Appendix 2 - Background Information
Sections D – L

Appendix 2 Background information

D. Stream basics

D.1 Some obvious facts about streams.

During the summer drought period, the streams are fed by groundwater sources. These sources are generally not noticeable since they are usually underwater. However, generally streamflow will increase in the downstream direction (a cumulative effect).

Stream systems are usually hierarchical, like a tree with branches. The base of the tree corresponds with the mouth of the stream, and the leaves represent the water collection areas on the ground. The drainage pattern for a watershed provides information about its hydrologic characteristics.

D.2 Stream size

Stream size is an important factor that is often ignored in temperature management discussions. Key points:

1. There are more small streams than large streams.
2. Small streams generally have a larger percentage of groundwater inflow.
3. There is less total energy in a small stream.
    a. less erosive energy and a smaller channel
    b. different channel composition
    c. less water
    d. smaller channel, different width to depth ratio
    e. smaller drainage area
    f. steeper gradient –
4. Small streams are easier to shade.

Conclusion: different sized streams will have different characteristics. It is important to have a way to designate the stream size at a point of interest.

Distance from the watershed divide

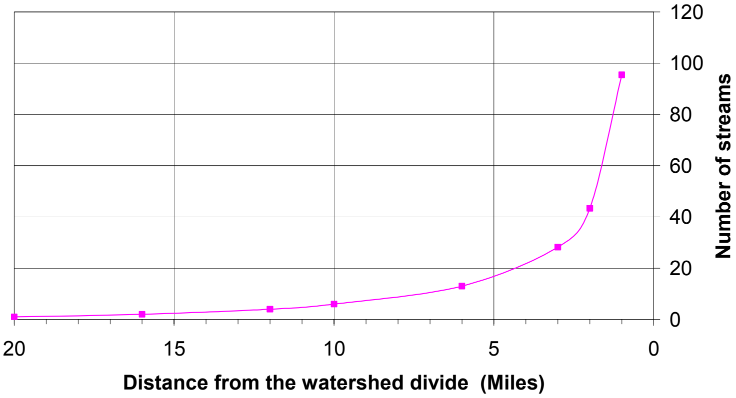
A useful indicator of stream size is to measure the distance from the point to the watershed divide. To find this distance, imagine going up the stream and, when a fork is reached, take the one with the larger flow. This should eventually lead to a point were surface flow stops and the water is emerging from the ground. Continue directly upslope perpendicular to the topographic contours to the ridge. The distance value from the starting point to the ridge is the value that is used throughout this report.

Note: The distance to the watershed divide is useful as a coarse, large scale indicator of stream size because it is relativity easy to determine from a map. However, for analysis of streams at the headwaters, the actual point of emergence is needed for detailed analysis of temperature profiles. Also, on the large scale, differences in geology, water impoundments and withdrawals, and topography can affect the relationship.

Since the stream system is hierarchical, there will be more small streams than large streams. Figure 1 shows a typical example of the relative numbers for a tributary with a mouth that was 20 miles from the watershed divide. Other ways to designate the size of a stream at a particular point are: Watershed area, active channel width, bankfull channel width, channel depth, size of substrate, and streamflow for a particular recurrence interval (i.e. 2-year peak-flow value).

D.3 Small streams are important

Figure 1



Stream Size Distribution
Elk Creek

It is apparent from the figure that there are many more small streams than large streams. For watersheds in the north county the number of streams decreases by half for every 4 miles further from the divide. In other words, there are twice as many 8 mile streams as 4 mile streams; twice as many 16 mile streams as 20 mile streams etc.

Small streams are important because of their abundance and their cooler temperatures. However, the smaller flows often result in limited habitat and they may even lose some surface flow during the summer months. French Creek near Glide is a small tributary that often loses surface flow during the summer but is recognized as an important coho spawning area. Pools can remain cool with hyporheic circulation and, with sufficient cover, can provide rearing space for a limited number of fish.

D.4 Drainage density / contributing area

Watersheds tend to have a characteristic drainage pattern that is generally consistent across a wide range of spatial scales (Linsley, Kohler et al. 1975). One useful measure of stream network geometry is the drainage density defined as the ratio of the sum of all the stream lengths within a watershed divided by the area of the watershed. Typically the value is expressed as miles per square mile. Since the ratio is not dimensionless, the value will depend on the units used. To convert from miles/per square miles to km per square km, multiply the density value by 0.62 miles/km.

The value of the drainage density is highly dependent on the type of streams included in the count. For example, if dry draws are counted as streams, then the density value will be higher. For that reason, some caution should be used when comparing density values from different reference documents. However, within a given study, if the same definition of stream was used throughout the study, the drainage density value provides a good indication of the water holding capacity of the watershed. Watersheds with a high density value tend to retain less water and have flashier storm flow.

A useful related index is the “constant of channel maintenance” (“C”) which is the area, in square feet, required to maintain one foot of channel. When the stream density (“D”) is in miles/square miles, C=5280/D.This value shows that every foot of stream has an area associated with it that supplies water to that segment. This value also tends to remain independent of the size of the watershed (Haggett and Chorley 1970).

The Table shows some typical values that could be found in the Umpqua Basin. For example, it indicates that, for a watershed with a density of 7 miles per square miles, each foot of channel has a groundwater supply strip that extends upslope on both sides of the channel about 375 feet. Comparison with field observations can provide an indication of the relative groundwater inflow contribution in the area. If, for example, the distance was greater, this would suggest that there may be a larger than average groundwater component with corresponding cooler stream temperatures (The topographic slope and soil type also would affect capacity).

D mi/sqmi	C sq ft/ft
5	1056
6	880
7	754
8	660
9	587

E. Flow basics

Note: The next phase of this project will include a detailed analysis of the flow data available on the Umpqua with emphasis on low flow characteristics.

Summer in the Umpqua Basin is typically a prolonged dry season and the surface flow of most of the streams decreases in a manner typical of an exponential decay function. As the amount of stored groundwater that was accumulated in a watershed is depleted, the flow approaches a “base flow” condition. With reduced flows, the source point where water first appears in the upstream end typically moves downstream. Also, the wetted width of the stream decreases, with a corresponding reduction in water volume in the channel. The reduction in depth can influence the amount of water that is stored in the adjacent banks.

E.1 Uniqueness of low flow conditions:

Streams in the Umpqua Basin experience a wide range of flows with water yields that vary by a factor of 4000 between a record peak flow and the lowest summer low flow. The large winter flows produce the channel forming events that move the bedload, cut the channel and form pools. In the winter, the stream energy is generated by water moving down the vertical displacement to be dissipated in the pools. This turbulence is very powerful and causes the characteristic pool-riffle pattern. During the summer drought period, the streamflow decreases gradually and many streams tend to become a series of interconnected (or in some cases isolated) pools.

The uniqueness of the lowflow condition needs to be emphasized because many computer models for streamflow and stream temperature were designed for average flow conditions which are very different than lowflow conditions. For example, factors such as the effective travel time, uniform flow, dispersion and hyporheic flow interaction are very different for low flow. Most streamflow models were not designed for low flow use and can produce erroneous results if carelessly applied. For low flow conditions, models that simulate the stream as a series of reservoirs may be more appropriate.

E.2 Sources of flow variability

Obviously precipitation increases flows. There is a lot of material on factors relating to peak flows and related management activities. The emphasis here is restricted to low flow conditions.

Storage Depletion

The most dominant factor affecting summer low flows is simple storage depletion which causes the flow hydrograph to tend toward an exponential decay pattern typical of storage dependent processes. This smooth, downward curve may be interrupted occasionally by some minor summer precipitation.

Since the rate of depletion may not be the same for all storage sources, the relative effects of the different sources (in and out of a region) can change throughout the summer season. This distinction is important if the sources supply water at different temperatures (See Appendix 2:E.4 - Water Storage for more information).

Changes in viscosity

Recent studies have shown that, for losing reaches with large diurnal stream temperature variation (50-77°F); changes in water viscosity can result in stream losses of 25% (3.5 l/sec) over a distance of about 500 feet (Constantz, Thomas et al. 1994). (These studies were conducted in areas with no vegetation to cause a transpiration effect.) Since some Umpqua Basin stream temperatures get up into the 70°F range, changes in viscosity may be a significant factor in the net heat exchange in some small streams under low flow conditions.

Evapotranspiration

Evapotranspiration can also have a noticeable influence on streamflow under low flow conditions. During the warm portion of the day local flows may decrease due to the higher rate of evapotranspiration. With darkness and/ or cooler temperatures, the streams will regain the flow.

A study on the HJ Andrews Experimental Watershed showed that both sapwood and streamflow had a pronounced diel pattern (See Figures 2 and 3). Since the stream was in the headwaters with a daily stream temperature variation of 1-2 °C, the viscosity effect was considered negligible. The study estimated that the broadleaf vegetation averaged 0.73 mm/day and the conifers averaged 1.06 mm/day. By comparing the sapwood rates and the change in stream flow, it was estimated that about 0.3% of the vegetation in the watershed contributed to the daily loss of water (Bond, Moore et al. 2001).

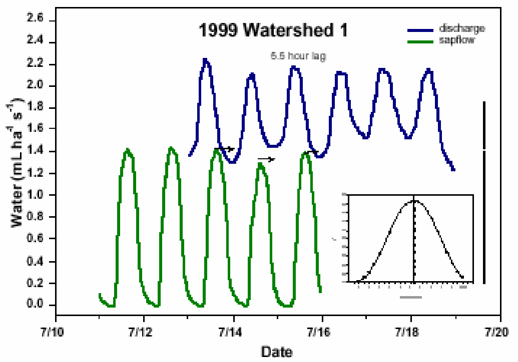


Fig. 2. Daily dynamics of sap flow and stream flow in WS1 in 1999

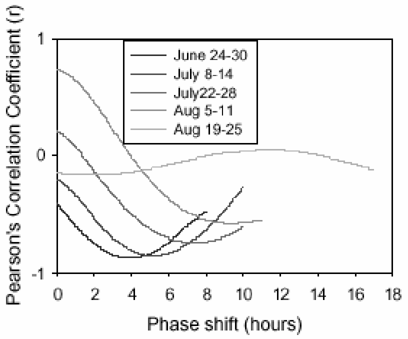


Fig. 3. Time lags between maximum sap flow and minimum stream flow in WS1 in 2000.

Water withdrawals / irrigation

Water withdrawals and irrigation can also influence flow. These uses can vary drastically over time and distance and the effects (positive or negative) will depend upon the particular situation.

E.3 Water flow and temperature

The way water moves can affect its temperature. Each type of flow usually provides a different contribution to the net thermal loading of a stream. During low flow conditions these differences can be significant.

Surface flow

This is the flow that is seen and is often regarded as the flow. It is also the flow that gets measured by current meters to obtain local flow measurements. During high flow periods it is the dominant component but it may become increasing less so during low flow conditions. The behavior of flow is determined by the effects of viscosity and gravity relative to the inertial forces of the flow. This flow can be laminar, turbulent or transitional. With laminar flow, water particles appear to move in streamlines and thin layers of water seem to flow over each other. A given quantity of water flowing down a given slope in a channel with a given shape and roughness will achieve a unique depth for that set of conditions. This relationship is expressed in the well-known Manning formula that uses an “n” value to represent the roughness term. This value usually varies between 0.01 and 0.15 (Chow 1959).

Dispersion is an important effect during low flow. Individual water particles follow their own pathway and typically move randomly through a wide range of velocities. This dispersion effect causes water particles with different temperatures to mix together and produce an average value as they move downstream. As a consequence, the high and low temperature values obtained in an exposed stream reach will tend to be reduced to the daily mean as it moves downstream.

The effective velocity of the individual water particles determines how long they can interact and adjust to the local environment. During lowflow conditions, this velocity can become increasingly slow. A fluorometric dye study is the best way to measure this velocity (Bartholow 1989). A fluorometric dye study in Yoncalla Creek (Elk Creek watershed) in August of 1999 showed an effective velocity of 50 feet per hour over a distance of 2000 feet (Smith 1999).

Groundwater inflow

Groundwater inflow comes from the water table storage and supplies the summer base flow. Since this water is relatively cold, (See Appendix 1:A.1) it plays an important role in providing cold water refuge during the summer. Determining the amount of groundwater inflow can be is problematic since low flows are usually difficult to measure, and the groundwater contribution is relatively small. The size and water capacity of the local contributing area can help provide an indication of the potential flow (See Appendix 2:D.4).

Hyporheic flow

Hyporheic flow describes the exchange of streamflow and groundwater in the permeable, course-grained gravel deposits within the channel and floodplain. The National Water Quality Assessment that was conducted in the Willamette River indicated that hyporheic exchange could account for 15% of the total flow (Wentz, Bonn et al. 1998). As flows recede, the ratio of hyporheic to total flow increases. Flows out of the gravel into the stream tend to provide local cooling by adding cooler water. Flows into the gravel from the stream also tend to provide cooling by dissipating the excess heat into the landmass. For example, an isolated pool that is experiencing hyporheic circulation could remain relatively cool; the inflow would bring in cool water and the outflow would remove the heated water, thereby avoiding an accumulation of heat.

Hyporheic flow can be observed in small channels during the low flow period. It is common to see a small channel disappear into the gravel bed and then reappear further down stream. The effect is harder to notice in isolated pools when the flow rate is small with respect to the volume of water in the pool. Nevertheless, in many cases it is likely that hyporheic flow can be associated with the pool. Naturally, if the level of the pool is remaining constant, the inflow must be equal to the outflow.

It is difficult to measure the effect of hyporheic flow directly. Comparison of careful flow measurements may provide an indication. For example, flow measurements in bedrock control reaches would tend to have a minimal hyporheic component and could be compared with flows in nearby reaches with more permeable streambeds. Dye studies can be used to trace and quantify hyporheic flow (Wentz, Bonn et al. 1998).

Channels with permeable beds may contain a longitudinal hyporheic flow component that varies along the channel as the permeability of the channel bed changes. For example, upwelling flow (gaining reach) may occur with a corresponding increase in surface flow when a channel changes from a permeable bed to a nonpermeable bedrock bed and then loses flow through downwelling (losing reach) when the bed changes back to a permeable condition. These changes in flow patterns contribute to hydrologic retention. Water moving through the substrate material would have more time to interact with the cooler subterranean environment (Boulton, Findlay et al. 1998).

Lateral groundwater inflow may occur from neighboring source areas. “Dry” tributaries that show no surface flow may supply significant quantities of cooler groundwater which may be apparent at the mouth of the tributary.

Bed composition can affect the magnitude of the hyporheic flow component. Dye studies on the Willamette showed that streams with pool-riffle gravel beds had hyporheic storage three times greater than silt-bed channels (Wentz, Bonn et al. 1998).

Since flow through a gravel bar is slower that the flow in the open channel, heated water particles that pass through the gravel will emerge at a later time than their open channel counterparts. As a result, the emergent water from the bar may be cooler during the warm part of the day and warmer during the night (See Appendix 2:G.1 and H.2). .

Pool Flow

Pools are critical areas for fish during the warm, low flow period, and the associated hydraulics are very different at that time. There are several factors that need to be appreciated.

> Dispersion: a small flow entering a large pool will mix with the larger volume. An analogy would be small creek entering a reservoir. This will tend to have an immediate averaging effect on the concentration of any contaminant (including warm water). For temperature, the output of the pool will fluctuate on a diel basis around this average value.
>
> Circulation: Circulating water can extend the amount of time that individual molecules will remain in that environment. If this environment is cooler, the pool can have a cooling effect.
>
> Pressure gradient: Pools provide a head of water that can facilitate downslope hyporheic flow.
>
> Stratification: Some pools may become thermally stratified and provide a cool refuge zone. This zone can become larger with decreasing flow due to reduced turbulence (Bartholow 1989).
>
> Zero surface flow: Many streams in the Umpqua Basin “go dry” during the summer. In some cases it is obvious that surface flow resumes further downstream. In other cases, there are a series of isolated pools with no apparent flow. However, temperature data from the Umpqua shows that, in some cases, the pool temperature goes down as surface flow recedes.

E.4 Water storage

Stored water that reaches the stream contributes to the net volume as well as the net temperature of the stream. If the temperature of the stored water is different than that of the stream, it will influence the net temperature of the stream.

Groundwater Storage

This water may come from several different areas. Watersheds, by definition, are collection basins for precipitation that enters the soil and gradually moves into the stream. The temperature of this ground water generally corresponds to the mean annual surface temperature and is about 52°F in the central portion of the Umpqua Basin (See Appendix 1:A.2).

Groundwater storage is directly related to the water table that, in turn, can be affected by management activities. Incised channels can lower the water table by draining and by reducing flood recharge.

Hyporheic Storage

Water is also stored temporarily as it moves slowly through the hyporheic zone. While there isn't much information about temperatures in this zone, it is expected that the water temperature emerging from the zone would be similar to the current daily average stream temperature. For example, some of the warm water heated during the late afternoon could enter the hyporheic zone, thus removing some heat from the surface water. Downstream, water from the zone could enter the stream with a net reduction in stream temperature. This effect is frequently observed in FLIR data that shows, in the late afternoon, that the water directly downstream from midstream gravel bars is cooler than water in the center of the channel (See Appendix 2:E).

Bank Storage

Water at a given level may also be stored in the bank zone that is in direct contact with the water. As the water recedes, the water in the bank zones is released and affects the flow and temperature. In areas with large alluvial deposits, this type of storage can be considerable.

Pool Storage

Likewise, water in a pool can be temporarily stored and its temperature influenced by the local environment. Water in a pool may become stratified with a warm surface layer and cooler lower layers. The temperature pattern for a particular pool can depend upon many factors that include extent of surface exposure to direct sunlight, mean daily temperature, temperature and the extent of inflowing water and the water circulation patterns.

Floodplain storage.

This type of storage is similar to bank storage because it is related to recharge during high water levels. However, since the area in contact with water can be much greater, more water can be stored during the high water period. These floodplains can be relatively large, especially in the lower part of the watershed and, if they are fully recharged during winter flooding, can make significant contributions to summer flow.

E.5 Estimating Base Stream Flows

Maximum seasonal stream temperatures typically occur during low flow conditions. As water recedes, depth and effective flow velocity decrease and the proportion of groundwater contribution may also change. To model these effects it is often desirable to have flow data available for the duration of the study. The procedure described in this section provides a methodology for estimating base flow for the entire season based on one or two flow measurements.

During the summer the flows in the Umpqua Basin tend recede at a base rate that is relatively predictable. Figure 1 shows data typical of the numerous stream gages located within the basin. Note that summer precipitation events cause a temporary disruption in the curve but typically within about 10 days the pattern reverts to the base flow recession curve.

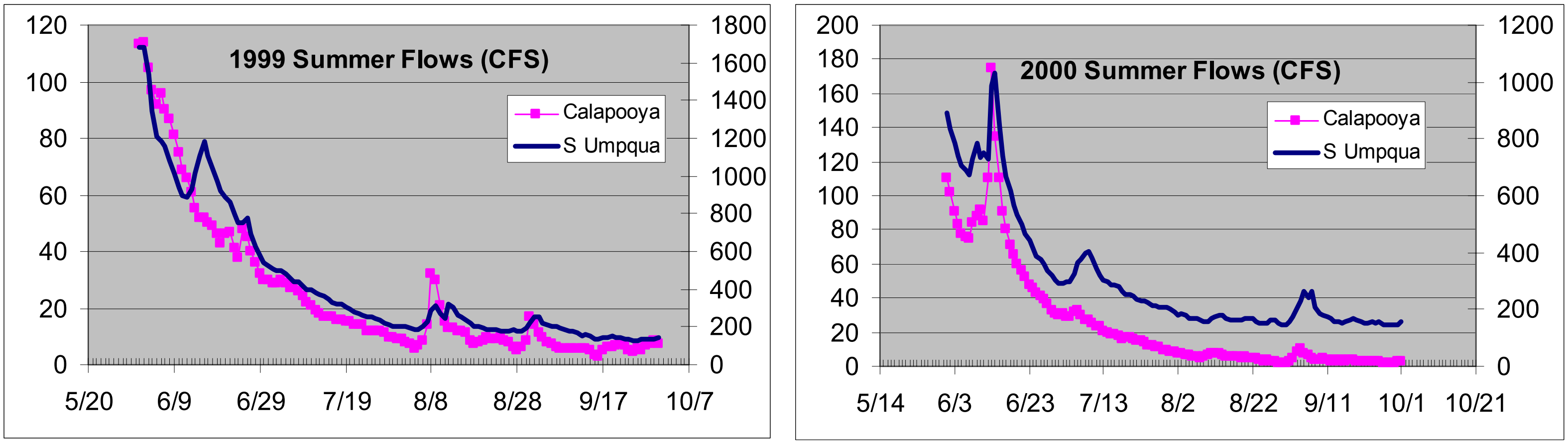
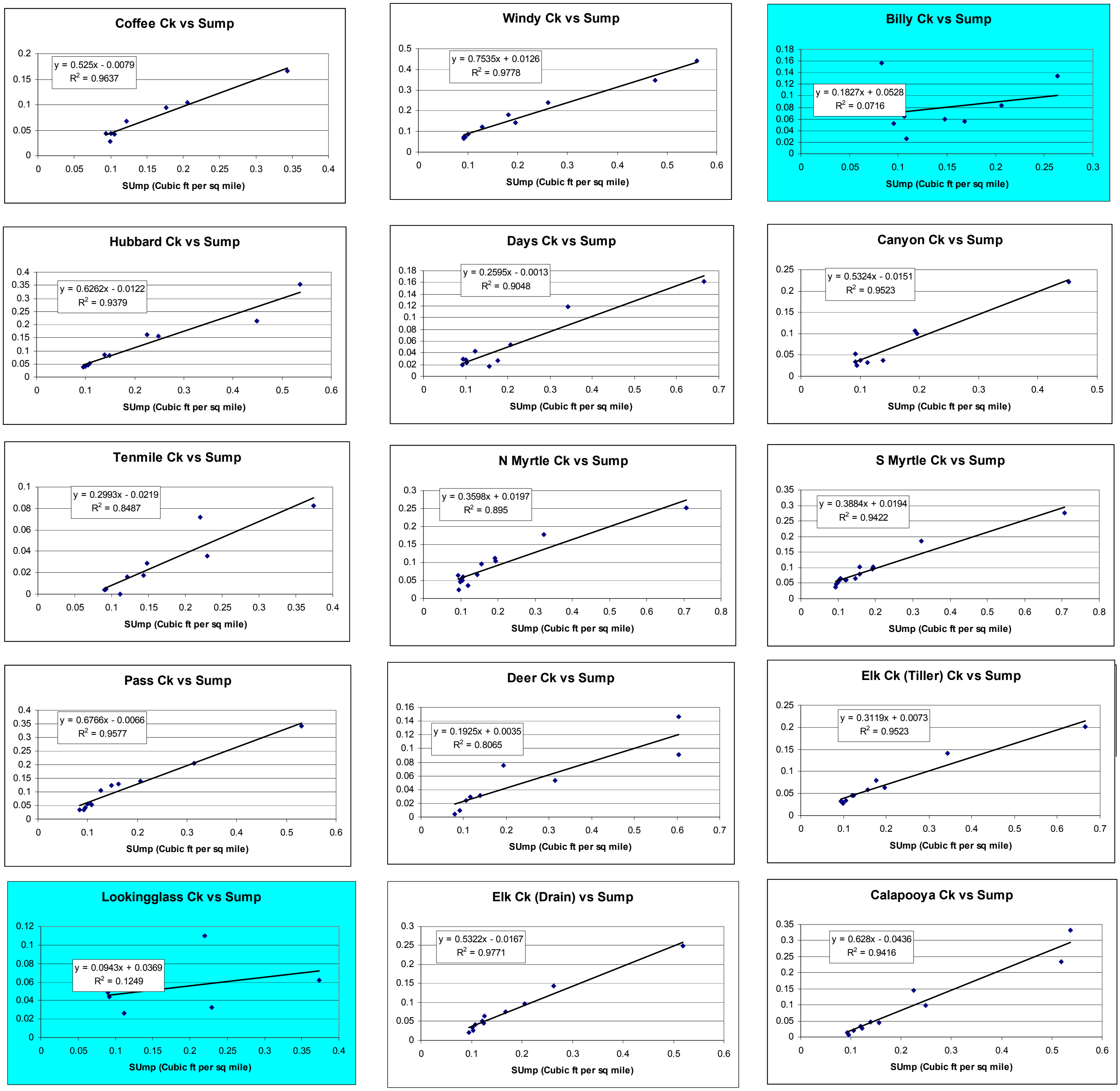


Figure 1 Summer Flows for the S Umpqua at Brockway and Calapooya Ck near Oakland

During the summers of 1999 and 2000, the UBWC under the guidance of the Douglas County area watermaster took streamflow measurements throughout the basin. Figure 2 shows the relationship between some of these values and the daily flow that was recorded at the South Umpqua gage station at Brockway. Note that most of the sites had R-squared values over 0.90. The shaded charts had correlations with R-squared less than 0.80. It is of interest to note that both streams with poor correlations have reservoirs upstream.

Figure 2 Regression curves for several sites. Note flow is normalized to CFS per sq mile (CSM).



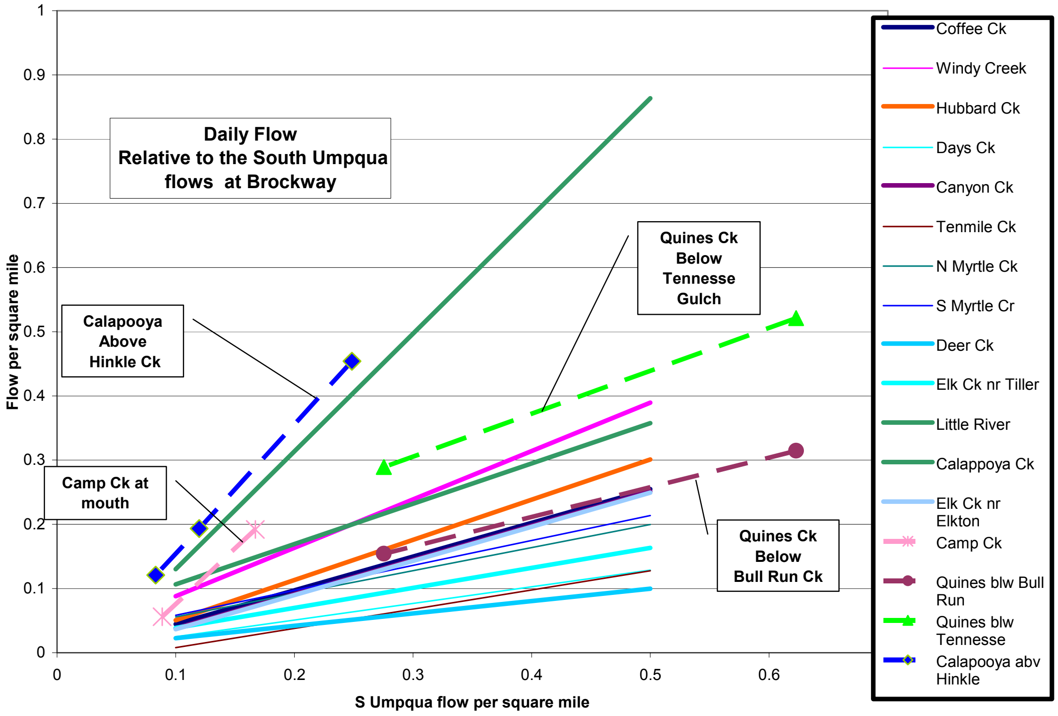


Figure 3. Regression lines from the calibration sites and data from four evaluation sites.

The solid lines in Figure 2 display a summary of the regression equations established from the data in Figure 3. Since the pattern is fairly orderly, it can be used to estimate base flow values at a site where one flow value and the drainage area at the site are known.

Data from four sites (Table 1) that had at least two values was used to evaluate the method. The measured flow was converted to cubic feet per second per square mile (CSM) by dividing the flow value by the area of the measured drainage and this value was plotted against the corresponding CSM value for the South Umpqua gage value for the same date. The results indicate that, with the exception of Camp Creek, a single point and the regression curves may be used to get a reasonable estimate of base flows at other dates.

index	site	date	flow	area	site csm	sump area	sump cfs	sump csm
b25	Camp Ck	7/17/2000	6.77	35.256	0.192024	1670	279	0.167066
b25	Camp Ck	8/31/2000	1.97	35.256	0.055877	1670	148	0.088623
b34	Calapooya abv Hinkle	7/9/1999	22.5	49.56	0.453995	1670	415	0.248503
b34	Calapooya abv Hinkle2	8/19/1999	9.58	49.56	0.193301	1670	200	0.11976
b34	Calapooya abv Hinkle2	9/15/1999	5.99	49.56	0.120864	1670	139	0.083234
b37	Quines blw Bull Run	6/18/1999	4.39	13.95	0.314695	1670	1040	0.622754
b37	Quines blw Bull Run	7/6/1999	2.15	13.95	0.154122	1670	460	0.275449
b39	Quines blw Tennesse	6/18/1999	4.2	8.06	0.521092	1670	1040	0.622754
b39	Quines blw Tennesse	7/6/1999	2.33	8.06	0.289082	1670	460	0.275449

Table 1 Evaluation site data

Caveats: This method has not been evaluated beyond the data presented here. Also, not all streams demonstrated a good correlation with the South Umpqua gage. For critical applications it is recommended that at least two base flow values (more than 10 days after a summer precipitation event) be collected.

F. Fish habitat notes

F.1 Habitat Site Index

Stream management and restoration in the Umpqua basin are directly related to fish habitat. The Oregon Department of Fish and Wildlife has done an extensive stream survey with detailed information about conditions that relate directly to fish habitat including stream shading. The companion folder on the CD “Fish Habitat survey” displays the inventoried shade and other data related to habitat features. This data is in GIS format so the user can query the data base to determine the prevalence of any combination of conditions within the Basin.

This information, along with the temperature data, can be used to evaluate habitat conditions at a particular site. Table 1 and Table 2 were developed by the Roseburg ODF&W to provide a guide for assessing the quality of a site.

Habitat Bench Marks

		Bench Mark Weighing scale 1-5	4-Excellent	3-Good	2-Fair	1-Poor	Row Totals
	Pools						
1	Pools area % (pctpool)	2	>44.99	30-44.99	16-29.99	<16	
2	Residual Pool Depth (residpd)						
a	small (1-3 ordered)	4	>=.7	.5-.6	.3-.4	<.3	
b	large (4th order or greater)	4	>=1.0	.8-.9	.5-.8	<.5	
	Riffles						
3	Width/Depth (wdratio)	3	<=.10.4	10.5-20.4	20.5-29.4	>=29.5	
4	Silt/Sand/Organics %area (rifsndor)	2	<=1	2-7	8-14	>=15	
5	Gravel % (rifgrav)	3	>=80	30-79	16-29	<=15	
	Reach Average						
6	Riparian Condition (ripv1) dom.specie	2	>=45	30-44.9	16-29.9	<=15	
7	Shade %						
a	stream width < 12 m	1	>=80	71-79	61-70	<=60	
b	stream width > 12 m	1	>=70	61-69	51-60	<=50	
	LWD						
8	Pieces/100 m stream (lwdpiece1)	3	>=29.5	19.5-29.4	10.5-19.3	<=10.4	
9	Volume LWD/100m stream (lwdvol1)	2	>=39.5	29.5-39.4	20.5-29.4	<=20.4	

Totals for Category

HABITAT BENCHMARK RATING SYSTEM

100-82	**EXCELLENT**
81-63	**GOOD**
62-44	**FAIR**
43-25	**POOR**

Coho Habitat Bench Marks

		Bench Mark Weighing Scale 1-5	4-Excellent	3-Good	2-Fair	1-Poor	Row Totals
	Channel						
1	Primary channel area (m2) (prichnarea)	2	>20,000	10,000-20,000	2,500-10,000	<2,500	
2	Secondary channel area (m2) (secchnarea)	3	>3,000	1,000-2,999	500-999	<500	
3	Gradient (%)	3	0-1.0	1.1-2.0	2.1-3.0	>3.0	
4	Valley Width Index (V.W.I.)	2	>=20	7-19.9	2.5-6.9	<2.5	
	Pools						
5	Pool Area %	2	>=45	30-44.9	16-29.9	<=15	
6	Residual Pool						
	small (1-3 ordered)	4	>=0.7	0.5-0.6	0.3-0.4	0.1-0.2	
	large (4th order & greater)	4	>=0.7	0.5-0.6	0.3-0.4	0.1-0.2	
	Riffles						
7	Width/Depth (wetted)	3	<10.4	10.5-20.4	20.5-29.4	>29.5	
8	Gravel % (Riffles)	3	>80	30-79	16-29	<15	
	LWD						
9	Pieces (lg/sm) 100 M Stream	3	>29.5	19.5-29.4	10.5-19.4	<10.4	
	Totals for Category						

HABITAT BENCHMARK RATING SYSTEM

100-82	**EXCELLENT**
81-63	**GOOD**
62-44	**FAIR**
43-25	**POOR**

F.3 Refugia

Many of the stream miles in the Umpqua exceed the summer stream temperature criterion but somehow still maintain significant salmonid populations. For example, stream systems such as Olalla / Lookingglass Creek are known to support populations of fall chinook, coho, steelhead and cutthroat trout but certainly exceed the temperature criterion.

During stream temperature monitoring it is usually the bulk water temperature that is measured. Circulating water tends to have a uniform temperature due to mixing but the interface between the main water mass and inflowing seepage zone may be significantly cooler (See Appendix 2:G.2) and very important during high temperature periods. In the larger streams, this local area inflow is usually proportionally much smaller and, since it is coming out of the bank or the channel bed, will not be easily detected. However, these areas do exist and may account for some of the survivability that apparently occurs in the lower reaches of the Umpqua Basin.

Larger inflow areas can occur on large channels that are associated with adjacent wetlands, floodplains, or dry tributary channels. These areas are more easily detected in the FLIR data.

F.4 Types of refuge areas

Groundwater Inflow

These zones have potentially the lowest temperatures but may be relatively small. The incoming water can be in the low 50 °F range. The temperature of the material at the interface will approach the temperature of the incoming water (See Appendix 2:G.2). If the fish can embed itself in the interface material such as silt or gravel, it can extend the effective size of the area. The interstitial area between large rocks can also be cool, especially if there is a seepage circulation between the rocks into the stream.

Subsurface interflow - hyporheic flow

Streams are known to gain and lose water. Generally the lost water is regained further downstream. The temperature of this water is strongly influenced by the medium that it passes through which, in turn may be strongly affected by evaporative processes. Also, since this water generally travels slower than the surface flow, the timing of the emergent water will not be synchronized with the diurnal surface water pattern. For example, in the late afternoon the surface water will be at a maximum temperature but the water emerging from the point bar may have entered the bar the previous night when the water was cooler, producing a cool refuge area.

Tributaries

In general, in the Umpqua Basin, a small tributary stream will be cooler than the larger main stream. (Exceptions may be the North Umpqua above Little River and streams with reservoirs. Streams of about the same size (stream order) will generally be similar in temperature at their point of confluence. Charles Coutant indicates that, where the temperatures are different, plumes associated with outflow from tributaries can extend downstream several kilometers. Distance depends on local turbulence (Coutant 1999). The cool zone at the mouth of a small tributary is typically small but, in association with the highly productive adjacent warm temperatures, provides a diverse habitat with food source and thermal refuge. Typically there is limited structure in these areas due to the high sediment exchange between tributary and the main stream. However, areas with protective cover appear to be very productive.

It should be noted that tributaries with no late-summer surface flow can carry significant amounts of cool groundwater to the area at the mouth of the stream. The larger rivers often have large alluvial terraces which can contain and pass large amounts of subsurface water. Along the South Umpqua it is not uncommon to see flowing tributaries “go dry” as they come off of the hill slope and enter this alluvial terrace (Water diversions may also contribute to this effect). This alluvial storage may be a key factor in keeping the central Umpqua system from being even warmer than it is (See Appendix 1:C.3).

Off-channel areas

Off-channel areas are pool and channel features that are associated with the larger, main channels. These areas may be remnants of abandoned channels or associated with tributaries. Often beaver activity is found in these areas. Both resident species and anadromous species can rear in hydrologically stable off-channel areas. In the winter they can provide resting areas for migrating fish and in the summer they can provide essential thermal refugia.

Since these areas are associated with the riparian areas of the larger streams and rivers, they have been heavily affected by streamside development. However, their importance to cold-water habitat may be particularly high for large systems like the Umpqua that typically reach high temperatures for an extended distance.

Some work has been done to evaluate the effectiveness of restoration of these areas. One study in British Columbia (Blackwell, Picard et al. 1999), available at http://srmwww.gov.bc.ca/frco/bookshop/docs/wrpr_14.pdf)showed that improvements to the quality of off-channel areas did not significantly improve smolt production but the creation of new suitable areas did have a benefit.

Management of these areas is particularly challenging. Their location along the main stream tends to generate conflicts with other land use options. Since they are vulnerable to flooding, the can easily be drastically impacted during flood events. To provide productive habitat they need to remain full, particularly during the drought season. Guidelines for project development are provided in the Oregon Restoration Guide (1999)

Some interesting web sites are: http://www.arwc.org/1%20pagers/alcoves.html and http://www.nwr.noaa.gov/pcsrf/2002/Mcginnis/tsld010.htm .

F.5 Habitat management strategies

Emphasis needs to be placed on refugia identification and management. Stream temperature management should be focused to locations and times relevant to use. If thermal refuges are critical they should be monitored (Coutant 1999).

The small tributary often forms the backbone of an anadromous fishery. In Oregon, these small streams provide the majority of the spawning and rearing sites for the fry. Thus onsite impacts are just as important as downstream impacts (Brown, Swank et al. 1971). This is particularly true if the onsite impacts become excessive.

Coutant stresses that alluvial valleys are poorly appreciated water storage reservoirs. The stored gravel, sand and silt can store cold groundwater that is recharged during the winter months. He also notes that streams in alluvial valleys may appear sluggish (implying warm) but can remain cool because of abundant riparian shading, frequent interchange with subsurface flow and additional cool groundwater (Coutant 1999).

Rip-rap bank reinforcement may provide low circulation refuge zones that aren't as impacted by the warm water associated with the diurnal peak temperature period. If the material is off of the bottom of the channel it can be self-flushing, thereby preserving the interstitial refuge spaces. However, rip-rap bank placement can have adverse effects associated with channel constriction and general channel stability. Particular care should be given to maintaining channel capacity.

G. Stream temperature spatial distribution

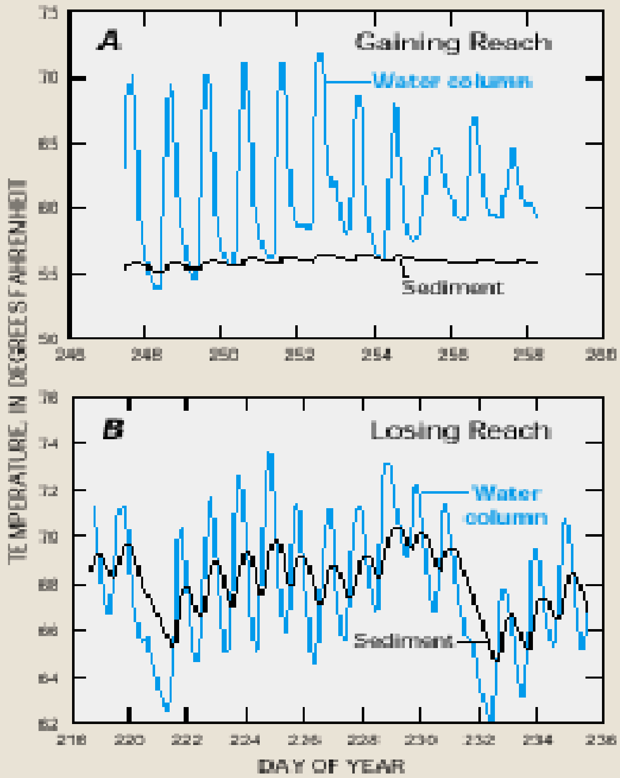
Stream temperatures vary by location within the watershed. The UBWC study was synoptic at the watershed level which meant that water temperatures at different sites could be compared for any given time. However, the data loggers monitored one point, which typically represented the temperature of most of the water. This ambient value is referred to as the **bulk temperature** to differentiate it from other temperatures that might be present in the stream. Small zones of colder water generated by local groundwater or hyporheic flow may be present but not detected by the sampling. However, these zones may provide crucial thermal refugia when the bulk temperature becomes excessive.

G.1 Stream segment scale

This section discusses the temperature distribution within a specific portion of a stream reach such as a pool or a riffle. Several heat exchange processes act on a volume of water at any given place and time (See Appendix 2:H.). The fact that the stream temperature data tends to be synchronized with the daily solar input suggests that the local conditions strongly influence the temperature of small streams during low flow conditions. Since the water is generally well-mixed, the bulk water temperature is uniform throughout most of the volume. However, the exceptions, where cooler water occurs, can be very important.

Four distinct types of cool-water areas have been identified by Bilby: (1) Lateral seeps, (2) pool bottom seeps, (3) cold tributary mouths and (4) flow through the streambed (Bartholow 1989). Generally the seepage areas are related to groundwater and are cooler than the inter-gravel flow which involves surface water. In the Bilby study, cool areas accounted for 1.6% of the surface area and 2.9% of the water volume based on a 3.5 km reach in a Washington stream.

A similar study on the Grande Ronde River found 77 cold water patches that occupied about 2% of the total surface area of a 16 km channel (Ebersole, Liss et al. 2003).



Ground-water temperatures generally are more stable than surface-water temperatures. Therefore, gaining reaches of Juday Creek in Indiana are characterized by relatively stable sediment temperatures compared to stream-water temperatures (A). Conversely, losing reaches are characterized by more variable sediment temperatures caused by the temperature of the inflowing surface water (B). (Modified from Silliman, S.E., and Booth, D.F., 1993, Analysis of time series measurements of sediment temperature for identification of gaining versus losing portions of Juday Creek, Indiana: Journal of Hydrology, v. 146, p. 131–148.) (Reprinted with permission from Elsevier Science-NL, Amsterdam, The Netherlands.)

Whether a stream segment is gaining or losing (Appendix 2:E.) flow can affect stream temperature. For gaining reaches, evapotranspiration may reduce the discharge of relatively cool groundwater in the afternoon, causing increased stream temperatures. However, if surface flow is reduced, the net result is cooling due to the higher proportion of cool groundwater. For losing reaches, the enhanced reduction in streamflow may facilitate increased atmospheric warming of reduced streamflows (See Figure above and (Constantz 1998)).

This groundwater influence can occur in streams of all sizes, even large streams with high bulk water temperatures, because all streams can receive groundwater inputs (See Appendix 2:D.). Since the temperature gradient at this interface is generally rapidly changing over a short distance, the volume of available cool water is small and as a result, the seepage temperature is not usually measured at a monitoring site. However, it is likely that these small cool areas are important refuge sites for temperature stressed fish. The fish may even be able to partially embed themselves in the finer sediment, to get the most benefit from this zone.

FLIR data is useful to identify areas of significant recharge to affect the surface water temperature. However, additional on-site monitoring would be necessary to fully define the thermal refuge area (Torgersen, Price et al. 1999). The temperature data collected in the UBWC study occasionally shows exceptionally cool areas, suggesting a local groundwater inflow zone.

G.2 Reach scale

The data from the Umpqua study shows that at the reach scale in small streams (less than 10 miles from watershed divide) a fairly uniform downstream heating trend in the bulk temperature is typically observed, with the rate of heating diminishing with increased distance. Irregularities in the profile usually have an obvious association with a change in local conditions such as a change in local climate (often related to shade conditions), change in groundwater hydrology, or inflow from a tributary (See Appendix 1:C.8, Appendix 2:I.).

During the summer low flow season, at the reach level, many streams have a pool riffle pattern, often with gravel accumulations at the base of the pools. While the bulk temperature may be high, there may be smaller local zones that have cooler temperatures. For example, local temperatures may be cooler at the downstream side of the riffle due to the inter-gravel flow. Likewise, deep pools with low flows may be stratified with cool water at the bottom of the pool. In this situation, decreasing surface flows can have the effect of actually increasing the volume of cold water habitat in the pool by (1) reducing the proportion of warm water in the mixture and (2) reducing the pool turbulence, thereby maintaining the stratification (Bartholow 1989).

G.3 Watershed scale:

At the watershed scale, average August stream temperatures on the Umpqua typically range from emergent groundwater at the source (about 54°F) to a mean surface temperature of about 75°F at the mouth with temperatures increasing in a logarithmic manner in the downstream direction. This pattern is generally attributed to (1) increasing stream width reducing the effectiveness of riparian vegetation to shade the stream surface; (2) decreasing proportion of cooler groundwater inflow relative to the flow of the channel; (3) increasing stream depth; and (4) increasing air temperatures at lower elevations (Sullivan, Tooley et al. 1990) (See Appendix 2:I**.** for theory and Appendix 1:C. for details of the patterns in the Umpqua Basin).

The 7DADM analysis (Appendix 1: C1-C7) shows that bulk temperatures will tend to cluster on or above a characteristic curve between the source and the mouth. Exceptions can typically be attributed to local anomalies such as the thermal refuge areas described in appendix 2:G.2.

The 7DADM analysis shows that, on the Umpqua under current conditions, the bulk water temperature will likely exceed the 64°F 7DADM criterion for streams at all points greater than either 4 or 7 miles from the watershed divide depending upon the watershed. Stream temperatures can reach any value within the data cluster zone between the curve and the upper threshold temperature (about 77 °F at 100 miles from the divide). Stream profiles of individual tributaries typically show a unique characteristic rising pattern within the data cluster with the main stem defining the curve at the longer distances.

There are several reasons why some tributaries have a different temperature profile that include:

Different flow regime – natural and water use effects
Different groundwater inflow- geologic or human related factors
Different vegetative cover
Different aspect

However, plotting the data against the distance measurement provides a good starting point for further analysis.

Other research uses the concept of "Threshold Distance" which is defined as the point where streams are sufficiently wide that shading by even mature forest vegetation provides no significant temperature protection. The report suggests that approximately 50 km (28 miles) appears to be a reasonable estimate. This estimation is based on the assumption that a river reaches the maximum system equilibrium point when shading is less than 24% of a 180° view of the sky (Sullivan, Tooley et al. 1990).

See Appendix 1:B.2 Thermal Equilibrium for an example using Umpqua data.

H. Basic stream heating concepts:

There are many processes and conditions that affect the temperature conditions in the riparian stream zone and a common understanding of these concepts will lead to better management decisions. Numerous references cover stream heating concepts in detail (i.e. (Satterlund 1972; Theurer, Voos et al. 1984; Sinokrot and Stefan 1993; Sinokrot and Stefan 1993)

H.1 Heat exchange processes

Stream temperature at a given point at a given time is determined by two general factors: the net amount of heat that has come from local heat transfer processes between the water and the local environment (see Processes below) and the net amount of heat that is being carried to and away from the point by surface and subsurface flow. During the day more heat comes in, the net effect is positive and stream temperature rises. During the night, more heat leaves, the net effect is negative and stream temperature falls. In the summer, on the average, slightly more heat comes in than goes out and there is a gradual increase in stream temperature throughout the summer. The rate of temperature change during the diurnal cycle shows that heat usually enters and leaves the stream at about the same rate.

There are six processes that exchange heat energy between water moving in a stream and its environment: (1) solar energy, (2) long wave radiation, (3) evaporation, (4) convection, (5) stream bed conduction, and (6) groundwater inflow/ outflow (Boyd and Sturdevant 1997)). The amount of heat at a fixed point in a flow stream is also influenced by the heat in the water flowing from upstream. Details on these processes are available in many references.

The following information was adapted from Coutant (Coutant 1999):

1) Radiation
   a) Direct solar (shortwave).
   b) Atmospheric (longwave).
   c) Riparian vegetation radiation.
   d) Water.
2) Stream evaporation
   a) Evaporation can occur directly on the surface. Water evaporating from the saturated edges can also contribute to the general cooling of the local environment. It is a function of both air circulation (wind) and relative humidity.
3) Convection
   a) Function of the evaporation heat flux, wind speed, atmospheric pressure and air-water temperature difference.
4) Streambed conduction
   a) This component is generally small but can become more important when there is hyporheic flow (Winter, Harvey et al. 1998).
5) Stream Friction.
   a) Generally negligible but can be noticeable for steep streams during cooler conditions.

Note that air temperature influences stream temperatures in several different ways. Large air masses moving through the area can strongly influence the processes through radiation, evaporation, and convection. See B.1 for more information.

H.2 Conditions affecting local stream heating processes

Local conditions affect the interaction of the heat transfer processes at any given location.

Riparian vegetation condition

Riparian vegetation can block a portion of the direct solar radiation by casting a shadow onto the surface of the water. Some of the intercepted heat energy is lost to evapotranspiration and the photosynthesis process. The remaining energy heats the canopy which is then exchanged with the local environment through the various processes (See Appendix 2:J. for shade information).

The effect of canopy height on longwave radiation intensity, air temperature gradients, wind speed and other factors can all influence the net thermal transfer by directly affecting the local micro-climate. These differences can affect both the day and night temperature patterns.

Channel Condition

Channel Shape

Wide channels have more exposed surface for the exchange processes to operate on. Also, wide channels will typically not receive as much shade cover. Deep, incised channels may have less width and the higher banks may provide topographic shade. Exposed pools will receive more direct sunlight. However, the deeper water and the influence of hyporheic interaction often result in lower temperatures.

Bed Composition

Exposed bedrock channels may accumulate more heat over the summer thereby contributing to higher maximum stream temperatures. Also, they may cause shallow, sheet flow to occur, resulting in more surface exposure. Bedrock pools may not have any hyporheic circulation and become warmer than pools in the graveled reaches. Increased groundwater inputs associated with the lower end of a gravel accumulation may decrease temperatures

Large gravel and cobble that protrude above the water surface can increase the heat-exchange contact surface area between the water and solar-heated rocks. Large rock accumulations below the surface can retain cool water interstitially during peak temperature periods thereby providing refuge areas.

Gravel accumulation often is associated with hyporheic flow and may provide cool refuge areas.

Channel association

Channels associated with alluvial terraces may have more groundwater inflow and hyporheic interaction thereby producing lower temperatures. Water temperatures near the mouth of a dry stream channel may be cooler due to subsurface contribution from the dry channel.

The location within the watershed determines the amount of accumulated flow, which in turn affects the size, shape and percent of groundwater contribution. Channels closer to the watershed divide are typically cooler.

For the same amount of direct solar radiation, water in wide, shallow channels will heat more than narrow, deep channels because it receives more heat radiation per unit volume of water. For the same reason, deep pools are typically cooler than shallow pools.

Channel stability is important to minimize erosion and keep the riparian vegetation intact. Generally, stable, low gradient streams have an active flood plain that remains vegetated after flood events, thus providing effective shade over the long term.

Channel aspect

Aspect can influence the heat exchange in two ways:

1. If the channel is shaded, the stream area will cause a gap in the shade wall. For example, a north-south flowing stream will not have any shade available as the sun passes through the noon period. Likewise, for an east-west stream, there will not be any shade on the water for a period in the morning and in the evening.

2. It is well known that steep south-facing slopes tend to be warmer and may have a distinctive vegetation association. A south facing headwater drainage can act as a parabolic collector and may have a warmer local environment which may contribute to surface water temperatures. This effect becomes more pronounced for steeper, headwater streams.

H.3 Relative influence of the local condition components

The net stream temperature is the sum of all of the thermal exchanges described in section #H1 combined with net heat contained in the water flowing into and out of the area.

There are an infinite number of combinations of the factors that influence local stream temperature and it is often difficult to predict exactly how a change in one factor will influence the temperature value. Computer temperature models can help by showing the effect of varying the input values on the final temperature. The result provides an estimate of the relative influence of the condition components.

The computer model SSTEMP, developed by the US Fish and Wildlife Service (Theurer, Voos et al. 1984; Bartholow 1989), was used to estimate stream temperatures for a typical scenario for the Central Umpqua Basin. In this example, the values of the inflow, groundwater inflow, shade, and mean air temperature were individually changed from the initial condition. Table 1 shows the corresponding values of the width, depth, mean temperature and maximum temperature that result from these changes when applied to a 1 km stream reach. While this range of change may be typical for streams in the Umpqua Basin, it should be noted that the magnitude of change can vary for different conditions.

Table 1 Sensitivity of stream temperature to input changes

***Shaded values indicate changed input parameter**

Inputs				Hydraulic Response		Temperature Response	
Inflow (cfs)	**Groundwater (cfs)**	**Veg Shade**	**Mean Air °F**	**Width Ft**	**Depth Ft**	**Mean Temp °F**	**Max Temp °F**
1	0.1	50%	70	12.62	0.141	67.23	74.01
1.5	0.1	50%	70	13.65	0.168	67.60	74.16
0.5	0.1	50%	70	11.09	0.106	66.77	73.88
1	0	50%	70	12.5	0.134	67.91	74.32
1	0.2	50%	70	12.74	0.148	66.61	73.69
1	1	50%	70	13.56	0.193	63.25	71.55
1	0.1	25%	70	12.62	0.141	69.52	78.48
1	0.1	75%	70	12.62	0.141	64.88	69.24
1	0.1	95%	70	12.62	0.141	62.96	65.25
1	0.1	50%	60	12.62	0.141	61.41	68.36
1	0.1	50%	80	12.62	0.141	73.77	80.20
1	0.01	50%	90	12.62	0.141	81.15	87.00

Note that this example shows that changes in groundwater flow, shade cover and air temperature significantly affect the stream temperatures while, in this case, the effect of changing flow does not appear to be as great. Other situations will produce different results.

CAUTION: While computer models are useful for this type of exercise, special care needs to be taken when applying a model to a particular stream. In particular, under low-flow conditions, some of the basic assumptions about the hydraulics and flow circulation patterns may not apply. Also it is difficult to account for the exact groundwater and hyporheic flow interaction.

I. Theoretical basis for the Cold Limit Line temperature profile

When a cold object is placed in a warm environment, it tends to reach the temperature of that environment in a logarithmic manner. It heats rapidly at first and then more slowly as it reaches the final temperature. The situation in a watershed is similar. In the summer cold groundwater emerges and eventually adjusts to the local environment. The situation is made more complex because the water is continually moving to different environments that are changing hourly and additional groundwater is being added along the way. It is common practice to approach this complex problem by first addressing a simpler steady state version and then superimposing the variable factors.

I.1 Equilibrium temperature

Many researchers use the concept of equilibrium temperature to derive a simplified mathematical model for stream temperature. **Equilibrium temperature** is a hypothetical temperature that water reaches under constant atmospheric heating/cooling where no more heat is transferred at the air/water interface. For short time intervals, air temperature values tend to lead the water temperature (See B.1) and a lag adjustment needs to be made to correlate air temperature with stream temperature. However, for longer time scales (e.g. weekly or monthly) linear regression models without lag work satisfactorily (Mohseni and Stefan 1999).

Based on basic heat transfer principles, the following equation for stream temperature can be developed. :

$$T=T_e + (T_o-T_e) \exp(-\{K_e X/\rho_c c_{pw} q\})$$

Where

T is stream temperature

T_e is the equilibrium temperature

X is the distance between the upstream temperature and the equilibrium temperature

ρ_c is water density

c_{pw} is the specific heat of water

q is flow per unit width of stream

K_e is the bulk coefficient of heat transfer and is a function of air temperature, dew point temperature and wind velocity.

(Mohseni and Stefan 1999).

Note that the exponent is a function of both distance X and unit flow q which is also a function of X. This exponent function can be determined empirically by fitting the equation to the UBWC temperature data. For example, in Figure A the equation is applied to the South Umpqua data collected in 1999 which produces the equation for the exponent (Figure A): That equation can, in turn, be used to determine q as a function of X.

where k^* is $K_e/\rho_c c_{pw}$. This equation indicates that the flow per unit width tends toward a relatively constant value in the larger streams (Figure B). No information on the pattern for the Umpqua has been found at this time.

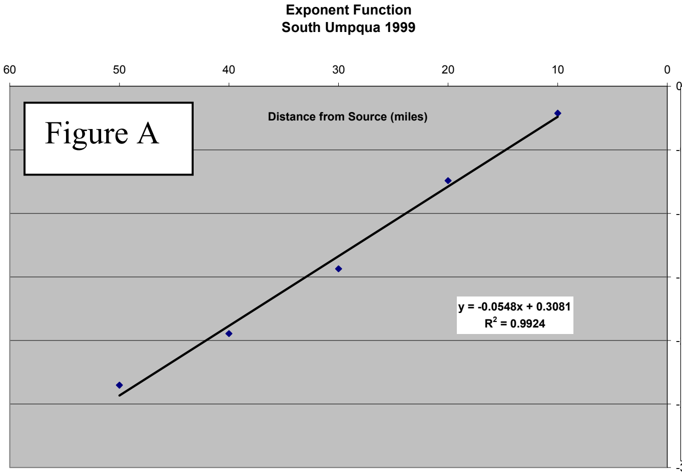


Figure A

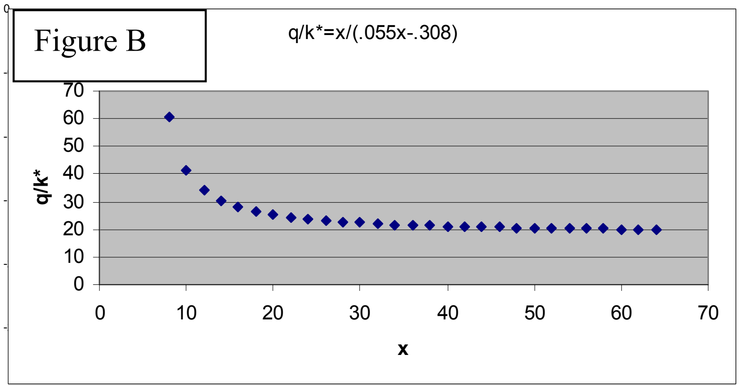


Figure B

I.2 Local equilibrium

It is apparent that stream temperatures in small, low flow streams are strongly affected by their local environment. The Umpqua data shows that the daily diurnal patterns are highly synchronized, with each site starting to warm with the arrival of the morning sun and cooling when the evening shade reaches the site. It is reasonable to assume that under homogenous conditions, the local groundwater inputs, the vegetative cover, and the local climate conditions can be approximately the same. A key factor that is changing significantly at this scale is the amount of surface flow which, in turn, affects the amount of exposed surface water and the proportion of groundwater to surface water. These changes appear to have a net effect on the local heating process that cause a characteristic rate of temperature change for that particular reach. Such “signature” patterns have been noted by others (Zwienlecki and Newton 1999). If the local conditions are optimal, these patterns match the Cold Limit Line (See Appendix 1:C.8).

However, as indicated in Appendix 2:H.2, many factors can affect local stream temperature and, even in a homogenous environment, some of them such as flow, local air temperature, and channel shape change with distance. The Cold Limit Line suggests that there is a limit that defines the minimum temperature for a given distance from the divide. The challenge is to show how all of these factors combine in a theoretical model. The logarithmic curve is intuitively encouraging since it is common form for thermal gradients. However, it appears that a precise model would be difficult to formulate.

A synoptic temperature profile study that records both air and water temperature at several points between the emergent and final point may show better where and to what extent the mean daily air and water values coincide. This would help show to what extent local equilibrium occurs for different distance points and would have direct benefit for restoration planning.

J. Shade Notes

This section contains background stream shade related information to supplement the main report. Since stream shade, by definition, blocks direct solar radiation, it is generally recognized as a key factor when considering issues related to stream heating.

J.1 Historic shade conditions

The ODFW developed an analysis of historic, current and desired conditions for streams in western Oregon for the 1998 Oregon Plan for Salmon and Watersheds annual report (1998). In the report they estimate that between 15 and 25% of coastal watersheds in Oregon may have been in a “recently disturbed” condition at any given time due to floods, landslides and stand resetting fires.

They also established a reference condition database by sampling streams that had reference condition characteristics. The table shows that 25% of the “reference condition” sites had 90% or better closure while 75% of them had better than 68% closure.

Quartile	Amount of exposed sky in Degrees	Percent Sky Exposure (% of 180 degrees)	Percent Closure
1st	18 degrees	10%	90%
2nd median	32 degrees	18%	82%
3rd	57 degrees	32%	68%

The paper notes that some possible bias was identified in the study, which was not based on a random sample. Modern fire suppression may have reduced the percentage of disturbed areas. Also, the channels had an average channel width of 52 feet. Smaller channels would tend to have to have a higher percentage of closure.

J.2 Shade measurement methodology

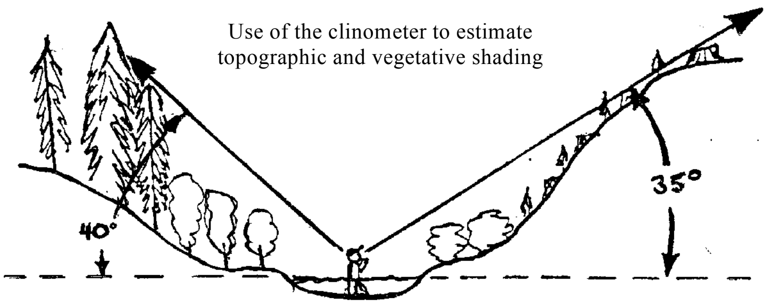
There are several terms and methods being used to designate the quantity of stream shade and generally the associated values are not directly interchangeable. For that reason, care must be taken in comparing shade values between studies that are using different methods and possibly different measured values.

In this report the following definitions apply:

1. **View-to-sky** – Forest densiometer. A spherical densiometer provides an estimate of the % sky visible in the total hemispherical view. Readings are typically taken in four directions from mid-channel and averaged.

2. **Shade- Solar Pathfinder®-** The Solar Pathfinder® displays the hemispherical view and shows the solar path for any given date. This allows for the determination of the % Shade specifically for any date of interest.

3. **Closure**- a hand held clinometer measures the angle from the horizontal to the edge of open sky as viewed at right angles to the stream. The sum of these angles is subtracted from 180° and then divided by 180° to give a "% Closure" value. **Figure J1** shows an example with closure of 42%. Often the % Open Sky is cited which is simply 100 - % Closure.



In this example the Percent Closure is 75/180 or 42%.

Figure J1

4. **Vegetative Shade density-** Vegetative shade density is a measure of the effectiveness of vegetation to block sunlight. For example, a tree with 70% vegetative density would block 70% of the direct solar radiation passing through it.

5. **Reach Shade Density-** Reach shade density is a measure of the effectiveness of the entire riparian shade wall to block sunlight. Since the shade wall may have voids with no vegetative shade, the reach shade density is the product of the percentage of cover times the average vegetative density. For example, if the average shade density of the trees were 70% and the shade wall along the reach contained only 50% trees, the reach shade density would be 35%.

6. **Effective Shade-** This value is calculated using an algorithm that calculates the total shade received by a stream for a specified day and gives an average "effective value" for the entire day. The calculations typically require stream width, tree height, reach shade density and overhang information. The value calculated should correspond to the % Shade measured by the Solar Pathfinder®. The SSHADE model which was developed as a utility for the SSTEMP and SNTEMP models (Theurer, Voos et al. 1984) was modified to run in Excel® and is used for this project to calculate % Effective Shade. The SHADOW program developed by Chris Park of the Forest Service also calculates effective shade with similar results.

   It should be noted that the SSSHADE model calculates shade as having 100% density and then adjusts the output by the corresponding reach density value.

J.3 The solar path

The location and extent of the shadow produced by a shading object is determined by the size of the object and the position of the sun. The position of the sun can be described by measuring two angles, the solar azimuth and the solar altitude. The solar azimuth angle is measured on the horizontal plane and, in this case, is measured clockwise with 0° as north. Thus 90°, 180°, and 270° denote east, south, and west directions respectively. The solar altitude angle is measured in a vertical plane starting from the horizontal. Thus an angle of 0° denotes the flat horizon while an angle of 90 ° is directly overhead.

During the spring and summer the sun moves across the sky in an arc starting in the morning on the NE horizon, rising to maximum in the due South direction at noon and then descending and setting in the evening in the NW.

This arc gets higher in the sky as the season progresses; reaching a maximum noon altitude angle during the summer solstice on June 22 at which time it starts to decrease again.

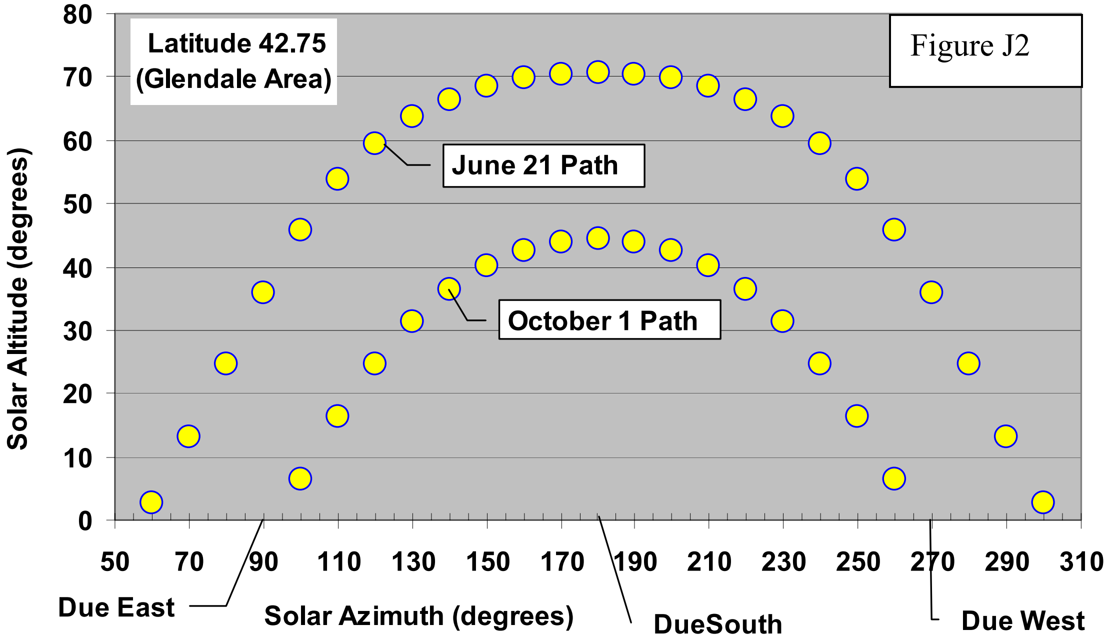


Figure J2 shows how the solar path varies in the latitude associated with the Glendale area. The upper curve shows the highest path that the sun takes which occurs during the summer solstice on June 22. The lower curve shows the path at the end of the summer season on October 1 (and March 13).

The solar altitude also changes with latitude, decreasing at locations further north as shown in Table 1 for representative dates and locations in Douglas County. Note that the higher latitude in the North County area results in less than a degree decrease in the solar altitude angles. Consequently, this table can be used to estimate shade patterns anywhere in the county.

Table 1 Comparison of solar altitude between South County and North County locations.

		Latitude 42.75 degrees **North of Glendale**					**Latitude: 43.5 degrees** **Between Yoncalla and Oakland**				
	Date:	**21-Jun**	**1-Jul**	**1-Aug**	**1-Sep**	**1-Oct**	**21-Jun**	**1-Jul**	**1-Aug**	**1-Sep**	**1-Oct**
	Declination:	**23.5**	**23.2**	**18.2**	**8.6**	**-2.9**	**23.5**	**23.2**	**18.2**	**8.6**	**-2.9**
	Solar Azimuth		**Solar Altitude angle (degrees)**					**Solar Altitude angle (degrees)**			
	50	-6.0	-6.4	-12.6	-24.4	-38.3	-5.6	-5.9	-12.1	-23.8	-37.6
	60	2.6	2.3	-4.5	-17.3	-32.1	3.0	2.6	-4.1	-16.8	-31.5
	70	13.1	12.6	5.3	-8.4	-24.3	13.1	12.7	5.5	-8.1	-23.7
	80	24.5	24.1	16.3	1.8	-14.8	24.2	23.9	16.2	1.9	-14.5
Due East	**90**	35.9	35.4	27.4	12.7	-4.3	35.3	34.9	27.0	12.5	-4.2
	100	45.8	45.4	37.6	23.1	6.5	45.0	44.6	36.9	22.7	6.3
	110	53.7	53.2	45.9	32.2	16.3	52.8	52.4	45.1	31.6	15.9
	120	59.5	59.1	52.3	39.5	24.7	58.5	58.1	51.5	38.8	24.1
	130	63.6	63.2	57.0	45.2	31.3	62.7	62.4	56.2	44.4	30.7
	140	66.5	66.2	60.4	49.4	36.4	65.6	65.3	59.6	48.6	35.7
	150	68.5	68.2	62.8	52.4	40.0	67.6	67.3	62.0	51.6	39.3
	160	69.7	69.5	64.3	54.3	42.5	69.0	68.7	63.6	53.6	41.7
	170	70.4	70.2	65.2	55.5	43.9	69.7	69.4	64.4	54.7	43.1
Due South	**180**	70.7	70.4	65.5	55.8	44.4	69.9	69.7	64.7	55.1	43.6
	190	70.4	70.2	65.2	55.5	43.9	69.7	69.4	64.4	54.7	43.1
	200	69.7	69.5	64.3	54.3	42.5	69.0	68.7	63.6	53.6	41.7
	210	68.5	68.2	62.8	52.4	40.0	67.6	67.3	62.0	51.6	39.3
	220	66.5	66.2	60.4	49.4	36.4	65.6	65.3	59.6	48.6	35.7
	230	63.6	63.2	57.0	45.2	31.3	62.7	62.4	56.2	44.4	30.7
	240	59.5	59.1	52.3	39.5	24.7	58.5	58.1	51.5	38.8	24.1
	250	53.7	53.2	45.9	32.2	16.3	52.8	52.4	45.1	31.6	15.9
	260	45.8	45.4	37.6	23.1	6.5	45.0	44.6	36.9	22.7	6.3
Due West	**270**	35.9	35.4	27.4	12.7	-4.3	35.3	34.9	27.0	12.5	-4.2
	280	24.5	24.1	16.3	1.8	-14.8	24.2	23.9	16.2	1.9	-14.5
	290	13.1	12.6	5.3	-8.4	-24.3	13.1	12.7	5.5	-8.1	-23.7
	300	2.6	2.3	-4.5	-17.3	-32.1	3.0	2.6	-4.1	-16.8	-31.5
	310	-6.0	-6.4	-12.6	-24.4	-38.3	-5.6	-5.9	-12.1	-23.8	-37.6

J.4 Determining shadow position

To manage the amount of solar exposure to a site it is necessary to know what will cause shade at a point at different times of the year. The information in Table 1 can be used for that purpose.

For example, the table can be used to determine exactly which trees will produce a shadow that extends across a stream to points on the opposite bank. Figure 3 shows an observer measuring the angle to the top of the shading tree from a point on the opposite bank of the stream. In this case the observer is looking due south and measures an angle of 70°. The table shows that maximum solar altitude angle is 70° in Douglas County. Therefore, at noon, when the sun is highest, the point will always be shaded by the tree. That means that the shadow of the tree will extend from the base of the tree to, or beyond, the point of the observer at any time of the year when the sun is at the noon position. If the tree were shorter, for example, with a 56 angle, the point would not be shaded at noon until after October 1 and would continue to have noon shade until about March 13.

To determine the tree requirements to provide shade at other times of the day, it is necessary to check the shade angle for the other solar azimuth angles. If the observer turned to either the SE or the SW, the effective shade angle for June 21 would be 65° and trees exceeding that angle would also shade the point on June 21 as the sun passes through the SE and the SW. It is helpful to remember 70° for due south and 35° for east and due west. Thus, the observer can determine the highest solar path by first facing due east to measure a 35° vertical angle. Then, while turning clockwise to the south, increase the angle up to 70° and then move back down to 35° at the west. This process can be repeated at other points along the stream to determine the maximum solar path and the corresponding "shade wall" needed to fully shade a stream for any time of the day. For wide streams it quickly becomes obvious that it is impossible to have trees on the opposite side of the stream tall enough to completely shade the entire stream around the summer solstice period. The maximum height of the mature trees then determines the maximum possible shading for these types of streams. The table can be used to estimate the dates that the stream would be fully shaded by the mature trees.

Note also that the height of the observer adds a "margin of safety" since the shade wall height could be reduced by the height of the observer if s/he is standing upright at the edge of the stream.

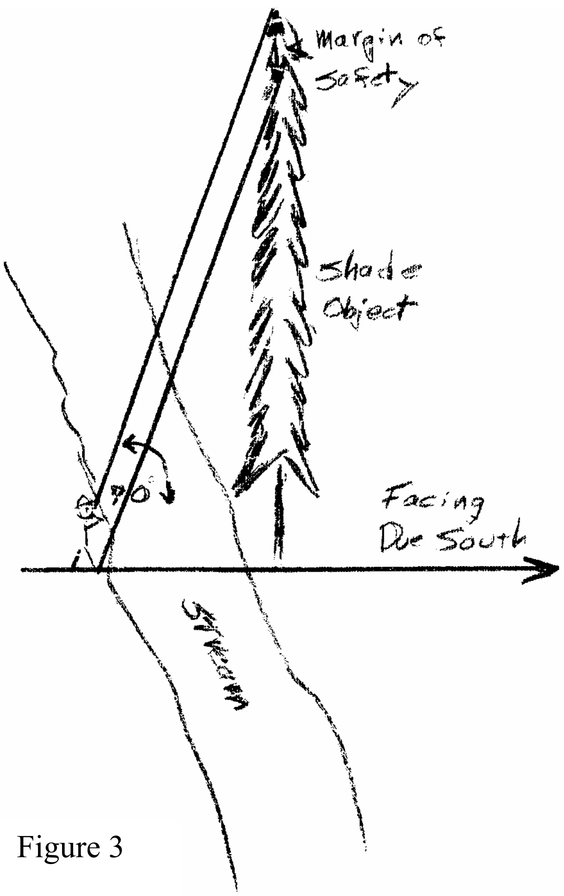


Figure 3

J.5 Buffer effectiveness

Air temperature

It has been shown that the microclimate in a riparian area can affect stream temperature (See appendix 2:H.1). However, there hasn't been much work comparing the microclimate of a buffered stream with an unharvested area. It has been shown that, in western Washington forests, air temperatures tend to be slightly cooler on the bank compared to temperatures 15-25 meters upslope perpendicular to the bank. The evaporation of the surface and of the saturated soils probably contributed to this effect. The differences observed were higher (2% vs. 1%) in exposed areas with no buffer. This is consistent with the fact that evaporative cooling effects become more pronounced with higher temperatures (Mohseni and Stefan 1999). In areas that had buffers, the air temperatures in the harvest area beyond the buffer were typically 15% higher (Sullivan, Tooley et al. 1990).

Figure 4 shows the results of another study from the Six Rivers National Forest in Northern California that measured air temperatures and relative humidity above the stream as a function of the buffer width over the course of a summer (Ledwith 1996). These results represent only one scenario and may vary with different conditions. However, they do suggest that the microclimate associated with the stream can be influenced for a distance of over 100 meters from the stream. Unfortunately this study does not provide any stream temperature information.

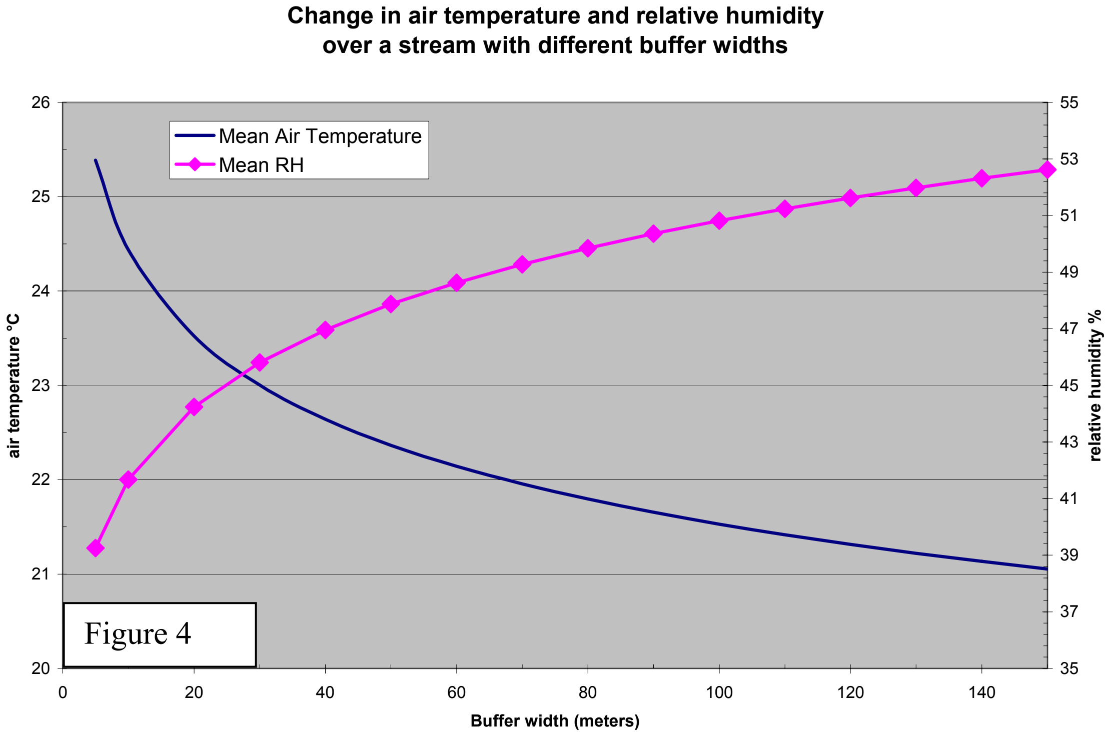

Change in air temperature and relative humidity over a stream with different buffer widths

Figure 4

Stream Temperature

Stream buffers are generally effective in maintaining stream temperatures however, the results can vary. Many factors contribute to stream heating (See Appendix 2:H.3) and detailed information is required to fully compare results.

As shown earlier, the direct shade component can be easily assessed. More information is needed on the relationship between the buffer size (height, width, density) and the resulting local environment.

K. Notes on the Oregon water temperature standard

Note: the Oregon water temperature standard is currently being revised. This section will be updated when this process is completed. Current update can be obtained at http://www.deq.state.or.us/wq/standards/WQStdsTemp.htm. The remaining discussion in this section addresses the old standard and the EPA recommendations for standard revision.

Compliance with the Oregon state water temperature standard is often a concern of land managers in the Umpqua Basin. This section contains some general information related to the current standard and some notes from the EPA Region 10 Temperature Water Quality Criteria Guidance Development Project that is developing recommendations for updating the existing criteria.

K.1 Current standard

The following summary of the current standard was provided by Bobbi Lindberg of DEQ:

> The Clean Water Act Section 303 requires states implementing the Clean Water Act to adopt standards for water quality. The current Oregon temperature standard was adopted in 1996, and establishes numeric criteria for certain salmonid life stages. The criterion for salmonid rearing is 64 degrees F; for spawning, the criterion is 55 degrees F. When Bull trout are present, the criterion is 50 degrees F.
>
> The numeric criteria are only a portion of Oregon's temperature standard. The standard requires a management plan when the moving average of the daily maximum values over a seven day period exceeds the appropriate numeric criterion (64 for rearing; 55 for spawning). Sources which are in compliance with the management plan shall not be considered as causing or contributing to a violation of the numeric criterion. Once all feasible steps have been taken under the management plan to meet the criterion, the actual temperature achieved will be the temperature criterion for the waters covered by the management plan.

This standard was designed to protect the native aquatic species that are most sensitive to warm temperatures (Chinook salmon, coho, steelhead, cutthroat, bull trout and the first-year tadpoles of tailed frogs) (1995).

As indicated above, the temperature data from the Umpqua Basin shows that many streams in the basin exceed the 64°F criteria.

K.2 Concerns with the current criteria

Oregon's temperature standard contains criteria for protecting various life stages of salmonids. The 64°F criterion protects rearing of salmonids, while the 55°F criterion protects salmonid spawning. While the criteria are only a portion of the temperature standard, they are the focus of concern with the standard.

It has been suggested that application of a single numerical criterion for stream temperature does not adequately address the variability in conditions and the variability in use, both temporal and spatial. The following section is an abridged excerpt from the ***EPA Temperature Criteria Task Group (Poole, Dunham et al. 2001).***

> **There are several reasons why a single threshold approach to determining water quality criteria can be problematic.**
>
> **Stream temperatures associated with increased biological risk might occur relatively frequently in some stream reaches under natural conditions. Natural stream conditions would violate temperature thresholds that were predicated on eliminating biological risk to individual fish. Natural stream temperatures vary across space and time, particularly in large, dynamic landscapes such as the Pacific Northwest. Applying a conventional standard may result in two undesirable consequences. First, human-caused warming of the best thermal habitat may be allowed where local stream temperatures are naturally below the water quality criterion. Second, streams naturally warmer than the criterion will be identified as candidates for remediation. Salmonids require a variety of cold water temperatures, but a single threshold standard does not recognize the diversity of water temperatures needed by various species and over space and time.**
>
> **Temperature standards are developed primarily to protect aquatic biota as the beneficial use most sensitive to water temperature. Yet, water temperature is the expression of a set of heat transfer processes that are in turn influenced by the physiographic, climatic, and hydrologic variables acting on a particular stream segment. Some of these variables can be altered by human activity and some cannot. Therefore, in setting water temperature standards to protect aquatic biota both the biological and physical processes must be considered. A good standard will protect high-quality habitat and guide restoration of degraded habitat, while recognizing that some naturally warm reaches are also part of the aquatic landscape. It will limit the extent to which the standard may be under-protective in some locations and overly stringent in others.**

Oregon's current temperature standard uses numeric criteria to assess stream temperature, but also contains provisions allowing the criteria to be amended after human-caused warming has been removed to the extent feasible. If a temperature management plan is implemented which does remove human-caused warming to the extent feasible, then the temperature criterion is amended to the temperature achieved by implementing the plan. However, as noted above, the current standard does not explicitly prevent human-caused warming where local temperatures are below the applicable criterion. Thus the standard contains provisions to prevent overly stringent criteria but is still under-protective of the best thermal habitat.

The Oregon Department of Environmental Quality is in the process of reviewing and updating the state's temperature standard (as of October, 2003).

K.3 Uncertainties associated with numerical criteria

Table 3. Examples of uncertainties and certainties associated with determining criteria for water temperature standards based on protecting viable populations of salmonids in the Pacific Northwest Excerpt from (Poole, Dunham et al. 2001).

	Uncertainty	**Certainty**
How Cold?	Relationships between lab-derived temperature thresholds and requisite temperatures in the field	Salmonids can experience physiological stresses where water temperatures are not optimal
	Maximum allowable temperatures that will support viable populations	General ranges of water temperatures necessary for survival and reproduction.
	Precise thresholds of harmful temperatures (e.g., see Table 2)	Both lethal and sub-lethal effects affect salmonid survival
	Effects of multiple stressors	Thermal tolerance in salmonids is affected by other stresses and vice versa.
How Much, When and Where?	Mechanisms and dynamics of cumulative effects on stream temperature dynamics	Cumulative effects occur and can result in synergistic temperature changes within in streams subject to multiple disturbances.
	Patterns of environmental variability required to support populations	Complex physical habitat structure creates spatially and temporally diverse coldwater habitats that salmonids have evolved to exploit
	Historical thermal regimes in streams	Salmonid survival requires a variety of cold water temperatures that are well-distributed over space and time.
	Measures of historical fish distribution and trends in fish populations	Salmonid populations have declined precipitously and their distributions have been reduced throughout the region
	Data on the alteration of thermal regimes	Thermal regimes have been altered substantially over time; where altered, streams are generally warmer in the summer and more spatially homogeneous
Human Influence	Exactly what management actions are necessary to protect salmonids?	The types of activities affecting stream temperature
	Maximum levels of degradation that will allow salmon to persist	Salmonid populations require a safety buffer in the face of a variable environment

K.4 Draft criteria proposed by EPA committee

Work has been ongoing and progress is well documented in a series of issue papers (Materna 2001; Poole, Risley et al. 2001; Sauter, McMillan et al. 2001; Dunham, Lockwood et al. 2002). These papers are on the project CD. They can also be obtained with updated information at this site:
http://yosemite.epa.gov/R10/water.nsf waterrelated topics/ Water Quality Temperature Criteria
Note: Bull trout information is not included in the tables since the species is not present on the Umpqua.

K.4a Summary of temperature considerations for salmon and trout life stages

Ref. (2002)

Table 1 – Summary of Temperature Considerations for Salmon and Trout Life Stages

Life Stage	Temperature Consideration	Temperature & Unit	Reference
Spawning and Egg Incubation	*Temp. Range at which Spawning is Most Frequently Observed in the Field	4 - 14°C (daily avg) 39.2-57.2°F	Issue Paper 1; pp 17-18 Issue Paper 5; p 81
	* Egg Incubation Studies - Results in Good Survival -Optimal Range	4 - 12°C (constant) 39.2-53.6°F 6 - 10°C (constant) 42.8-50°F	Issue Paper 5; p 16
	*Reduced Viability of Gametes in Holding Adults	> 13°C (constant) 55.4°F	Issue Paper 5; pp 16 and 75
Juvenile Rearing	*Lethal Temp. (1 Week Exposure)	23 - 26°C (constant) 73.4-78.8°F	
	*Optimal Growth - unlimited food - limited food	13 - 20°C (constant) 55.4-68°F 10 - 16°C (constant) 50-60.8°F	
	*Rearing Preference Temp. in Lab and Field Studies	10 - 17°C (constant) 50-62.6°F < 18°C (7DADM) 64.4°F	Issue Paper 1; p 4 (Table 2). Welsh et al. 2001.
	*Impairment to Smoltification	12 - 15°C (constant) 53.6-59°F	Issue Paper 5; pp 7 and 57-65
	*Impairment to Steelhead Smoltification	> 12°C (constant) 53.6°F	Issue Paper 5; pp 7 and 57-65
	*Disease (lab studies) - Severe - Elevated - Minimized	18 - 20°C (constant)64.4-68°F 14 - 17°C (constant) 57.2-62.6°F 12 - 13°C (constant) 53.6-55.4°F	Issue Paper 5; pp 12, 14
Adult Migration	*Lethal Temp. (1 Week Exposure)	21- 22°C (constant) 69.8-71.6°F	(Table 4), 17, and 83-84 Issue Paper 5; pp 3-6 (Table 1), and 38-56
	*Migration Blockage and Migration Delay	21 - 22°C (average) 69.8-71.6°F	Issue Paper 5; pp 9, 10, 72-74. Issue Paper 1; pp 15 - 16
	*Disease (lab studies) - Severe - Elevated - Minimized	18 - 20°C (constant) 64.4-68°F 14 - 17°C (constant) 57.2-62.6°F 12- 13°C (constant) 53.6-55.4°F	Issue Paper 4; pp 12 - 23
	*Adult Swimming Performance - Reduced - Optimal	> 20°C (constant) 68°F 15 - 19°C (constant) 59-66.2°F	Issue Paper 5; pp 8, 9, 13, 65 - 71
	* Overall Reduction in Migration Fitness due to Cumulative Stresses	> 17-18°C (prolonged exposures) 62.6-64.4°F	Issue Paper 5; p 74

K.4b Criteria for summer use

Table 3. Recommended Criteria That Apply To Summer Maximum Temperatures *Notes: 1) 7DADM: Maximum 7 Day Average of the Daily Maximums; 2) "Salmon" refers to Chinook, Coho, Sockeye, Pink, and Chum salmon; 3) "Trout" refers to Steelhead and coastal cutthroat trout; 4) "may potentially occur" refers to waters that will likely support the use if temperatures are restored*	
Salmonid Uses During the Summer Maximum Conditions	**Criteria**
Salmon/Trout "Core" Juvenile Rearing Applies to core juvenile rearing habitat. Generally, core juvenile rearing applies to the furthest downstream extent of current summer use for areas of degraded habitat where current summer distribution is shrunken relative to historical distribution. For areas of minimally degraded habitat, this use would apply to waters of core use based on density and/or habitat features. This use also applies to juvenile rearing waters that currently meet this criteria. This use is generally in a river basin's mid-to-upper reaches, downstream from juvenile bull trout rearing areas. However, in colder climates, such as the Olympic mountains and the west slopes of the Cascades, this use may apply all the way to the saltwater estuary. This use is designed to protect high quality summertime juvenile rearing habitat for salmon and trout. Protection of these waters for juvenile rearing also provides protection for adult spring chinook salmon that hold throughout the summer prior to spawning and bull trout migration.	**16°C (61°F) 7DADM**
Salmon/Trout Juvenile Rearing and Juvenile/Adult Migration Applies to waters where summer salmon and trout juvenile rearing and juvenile/adult migration currently occurs and may potentially occur. This use extends downstream from the "core" juvenile rearing use. In many river basins in the Pacific Northwest, this use will apply all the way to river basin's terminus (i.e. confluence with the Columbia or Snake rivers or saltwater) This use is designed to protect juvenile rearing that extends beyond "core" juvenile rearing areas and migrating juveniles and adults.	**18°C (64°F) 7DADM**
Salmon/Trout Migration on Lower Mainstem Rivers Applies in the lower reaches of mainstem rivers (e.g. mid-lower Columbia river, lower Snake river, and possibly the lowest reaches of other large mainstem rivers) in the Pacific Northwest where based on best available scientific information (e.g. temperature modeling and pre-disturbance temperature data) maximum temperatures likely reached 20C prior to significant human alteration of the landscape. The narrative cold water refugia provision would require all feasible steps be taken to restore and protect the river functions (e.g,. alluvial floodplains) that could provide cold water refugia in these river segments. *Note: this recommendation is a combination of a numeric criteria (20°C) and a narrative WQS requiring effective protection of cold water refugia that together protects this use.*	**20°C (68°F) 7DADM, with a cold water refugia narrative provision**

K.4c Other recommended criteria

Table 4. Other Recommended Criteria

Notes: 1) 7DADM: Maximum 7 Day Average of the Daily Maximums; 2) "Salmon" refers to Chinook, Coho, Sockeye, Pink, and Chum salmon; 3) "Trout" refers to Steelhead and coastal cutthroat trout; 4) "may potentially occur" refers to waters that will likely support the use if temperatures are restored

Salmonid Uses	**Criteria**
Salmon/Trout Spawning, Egg Incubation, and Fry Emergence Applies to waters where and when salmon and trout spawning, egg incubation, and fry emergence currently occurs and may potential occur. Generally, this use occurs: a) in late spring-early summer for trout (mid-upper reaches), b) in late summer-fall for spring chinook (mid-upper reaches), c) in the fall for coho (mid-reaches), pink, chum, and fall chinook (latter three in lower reaches). This use is defined from the average date that spawning begins to the average date incubation ends (the first 7DADM is calculated 1 week after the average date that spawning begins).	**13°C (55°F) 7DADM**
Steelhead Smoltification Applies to waters where the early stages of smoltification occurs in steelhead trout. Generally applies in April and May for rivers where juvenile out-migration occurs except for the mid and lower Columbia and lower Snake rivers (e.g. the criteria would apply at the mouth of the major tributaries of the Columbia river basin). This use is designed to protect the early stages of steelhead smoltification. Smoltification of other salmonids is generally protected vis-a-vis the summer maximum criteria, but this criteria provides an added level of protection for other salmonids which can successfully smolt at higher temperatures than steelhead.	**14°C (61°F) 7DADM**

K.5 ODF and DEQ sufficiency analysis

In 2002 the Oregon Department of Forestry (ODF) and the Department of Environmental Quality (DEQ) jointly produced a report that addressed the adequacy of the Forest Practices Act in the achievement and maintenance of Oregon water quality standards on non-federal forestlands (2002)

Temperature

An evaluation of the temperature standard includes considering of all aspects of the antidegradation narrative standard and numeric criteria. The standard also includes conditions for cold-water refugia, dissolved oxygen, and natural lakes. These are not addressed in this analysis because either there was a lack of information available to evaluate such conditions or there was a lack of applicability to forest management activities. The DEQ has yet to develop the specific guidance necessary to identify cold-water refugia on the ground so it can be evaluated against the standard. Until that guidance is developed, the evaluation of FPA sufficiency in meeting the antidegradation standard relative to cold-water refugia is not possible. Water quality impairment related to dissolved oxygen is "generally not attributable to forest management practices as regulated by the EPA."(April 1998) Temperature impairment related to natural lakes is also generally not attributable to forest management practices. A detailed description of the standard is included in Appendix F.

The following is an evaluation of the temperature standard by specific stream types and sizes:

> Medium and small Type F streams: Current research and monitoring results show that current RMA prescriptions for western Oregon may result in short-term temperature increases on some Type F streams; however the significance of the potential temperature increases at a watershed (or sub-basin) scale is uncertain.
>
> Small Type N streams: Current research and monitoring results show current practices may result in short-term (two to three years) temperature increases on some Type N streams. The significance of potential temperature increases on Type N streams to downstream fish-bearing streams and at a watershed (or sub-basin) scale is uncertain.
>
> All other streams: Influences on stream temperatures from shade levels resulting from specific BMP prescriptions for the other stream category types have not been assessed due to a lack of relevant data. However, in light of the data and findings specific to medium and small Type F streams, and given the higher level of vegetation retention on large Type F streams, it is likely that the standard is being met on large Type F streams.

L. Human effects on stream temperature

Effective temperature management requires a sound knowledge of the effects of the various human activities on stream temperature. This section contains excerpts from various sources for review and comparison.

L.1 EPA draft guidance

See (2002)

IV.2. Human Activities That Can Contribute to Excess Warming of Rivers and Streams

Rivers and streams in the Pacific Northwest naturally warm in the summer due to increased solar radiation and warm air temperature. Human changes to the landscape have magnified the degree of river warming, reducing the number of river segments that are thermally suitable for salmonids and causing adverse effects to salmonids exposed to elevated temperatures. Human activities can increase water temperatures by increasing the amount of heat load into the river, by reducing the river's capacity to absorb heat, and by eliminating or reducing the amount of groundwater flow which moderates temperatures and provides cold water refugia. Specific ways in which human development has caused excess warming of rivers are presented in Issue Paper 3 and are summarized below:

1) Removal of streamside vegetation reduces the amount of shade that blocks solar radiation and increases solar heating of streams. Examples of human activities that reduce shade include forest harvesting, land clearing and grazing for agriculture, and urban development.
2) Removal of streamside vegetation also reduces bank stability, thereby causing bank erosion and increased sediment loading into the stream. Bank erosion and increased sedimentation results in wider and shallower streams, which increases the stream's heat load by increasing the surface area subject to solar radiation and heat exchange with the air.
3) Water withdrawals from rivers for purposes such as agricultural irrigation and urban/municipal and industrial use result in less river volume and generally remove cold water. The temperatures of rivers with smaller volumes equilibrate faster, which leads to higher maximum water temperatures in the summer.
4) Water discharges from industrial facilities, wastewater treatment facilities and irrigation return flows can add heat to rivers.
5) Channeling, straightening, or diking rivers for flood control and urban and agricultural land development reduces or eliminates cool groundwater flow in a river that moderates summertime river temperatures. Two forms of groundwater flow can be reduced from the above human actions. One form is groundwater that is created during over bank flooding and is slowly returned to the main river channel to cool the water in the summer. A second form is water that is exchanged between the river and the riverbed

> (i.e. hyporheic flow). Hyporheic flow is plentiful in fully functioning alluvial river systems.
> 6) Removal of upland vegetation along with soil compaction and increased storm runoff reduces the amount of groundwater that is stored in the watershed and that slowly filters back to the stream in the summer to cool water temperatures. Examples of upland vegetation removal include forest harvesting and agricultural and urban development.
> 7) Dams and their reservoirs can affect thermal patterns in a number of ways. They can increase maximum temperatures by holding waters in reservoirs to warm, especially in shallow areas near shore. Reservoirs, due to their increased volume of water, are more resistant to temperature change which results in reduced diurnal temperature variation and prolonged periods of warm water. For example, dams can delay the natural cooling that takes place in the late summer- early fall, thereby negatively impacting late summer-fall migration runs. Reservoirs also inundate alluvial river segments, thereby eliminating the groundwater exchange between the river and the riverbed (i.e. hyporheic flow) that cools the river and provides cold water refugia during the summer. Further, dams significantly reduce the river flow rate causing juvenile migrants to be exposed to high temperatures for a much longer time than they would under a natural flow regime.

It should also be noted that some human development can create water temperatures colder than in an unaltered river. The most significant example of this occurs when cold water is released from the bottom of a thermally stratified reservoir behind a dam (page 5).

L.2 - EPA technical synthesis

See (Poole, Dunham et al. 2001)

> In many river basins of the Pacific Northwest, land management activities have (1) reduced connectivity (i.e., the flow of energy, organisms, and materials) between streams, riparian areas, floodplains, ground water, and uplands; (2) altered floodplain function, wetlands, water tables, and base flows; (3) elevated fine sediment yields, making streams wider and shallower, with fewer pools; (4) reduced instream and riparian large woody debris that traps sediment, stabilizes stream banks, and helps form pools; (5) reduced or eliminated riparian vegetation; and (6) altered peak flow volumes and timing (FEMAT 1993, Henjum et al. 1994, Rhodes et al. 1994, Wissmar et al. 1994, National Research Council 1996, Spence et al. 1996, Oregon Coastal Salmon Restoration Initiative 1997, Quigley and Arbelbide 1997, McIntosh et al. 2000). Thus, human activities can alter stream temperature through a variety of complex and interactive pathways (Figure 4). In developing guidance for water quality criteria, we believe it is important to consider a wide array of pathways by which human actions alter temperature and the ways in which different approaches to temperature standards might be effective or ineffective at addressing the influence of each pathway (page 11).

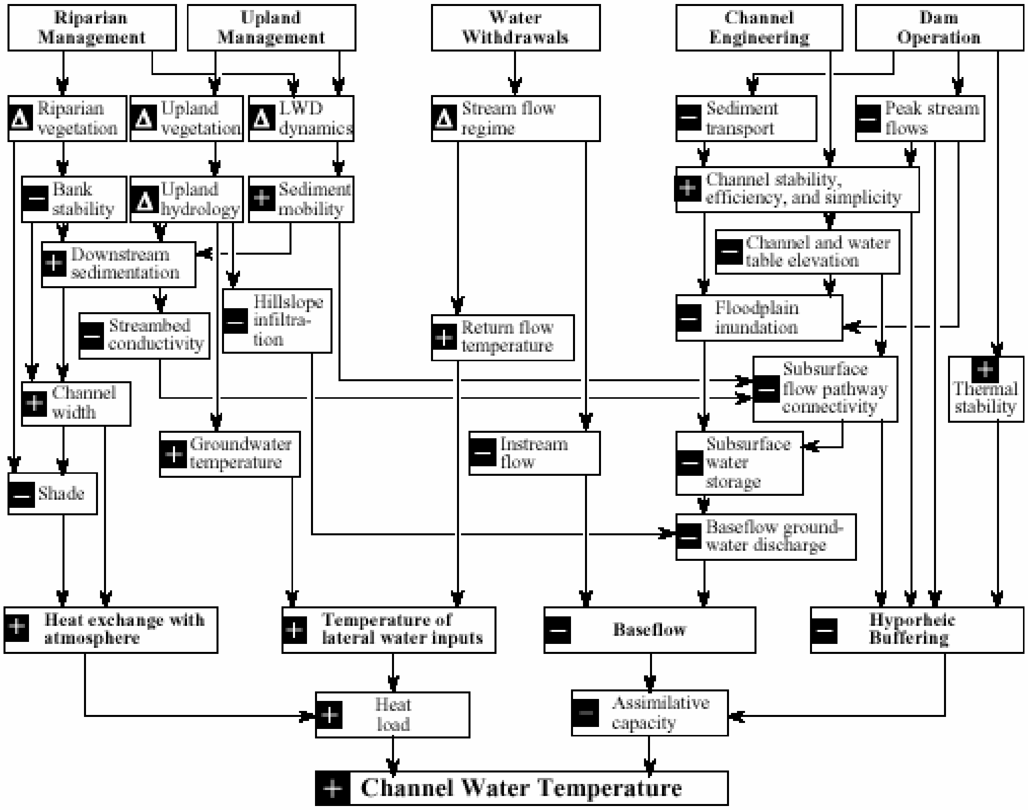


Figure 4. Some pathways of human-caused warming of stream channels (From Poole and Berman 2001.). The symbol "+" indicates an expected (but not certain) increase, "–" an expected (but not certain) decrease, and "Δ" either an expected increase or decrease depending on the specific circumstance or measurement used. This graphic is designed to illustrate the complexity associated with stream temperature dynamics. It is not intended to be a comprehensive summary. Additional arrows and boxes are possible under various conditions.