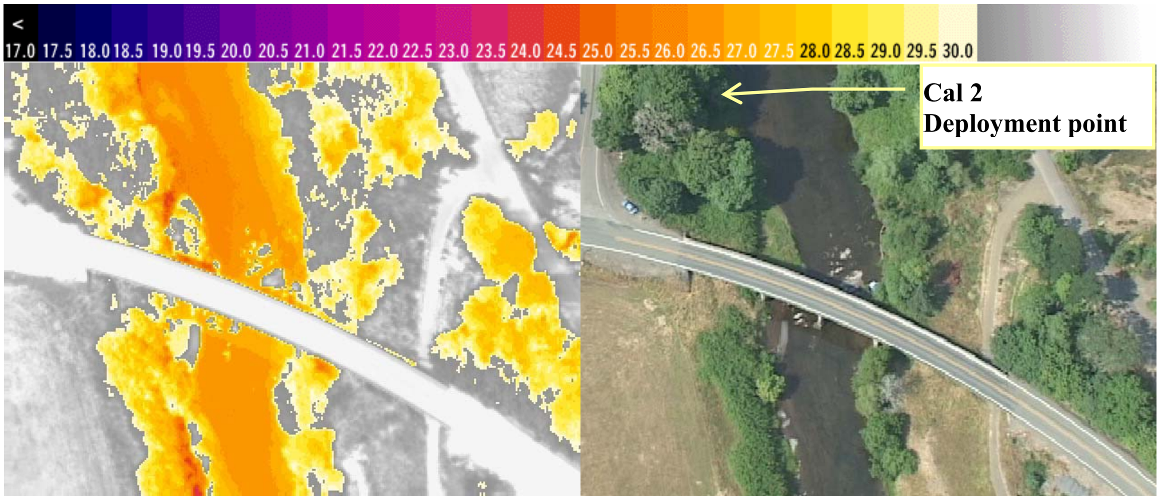
The set of photographs associated with the thermal imagery study provides an opportunity to observe the stream temperature in context with the local thermal environment. A preliminary examination of the thermal image data indicates that the high temperature zones may be associated with areas that are susceptible to direct solar inputs and the colder zones may have an association with increased ground flow.

Note: In all of the thermal images, the streamflow is from top to bottom of the picture. The shadows indicate the position of the sun at about 16:00 so they are pointing NE. The temperatures shown are in the color bar are °C.



Site Cal 1 near mouth of Calapooya Ck

The image at Cal 1 near the mouth of Calapooya Creek indicates that shading may be providing a local cooling effect. During the field work, it was noted that the right bank appeared to have high moisture content, suggesting there is also the possibility of some groundwater influence. The presence of a local 4°C temperature gradient suggests that the stream temperature is strongly influenced by its local environment. It is also apparent that the riparian canopies get relatively warm and that the roads and dry exposed area reach the highest temperature. This is consistent with the scenarios shown in Figure 1.



Site Cal 2 Calapooya Ck @ Cole Road

Site Cal 2 is of special interest because both studies show that it has relatively low water temperature.

It is apparent from the photographs that the shading is not exceptional. However, the topography shown in Figure 14 suggests that the small hills may be part of a formation that acts as a groundwater reservoir that supplies greater amounts of summer inflow. It was observed that other low temperature points on the profile also appear to be associated with constricted valleys.

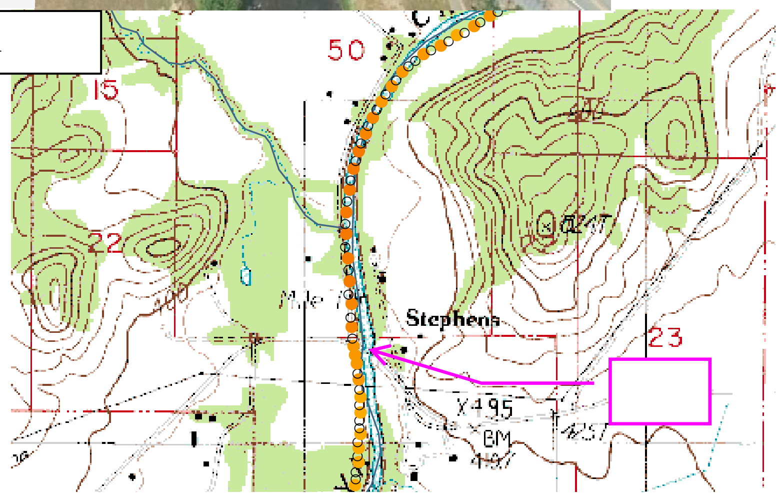
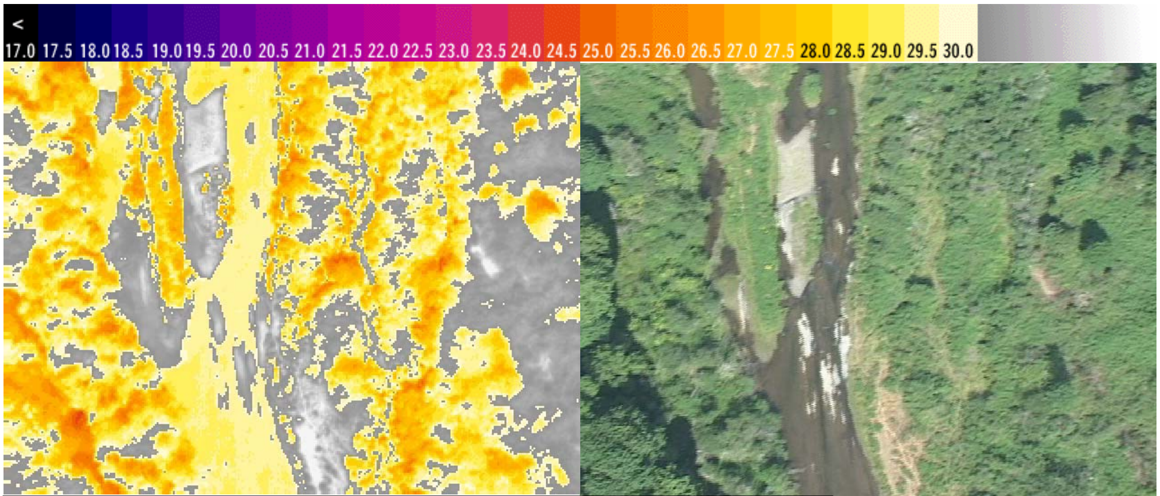


Figure 14 Topography at site Cal 02

It is interesting to note that the shade from the trees on the right side of the picture cause lower temperatures on the road but the shade zone under the bridge is actually warmer than the surrounding water. The probable explanation is that the concrete mass absorbs and holds heat and the longwave radiation from the bridge dominates the shading effect of the direct solar radiation.

River mile 17.5 is one of the warmest sections on the profile. It is characterized by a SW aspect, minimal shade vegetation and a braided channel condition resulting in high surface area and shallow depths. The effect seems to be fairly localized with some recovery occurring in the deeper water downstream. It is of interest to note that the gravel bar temperature is high and that there is no indication of cool hyporheic flow on the downstream side. However, in other situations the hyporheic outflow areas appear to supply cooler water.



River Mile 17.5 Calapooya Ck below Oldham Creek

The photographs for Cal 9 and Cal 10 were taken as part of the Hinkle Creek flight and a different thermal color scale was used. Hinkle Creek is flowing into Calapooya Creek from the top of the photo. The thermal plume from Hinkle Creek and the subsequent mixing is apparent.

Sites Cal 9 and Cal 10 Hinkle Creek @ the mouth

Longitudinal thermal adjustment

When a water molecule moves from one thermal environment to another, all of the heat transfer processes cause the molecule temperature to adjust to the equilibrium temperature of the new environment at a rate that is proportional to the temperature difference between environments. For example, the time for complete thermal adjustment of an isolated volume of water 0.5m deep that has been moved to another temperature environment may take several hours. The length of the transition zone is of interest because it is a measurement of the effect of an upstream condition and it is dependent on the travel time and the dispersion of the heated water molecules.

Travel time

Stream dye studies measure the downstream concentration of an injected traceable dye and provide the best method to measure the effective transport velocity of the stream (Bartholow 1989). The centroid or peak of the concentration curve can be used to measure the effective velocity of the heated water molecules. (Measuring the leading edge does not give an accurate result because it just denotes the arrival time of the first detectable concentration level and is dependent on the amount of dye injected.)

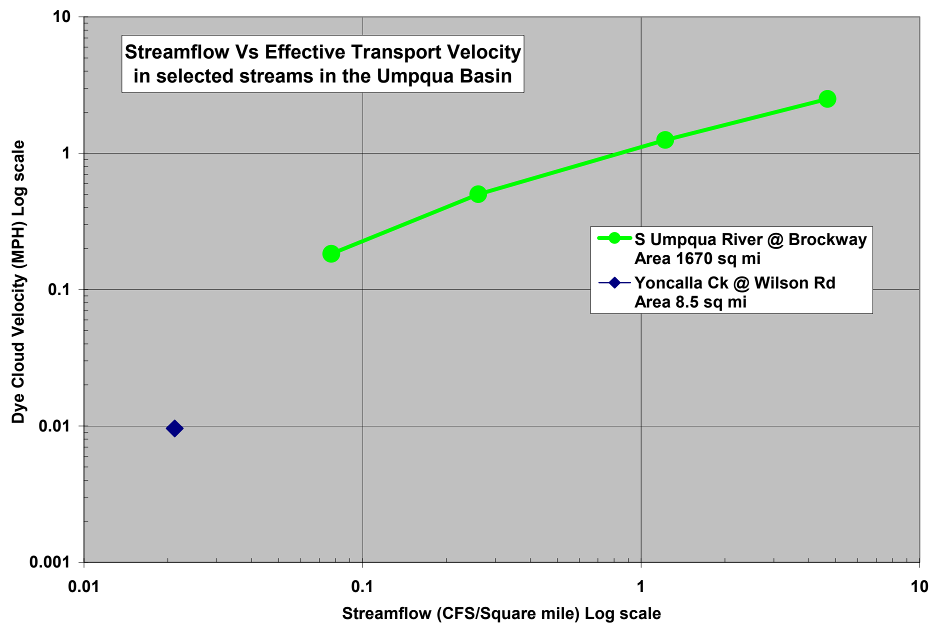


Figure 15 Effective flow velocity vs. prevailing flow in the Umpqua Basin

Figure 15 shows the results from some dye studies conducted in the Umpqua Basin (Laenen and Woo 1994; Smith 1999). Flow per square mile (csm) is used to normalize the watershed areas. Since nominal August flows in the Calapooya watershed are about 0.05 csm, the effective transport velocities are expected to be in the range of 0.1 mph.

Dispersion

The amount of dispersion or mixing that occurs as water flows from one environment can also affect the rate of thermal adjustment. For example, if the isolated volume of water mentioned above was scattered into the new environment rather than transported as a lumped mass, the rate of thermal adjustment would be much faster due to the increase in the effective surface area of the water volume.

Since temperature is essentially a measure of heat concentration, knowing how dispersion affects concentration can provide insight on how dispersion affects stream temperature. There have been several dye studies that have shown that concentration of a substance introduced into a stream or river will decrease by a “k” factor of about .001 by the end of the first hour (Lee 1995; Jobson 1997). This information can be used to estimate the effect of mixing within the transition zone.

The temperature of mixed water can be determined by the well known mixing formula:

$$T_3(Q_1+Q_2) = T_1Q1 + T_2Q_2.$$

where T is temperature and Q is flow.

If water is dispersed, its heat concentration (temperature) will be diluted by a loss factor k. In the case where T_1Q_1 is flowing into another environment with temperature T_2 and flow Q_1, the final temperature T_3 is given by the mixing formula:

$$T_3Q_1 = kT_1Q_1 + (1\text{-}k)\ T_2Q_1$$

$$T_3 = k(T_1\text{-}T_2) + T_2$$

An example using the value pf 0.001 for k and T_1 at 80°F and T_2 at 70°F would give a resultant temperature T_3 one hour later of 70.01°F due to mixing alone. The heat transfer processes would tend to reduce this difference further.

Field data confirmation

The discussion above suggests that, by combining the effects of travel time and dispersion, the transient effects should occur within one hour and within a distance of about 0.1 miles for late-season conditions in Calapooya Creek. The field data appears to support this conclusion in several different ways;

1. Figures three and four show that the daily diurnal water temperature appears to closely track the air temperature pattern measured at the sites as well at Eugene, OR (Figure 6). If there were a prolonged advective effect, the water signal would be expected appear more filtered.

2. Figure 13, the thermal imagery profile, indicates that the stream temperature is strongly affected by local conditions. The warm areas appear to have a strong association with direct exposure as shown in the photos for river mile 17.5 and the cooler areas may have an association with increased groundwater influence. The topographic map in Figure 14 suggests that valley areas may directly relate to colder stream temperature.

3. The thermal plume in the photograph for sites 9 and 10 appears to dissipate in a manner that is consistent with short transition times. The presence of local temperature gradients in all of the thermal imagery photos indicate rapid equilibration rates.

4. The observed evaporation flux rate indicates that the cooling processes can quickly match the direct solar inputs allowing for rapid thermal adjustment.

5. The thermal imagery shows steep local temperature gradients suggesting rapid thermal equilibration

Management Implications

Calapooya Creek is recognized as a watershed that has had a high amount of anthropogenic influences and is still a valued fishery resource. It is apparent from this study that there are opportunities to identify problem areas and take appropriate steps to improve the quantity and quality of the aquatic habitat within the watershed.

The results of this study indicate that, in watersheds similar to Calapooya Creek within the Umpqua Basin, the stream temperature at any point is highly dependent upon local conditions and is independent upon thermal conditions further upstream above the thermal transition zone. This local thermal environment can be affected by management activities that influence the channel characteristics, flow (including groundwater and hyporheic) and shade/ shelter characteristics of the area (Bogan, Mohseni et al. 2003).

The information shown in Figure 13 can aid in identifying areas that may be responsive to enhancement or improvement activities. However, a complete management strategy aimed at fishery improvement needs to include information on aquatic use of the target species for all life stages throughout the critical temperature periods. For example, hot zones within a stream system could act as thermal barriers to fish trying to migrate during a particular period. The diurnal temperature range and thermal refugia need to be considered as well as the maximum temperature values.

An important limitation on the temperature data used in this report – both thermal image and data logger - is the emphasis on the bulk stream temperature. It is important to keep in mind that groundwater inflow areas throughout the watershed are providing water with temperatures in the low 50s. Since the quantities are small and the location is usually subsurface, they are not easily found or detected Some studies indicate that the volume of these zones is less than 3% of the channel habitat (Bartholow 1989). However, these areas may be very crucial to the cold-water species during the warm portion of the diurnal cycle and hence are an important component of any habitat management plan.

Cited References

Bartholow, J. M. (1989). Stream temperature investigations: Field and analytic methods. Fort Collins, US Fish and Wildlife Service**:** 134.

Bogan, T., O. Mohseni, et al. (2003). "Stream temperature-equilibrium temperature relationship." Water Resources Research **39**(9): 1245.

Harris, D. D., L. L. Hubbard, et al. (1979). Magnitude and frequency of floods in Western Oregon. Portland, U.S. geological Survey**:** 29.

Jobson, H. E. (1997). "Predicting travel time and dispersion in rivers and streams." Journal of Hydraulic Engineering **123**(11).

Laenen, A. and W. H. Woo (1994). Stream velocities and reareation coeffiecients for the South Umpqua River between Tiller and Roseburg, Oregon, 1991. Portland, U.S. Geological Survey**:** 26.

Lee, K. K. (1995). Stream velocity and dispersion characteristics determined by dye-tracer studies on selected stream reaches in the Willamete River Basin, Oregon. Portland, U.S. Geological Survey**:** 39.

Moffatt, R. L., R. E. Wellman, et al. (1990). Statictical summaries of streamflow data in Oregon: Volume 1 - Monthly and annual streamflow, and flow-duration values. Portland, U.S. geological Survey**:** 413.

Oke, T. R. (1987). Boundary Layer Climates, Routledge.

Satterlund, D. R. (1972). Wildland watershed management, John Wiley & Sons.

Smith, K. (1999). Yoncalla Creek dye study. Roseburg, Umpqua Basin Watershed Council**:** 5.