BURNT RIVER

WATER TEMPERATURE STUDY

STEERING COMMITTEE FINAL REPORT

Prepared for the Burnt River Steering Committee by
David Duncan and Associates
Boise, Idaho

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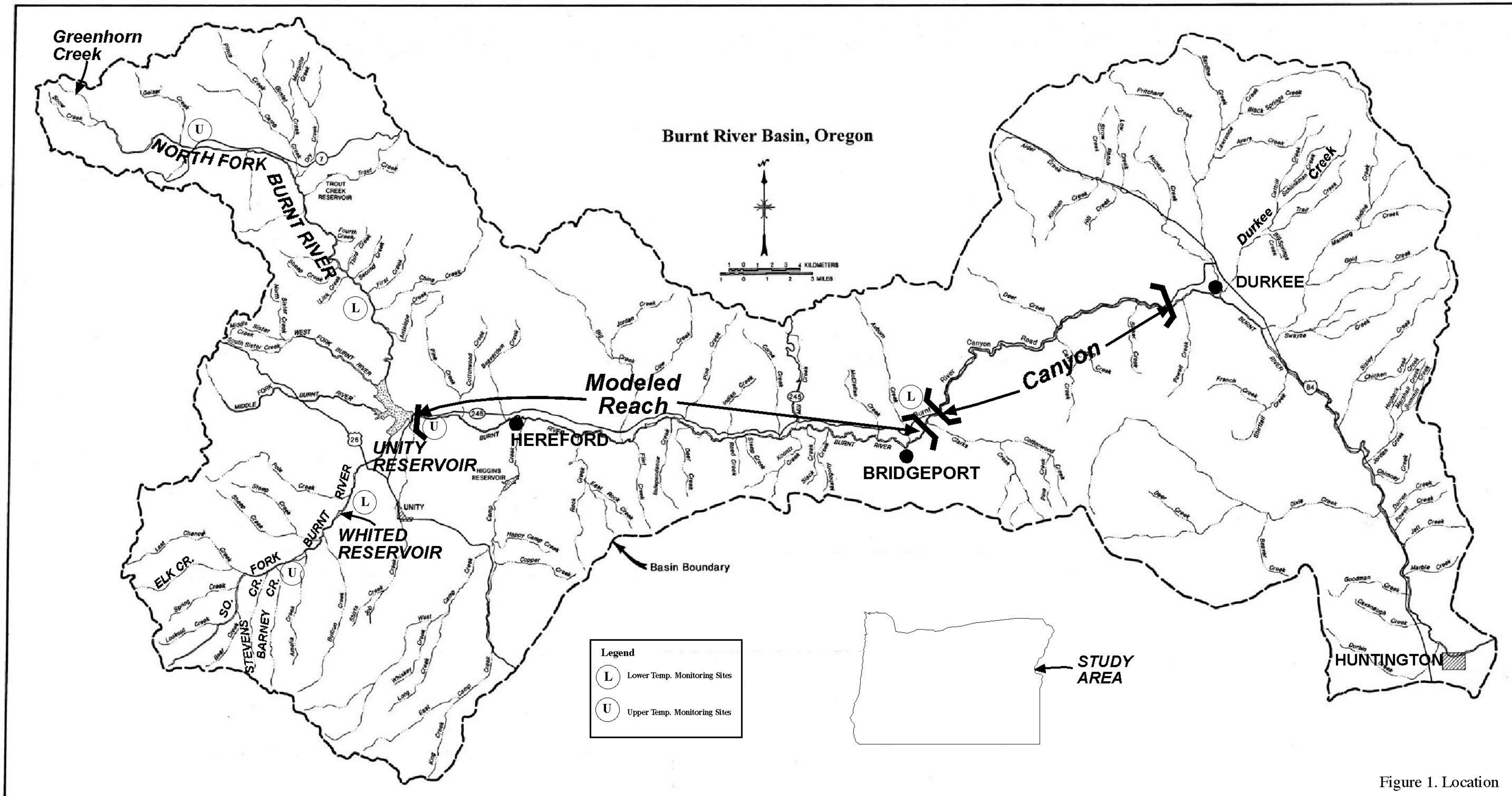

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INTRODUCTION

Study Description

Sixteen state and Federal agencies and organizations[1] signed a Memorandum of Understanding (MOU) which defines a water quality study of the Burnt River subbasin. The goals of the study are to provide a broadly-acceptable scientific basis for (1) developing and evaluating alternative approaches to dealing with water temperature concerns, and (2) exploring how these approaches might be applied in a pilot basin in the development of an agriculture water quality management area (1010)[2] plan as it relates to temperature.

The Burnt River Water Temperature Study was organized to include a steering committee and a technical committee. Study products include both research and committee reports. This report describes the work done by the steering committee to address the four objectives in the MOU[3]: (1) assess the factors in the Burnt River subbasin that contribute to current stream temperatures; (2) evaluate management practices that might reduce current temperatures; (3) develop and test a concept using riparian and stream characteristics as a surrogate for temperature goals; and (4) use the results of Objectives 1 through 3 as a basis for development of a 1010 plan by the Oregon Department of Agriculture. Research for the study was performed by the Bureau of Reclamation (Reclamation) and the Oregon State University (OSU) Rangeland Resources Department. This is not a research report. Readers should refer to reports prepared by the Rangeland Resources Department and Reclamation for specific discussions relating to research findings.[4] Reclamation research is summarized in the discussions of Objectives 1 and 2, and a summary of research findings provided by the OSU Rangeland Resources Department is attached as Appendix B.

This document has not been formally approved by any of the participating organizations and does not necessarily represent a consensus of the participants. In commenting on an earlier draft of this report, Environmental Defense has stated that it did not adequately communicate their view of the study's products and findings.[5]

Study Area

The Burnt River subbasin in eastern Oregon (see Figure 1) drains about 1,100 square miles that range in elevation from about 7900 feet to 2100 feet. Main tributaries originate in the Blue Mountains and join just upstream from Unity Reservoir. The reservoir stores spring runoff for irrigation of agricultural crops, mainly alfalfa and grass hay, and provides recreational opportunities. The primary irrigated areas include the area around Whitney on the North Fork, the area around the town of Unity on the South Fork, the area along the main stem from Unity Dam to the head of the Burnt River Canyon, and the Durkee valley below the canyon.

Reclamation studied the North Fork and the main stem and modeled the main stem[6] from Unity Reservoir to the head of the Burnt River Canyon downstream of Bridgeport. OSU studied four headwater tributaries (three South Fork and one North Fork) and the main stem.

OBJECTIVE 1: FACTORS CONTRIBUTING TO STREAM TEMPERATURES[7]

Objective 1: Through the use of a mathematical model(s) and properly functioning condition (PFC) analyses, and other tools, assess the factors in the Burnt River basin that contribute to current stream temperatures.[4]

Approach: Reclamation gathered field data on water temperatures, streamflows and other environmental factors from 1997 through 1999, developed a computer model of a section of the main stem, and identified factors affecting stream water temperature.[3] OSU studied the relationship of vegetation, elevation, weather, and land use to stream temperature on four tributary streams and the main stem.[3]

Baseline Temperatures

Upper Watersheds

The 7-day average maximum daily stream temperatures for 1998 at the upper monitoring sites on the main stem and the North and South forks are shown below in Figure 2. Maximum water temperatures on the upper South Fork were generally cooler than on the upper North Fork and the upper main stem. The South Fork is a north facing basin and has significantly higher flows in the summer months than does the North Fork. Maximum temperatures on the main stem below Unity Dam are greatly affected by reservoir temperatures. They start out the summer cooler than the upper reaches of the tributaries, but end up warmer by summer's end.

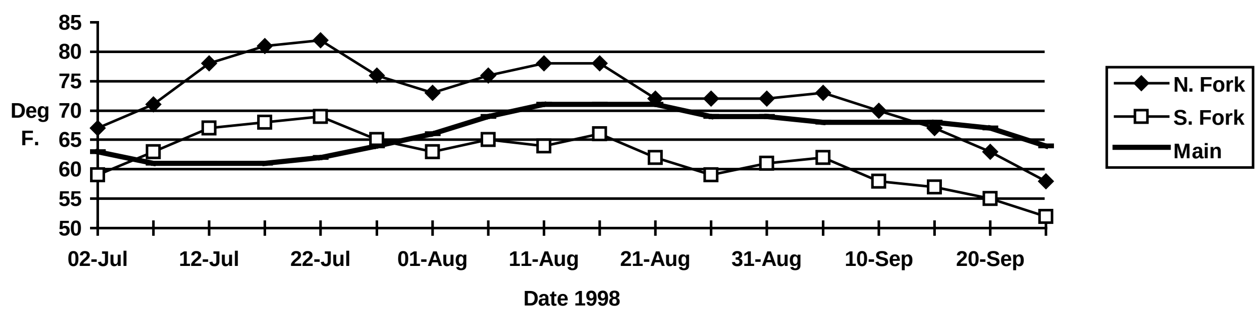

Figure 2. Seven-day Average Maximum Daily Stream Temperatures at Upper Monitoring Sites.[8]

Lower Watersheds

Seven-day average maximum daily stream temperatures for 1999 at the lower monitoring sites on the North and South forks and the station at the end of the modeled main stem reach are shown below in Figure 3. Seven-day average mean daily temperatures are shown in Figure 4. Maximum water temperatures on the South Fork were higher than those of the other two streams in early and late summer. Mean temperatures on the South Fork were lower than the other two streams during the middle of the summer. Maximum temperatures on the North Fork tended to be lower than the other two streams during those same periods.

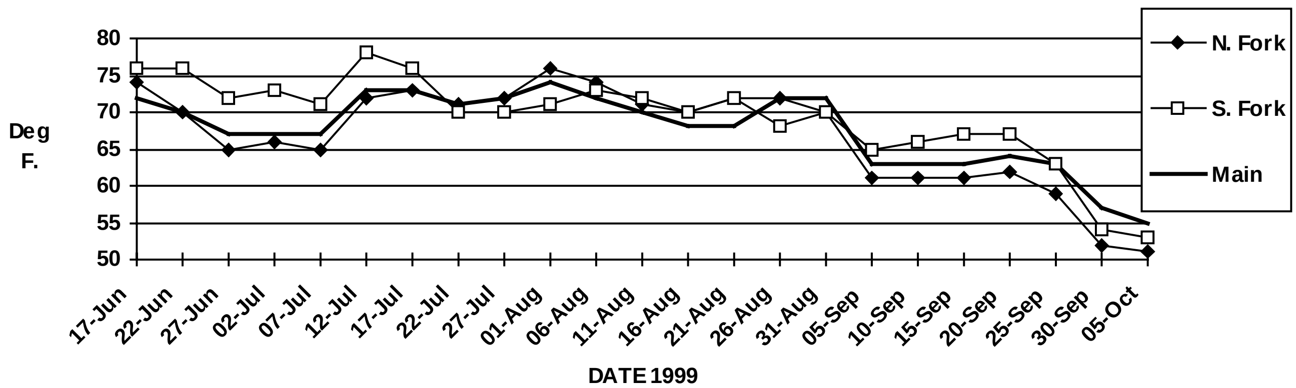

Figure 3. Seven-day Average Maximum Daily Stream Temperatures at Lower Monitoring Sites.[9]

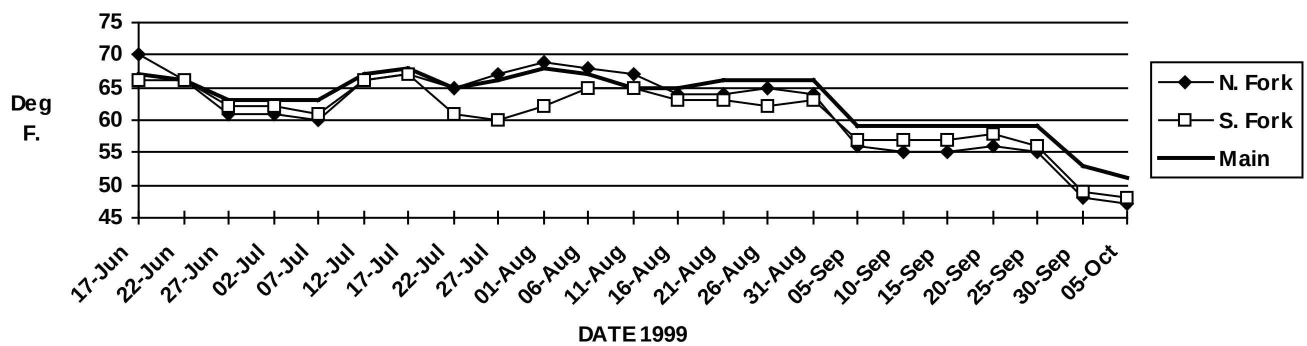

Figure 4. Seven-day Average Mean Daily Stream Temperatures at Lower Monitoring Sites.[10]

How Does Heat Energy Enter and Leave a Stream?

In December of 2000, Oregon's Independent Multidisciplinary Science Team (IMST) presented a stream temperature report to the governor. "The goal of the workshop was to review empirical evidence and to identify points of agreement, disagreement and knowledge gaps within the scientific community concerning the factors that influence stream temperature and fish responses to elevated temperatures."[11]

The IMST found that "[s]olar radiation is the principal source of energy that causes stream heating, and is the driver of many environmental factors that can influence stream temperature. At any given point and at any given time stream temperature is the result of a complex suite of environmental factors that transform solar energy and re-emit it as heat energy within the environment. The interactions and effects of these environmental factors are cumulative and complex, and vary by site, over time, and across regions."[12] The report did not go into detail on the physics of these complex factors, stating only that "[t]he net rate of gain (stream heating) or loss (stream cooling) as a stream moves through the environment is the algebraic sum of net radiation, evaporation, convection, conduction, and advection [groundwater inflow/outflow]."[13] Although there is general agreement on basic principles, there has been confusion over heat transfer processes, especially the transfer of heat between air and water and the role of long-wave radiation. This section describes the physics of heat transfer by utilizing actual Burnt River main stem data and presenting it in the context of the heat transfer processes listed in the IMST stream temperature report and a heat transfer diagram from DEQ's technical paper explaining the scientific basis for Oregon's stream temperature standard.[14]

Figure 5 shows that solar radiation (short-wave) and long-wave radiation (infrared) from the earth and the atmosphere are major sources of heat. Portions of the solar radiation are absorbed at the ground, reflected, or scattered in the atmosphere. Long-wave radiation from the atmosphere is absorbed by the ground or lost from the system and long-wave radiation from the earth is primarily absorbed by the atmosphere. Other heat transfer processes include evaporation and convection, but these processes transfer much less heat than radiation.

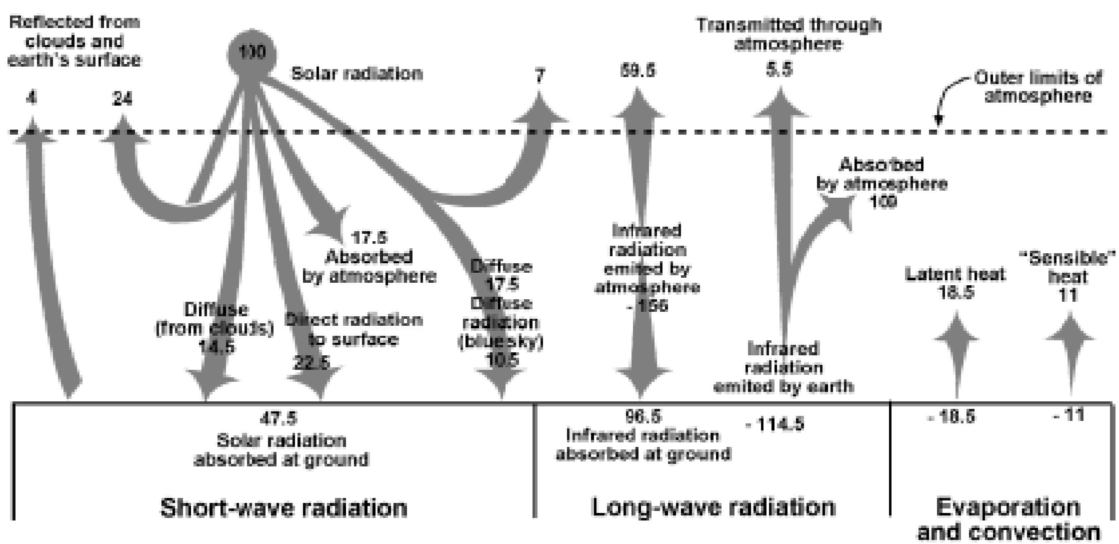

Figure 5. Budget of Radiation from the Sun, the Atmosphere, and the Ground.[15]

Reclamation and DEQ describe "…six processes [shown in Figure 6] that allow heat energy exchange between a stream and its environment: solar radiation, long-wave radiation, evaporation, convection, streambed conduction, and groundwater inflow/outflow."[16]

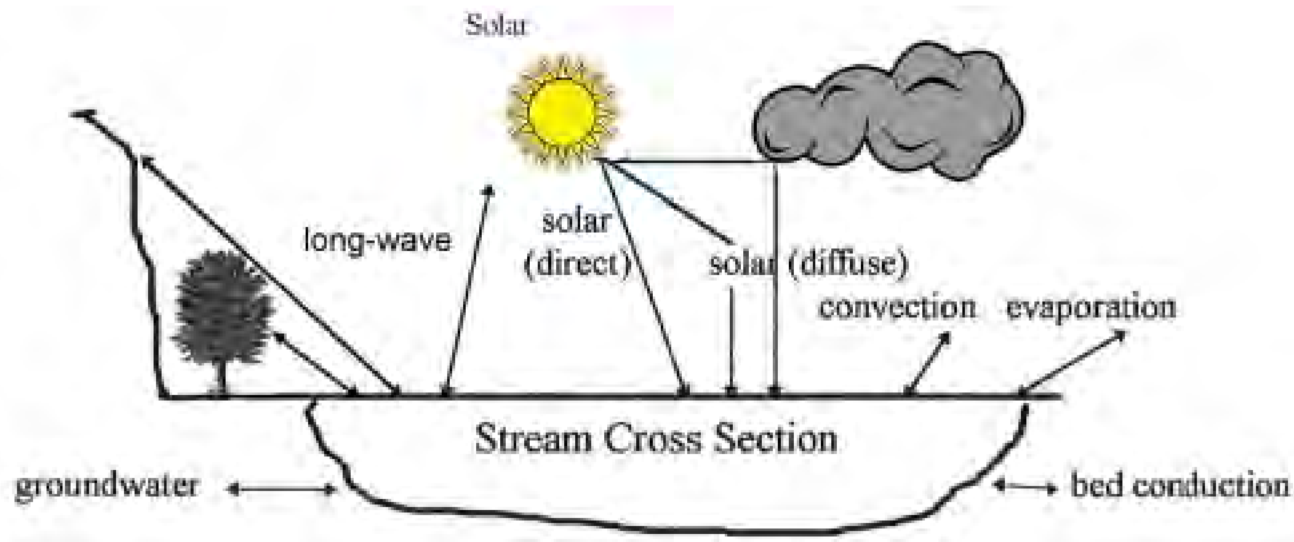

Figure 6. Processes that Involve the Transfer of Heat Energy.[17]

Radiation

The temperature of a stream depends upon the energy going into it and the energy coming out of it. Figures 7 and 8 below show energy processes that occurred in the lower Burnt River on a typical July day (July 10, 1999). Values were computed using weather station and stream temperature data and standard equations.[18] The analysis assumed 0 percent shade[19] and 1.5 percent cloud cover. Solar radiation was based on weather station data. Atmospheric radiation values were computed. With no shade and cloud cover they were largely a function of air temperature and relative humidity. Water radiation (a function of water temperature) was computed. Evaporation was computed based on measured wind speed, relative humidity, air temperature, and water temperature. Convection was computed based on measured wind speed, atmospheric pressure, water temperature, and air temperature.

As shown below in Figure 7, most of the heat transfer to and from a stream results from radiation. There are two forms – long-wave (infrared) and short-wave (visible and ultraviolet). Long-wave radiation transmits heat to the stream from the atmosphere, from riparian vegetation, and from topographic features such as canyon walls. Solar radiation transmits heat from the sun to the stream, either directly or from reflections off clouds. The stream surface emits long-wave radiation, cooling the stream while heating the surrounding environment.

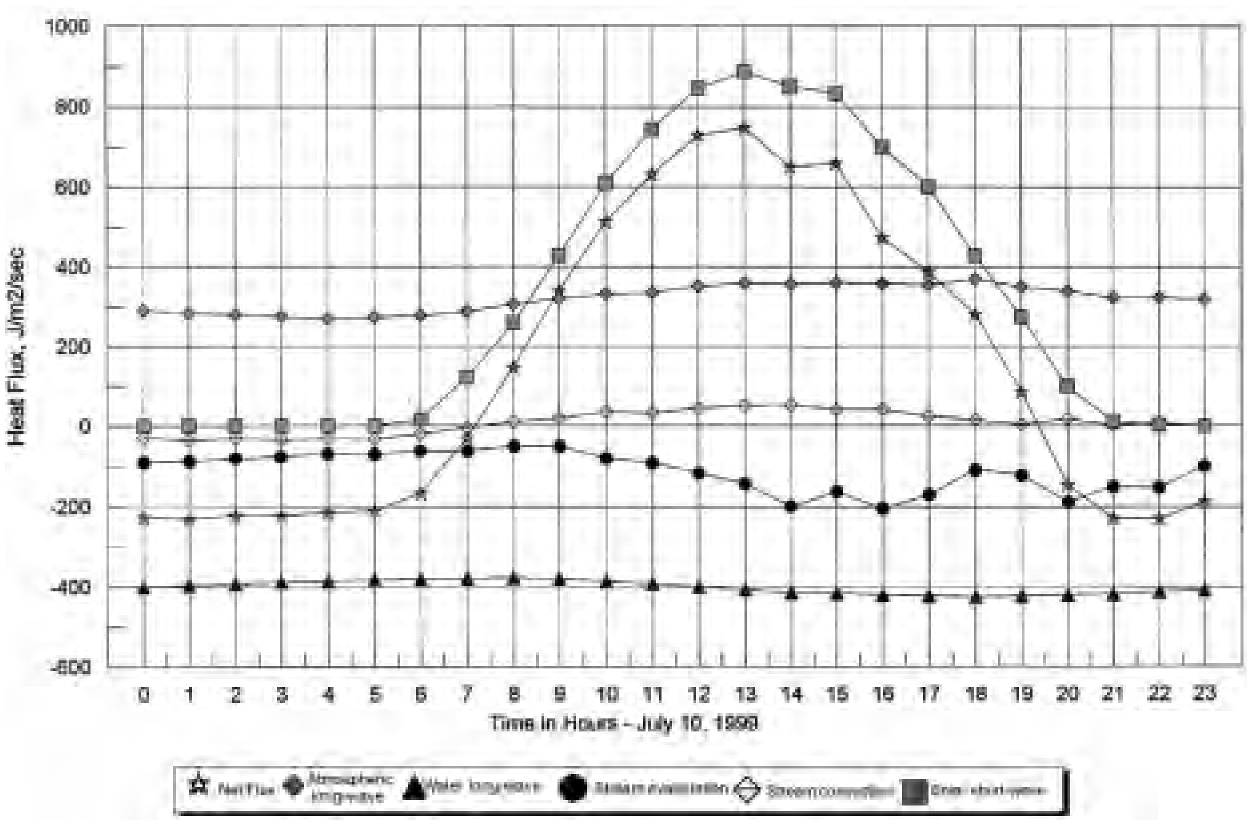

Figure 7. Energy Processes Occurring in the Lower Burnt River During One July Day.[20]

Figure 8 shows that combining heat gains and losses due to long-wave radiation obscures the fact that there is considerable loss of heat from the stream from water radiation and considerable heating from atmospheric radiation.

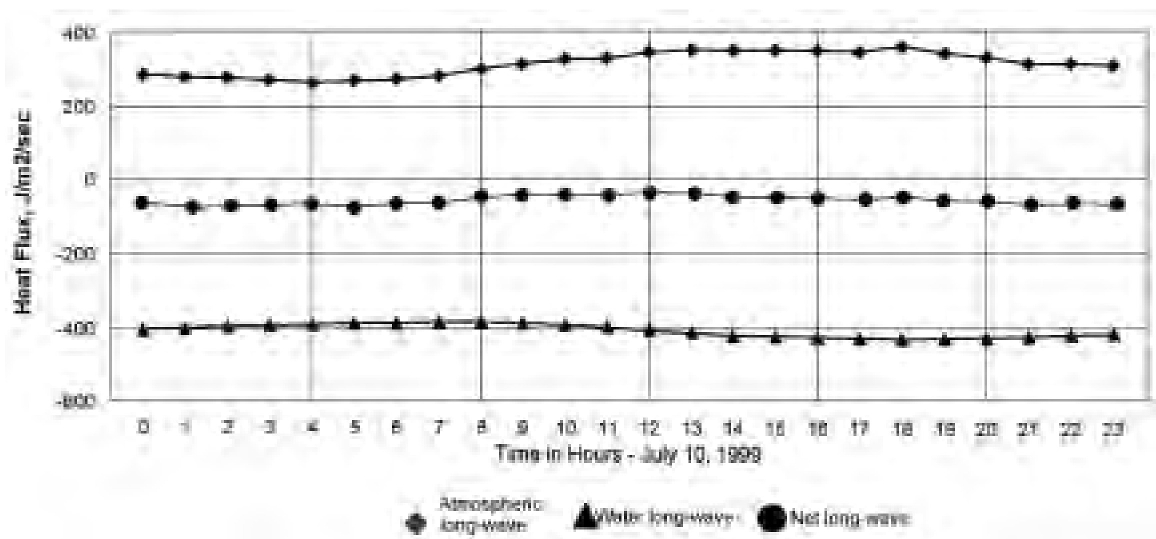

Figure 8. Long-wave Radiation in the Lower Burnt River During One July Day.[21]

Atmospheric Radiation

As shown in Figure 5, long-wave infrared radiation emitted by the atmosphere is the largest source of radiant energy absorbed at the Earth's surface – nearly double the amount of energy received directly from the sun (96.5 thermal units vs. 47.5). As the atmosphere becomes warmer, more heat energy is transmitted to a stream through long-wave radiation. Thus, air temperature is a significant factor in the heat load being imposed on a stream. Figure 7 shows that atmospheric radiation accounts for about half of the heat gained by the lower Burnt River during a July day.

Reclamation found a very high correlation[22] between air temperature and both mean and maximum daily water temperature. The correlation increased going downstream (0.5 downstream of Unity Reservoir to 0.9 at Huntington). This high correlation was expected because air and water are both heated by solar radiation and air temperature is a major component of atmospheric radiation. Reclamation used weather station data and a precise physical equation to determine the effects of atmospheric radiation. "The amount of atmospheric radiation entering a stream is affected by five factors: (1) air temperature (major factor), (2) vapor pressure which affects the emissivity, (3) cloud cover which converts short-wave solar radiation into long-wave radiation, (4) reflection of long-wave radiation at the water-air interface, and (5) the interception of long-wave radiation by riparian vegetation."[23]

Figure 7 shows that atmospheric long-wave radiation tends to be fairly constant, but rises during daylight hours. Reclamation's calculations of hourly heat fluxes showed that solar short-wave radiation was about 2.5 times as high as atmospheric long-wave radiation at its peak, but over a 24-hour period the average amount of heat gained from atmospheric radiation was about equal to the solar (345 joules/meter^2/second for solar radiation vs. 330 for atmospheric radiation).[18]

Modeling runs performed by Reclamation to specifically assess the independent impacts of air temperature showed main stem water temperatures would likely be between 3-4 °F cooler than average during unusually cool periods in the summer (one standard deviation below the mean), and 3-4 °F warmer than average during unusually warm periods (one standard deviation above the mean).[24]

Radiation from Riparian Vegetation and Topographic Features

Riparian vegetation blocks both solar and atmospheric radiation, although the vegetation itself will emit long-wave radiation. To assess sensitivity to shade, Reclamation estimated the hourly heat fluxes if the main stem could receive 50 percent shade.[25] [26] Under these conditions, the total long-wave radiation from the atmosphere and riparian vegetation would likely be about 15 percent higher than without the vegetation; the riparian vegetation accounted for about 55 percent of the total radiation. However, these increases were estimated to be more than offset by a 50 percent reduction in solar radiation reaching the stream, leaving the stream temperature lower as a result of the increased vegetation.

The Burnt River Canyon has high walls that provide shade, and has good riparian vegetation; yet, stream temperatures rise more in this river reach than elsewhere. The heating in the canyon appears to be largely due to heat transfer from the rocks (long-wave radiation) and high air temperatures.

Solar Radiation

If you stand in the sun, you get warmer than if you are in the shade. A stream is no different. Previous studies have found that: (1) stream temperatures increase with removal of streamside vegetation;[27] (2) shade reduces stream heating in small (low flow) forested streams by reducing the amount of direct solar radiation;[28] (3) removal of riparian vegetation has only a modest effect on mean stream temperature since the energy gained from the increased solar radiation is partially offset by the increased energy loss by radiation to the sky;[29] and (4) shading is associated with significant differences in daily maximum air temperatures.[30]

Supplemental modeling runs[31] were performed by Reclamation to specifically assess the independent impacts of solar radiation. These showed that the mean main stem water temperatures would likely be between 2-3 °F cooler than average during cloudy periods (solar radiation one standard deviation below the mean) in the summer, and 2-3 °F warmer than average during clear periods (solar radiation one standard deviation above the mean). Maximum water temperatures were predicted to be about 4 °F cooler than average during cloudy periods.[32]

Water Radiation

Figure 5 above shows that long-wave radiation is the largest source of energy emitted from the earth's surface. Figure 7 above shows that more energy is lost to the atmosphere through long-wave water radiation than is gained through long-wave atmospheric radiation.

Evaporation

As the motion of water molecules increases in response to increased heat energy they begin to overcome the molecular attraction to liquid water, causing more molecules to escape as water vapor and releasing heat in the process. Wind assists evaporation by removing escaping water molecules before they are forced back into the water surface. Figure 7 above shows that a great deal of evaporative cooling took place on the Burnt River on July 10, 1999. The cooling picked up along with the wind during the heat of the day and then subsided in the evening hours. On July 14 the average wind speed was 2.8 miles per hour (mph) instead of the 1 mph observed on the 10th, and the evaporative cooling was twice as great, averaging 228 joules/meter^2/second.[33] Shaded streams tend to have less evaporative cooling because they heat less and have less wind exposure; however, no attempt was made to measure these effects in the Burnt River.

Convection and Conduction

In conduction, heat is transferred from molecule to neighboring molecule with no mass motion of the air or water being involved. Convection is the process of transfer of heat from one place to another by the actual mass motion of heated water or air from one place to the other.[34] Although a great deal of heat can be transferred between air and water through radiation, relatively little is transferred through convection since the thermal conductivity of air is very poor. Figure 7 shows only a small amount of heat is transferred by convection between air and water. Convection added an average of about 27 joules/meter^2/second to the main stem near Durkee during the day. At night, the stream lost an average of about 24 joules/meter^2/second back to the air. Over ten times more heat was transmitted from the air to the river by long-wave radiation (an average of 322 joules/meter^2/second) than by convection (see Figure 7 above).

Streambed Conduction

The Oregon DEQ[35] has suggested that unshaded shallow streams tend to receive some heat energy from streambed conduction during summer days. To the extent that a streambed contains a greater amount of solid rock, the heat release would be slower. No attempt was made to measure heat transfer through bed conduction in the Burnt River.

In contrast, data from the Wallowa-Whitman National Forest soil survey program indicates that the heat flux from streambed to stream during the summer will change as the stream flows toward the mouth. In the headwaters, the streambed is often warmer than the water; whereas in the lower elevation areas, the streambed is cooler than the stream. Streambeds along the reach modeled by Reclamation (Unity Reservoir to Bridgeport; 3700 to 3400 feet elevation) would be about 10 °F cooler than maximum daily water temperatures during the summer and about in equilibrium with nighttime temperatures.[36]

Groundwater

Previous studies have found that: (1) stream systems that receive a large influx of groundwater exhibit a high degree of thermal constancy;[37] (2) groundwater influx can have a depressing effect on stream temperature;[38] (3) groundwater temperatures are normally within 2 °F of the mean annual air temperature;[39] and (4) groundwater is warmer at lower elevations.[35]

Reclamation found that periodic decreases in stream temperatures in the South Fork between Whited and Unity Reservoirs are likely due to subsurface return flows from irrigation. Reclamation also found that stream temperatures in the main stem increased in the downstream direction from the dam during the first part of the irrigation season when most of the return flows are warm surface flows and groundwater return flows are limited. In the late part of the irrigation season more of the return flow is cool groundwater and the temperature profile flip flops with stream temperatures decreasing in the downstream direction. Modeling runs suggested that if these late-season sub-surface return flows were reduced through increased irrigation efficiencies, stream temperatures would increase.

Stream Characteristics Important to Temperature

Elevation

Elevation has been defined by the IMST as one of eight factors affecting stream temperature.[40] The thermal environment is warmer at lower elevations. Groundwater inputs are warmer and more heat is transferred to the stream from the warmer air (primarily through radiation). Air, soil, and water temperatures in the Burnt River subbasin increase about 2 °F for each 500 foot drop in elevation.[41]

Aspect

The tributaries that drain north facing basins, including the South Fork, Camp Creek, and Clarks Creek, normally have higher base flows and lower stream temperatures during the spring and summer months than south facing basins such as the North Fork and Pritchard Creek.

Topographic Features

The Burnt River heats up considerably as it goes through the Burnt River Canyon. The canyon has high walls that provide shade and good riparian vegetation, even though the USFS and BLM permit livestock grazing in the canyon. However, stream temperatures rise more in this river reach than elsewhere on the Burnt River. This heating appears to be largely due to heat radiating from the rocky canyon walls and high air temperatures and perhaps also due in part to the relative absence of subsurface flows into the river.

Flow

As flow rate decreases, the volume of water that is involved in the heat energy balance is reduced but heating processes remain relatively unchanged. The result is that during heating periods the stream tends to accumulate more energy per unit volume. The daily fluctuation of temperature in a low volume stream such as the North Fork in summer will be far greater than that of a large volume stream.[42]

Reclamation found that the North Fork has flows of only 1-3 cfs at the lower gauging station during the summer and often has stream temperatures in excess of 80 ºF. The South Fork, with flows of 15-30 cfs at the forest boundary, tends to run cooler than the North Fork.

Channel Width and Depth

As the width of a stream channel increases, so does its surface area, increasing the amount of heat energy exchange that occurs between the stream and its environment. If flow remains constant, stream widening results in reduced channel depth. A shallower depth may allow solar energy to strike the streambed and increase streambed conduction. In sensitivity tests, Reclamation modeled a main stem channel 30 percent narrower than the present channel[43] and predicted that the narrowing would result in about a 2 °F decrease in summer stream temperatures.

The highest summer sun angle in Oregon is roughly 70 ºF.[44] On some reaches of narrow east-west oriented tributary streams riparian vegetation will block solar radiation throughout the entire day. If the angle from the top of the canopy to the opposite bank is less than 70, solar radiation will reach the stream during part of the day. Reclamation surveyed 10 river cross sections in the modeled reach from the Unity Dam to the canyon and found the main stem (shown in Figure 9 below) to average about 40 feet in width. The soils and channel type along much of the main stem will support natural growth of willows ranging from 5-15 feet in height.[45] "Cottonwood would be unlikely to occur naturally within the Hereford [modeled] reach of the river."[46] [47] Even if sections of the main stem contained dense willow stands in riparian areas they would receive solar radiation whenever the sun elevation is greater than 30 degrees, and (as shown in Figure 9) only about 11 percent of the 40 foot width of the modeled reach of the Burnt River would be shaded at the highest summer sun angle.

Figure 9. Vegetation Shade Angle.

Vegetative Shade

The Reclamation study found that the most heavily shaded section of the North Fork displayed lower diurnal swings than the other sections even though it had very low water volume. Reclamation used model sensitivity runs to assess the effects of <u>theoretical shade percentages</u> on the main stem. Global shade values of 15 percent were predicted to decrease temperatures up to 2 °F. Most participants felt that given the present stream width and soil conditions, shade values beyond that level were unlikely. Many participants felt that 15 percent was beyond the current resource capability. Some felt that if taller species could be propagated in the study reach and the stream narrowed through riparian improvements, higher shade values could be attained. The highest theoretical value for shade studied by Reclamation was 50 percent. The model sensitivity run using 50 percent shade predicted a drop in mean stream temperature of about 4 °F and a drop in maximum temperature of about 5.5 °F.

Reservoirs

Without Unity Reservoir, the stream flows in the Burnt River during the summer and fall months would be much lower (10-15 cfs vs. 90-130 cfs) than currently exists. Higher flows slow the warming process. Larger stream flows (larger water volumes) take longer to increase in temperature than smaller flows.

Figure 10 below displays the measured 1999 mean daily 7-day average stream temperatures for the lower South Fork before it flows into Unity Reservoir and measurements for the main stem immediately below Unity Dam. Figure 10 indicates that the outflow from the reservoir is cooler than the inflow in the early part of the irrigation season and is warmer than the inflow later on in the year. The inflow temperatures for the North Fork are not shown in Figure 10 because its flows just above the reservoir are very small and their temperatures are unknown.

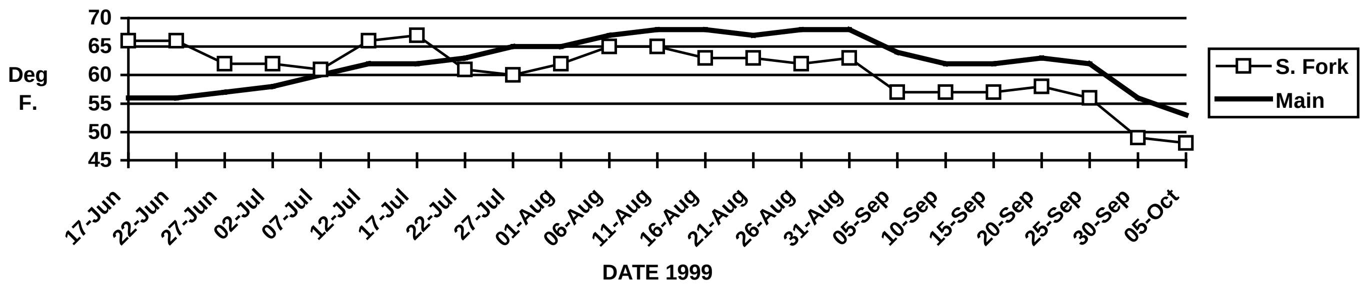

Figure 10. Unity Reservoir Inflow and Outflow – 7-day Average Mean Daily Stream Temperatures[48]

Figure 11 below displays the measured 1999 maximum daily 7-day average stream temperatures for the lower South Fork and the main stem immediately below Unity Dam. Figure 11 indicates that the outflow from the reservoir generally has lower maximum daily temperatures than the inflows from the South Fork for most of the irrigation season. In late September and beyond, the temperatures of the inflows are less than the outflows from the reservoir, reflecting cooler air temperatures and shorter day heating periods.

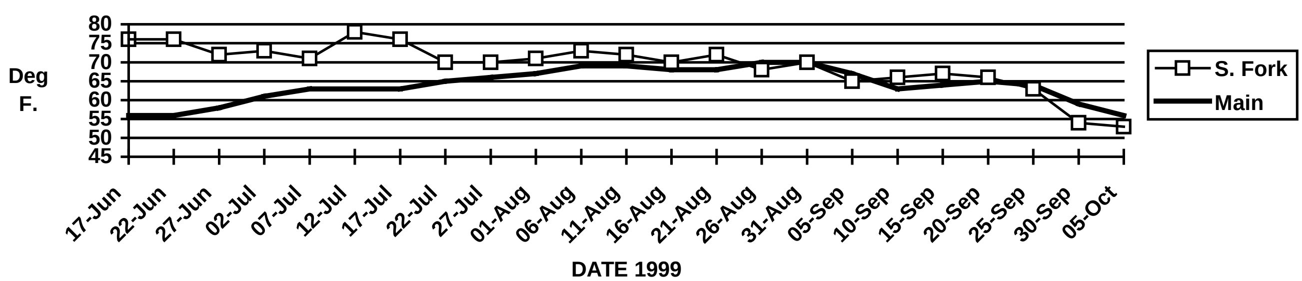

Figure 11. Unity Reservoir Inflow and Outflow – 7-day Average Maximum Daily Stream Temperatures[49]

The diurnal temperature fluctuation of the river for several miles below Unity Reservoir is smaller than in the river farther downstream. The effects of the reservoir on temperature and diurnal fluctuations are seen most strongly in the first 5 miles below the reservoir. The effects largely disappear 10 miles below the reservoir.

The irrigation facilities on the South Fork above Unity Reservoir significantly alter stream temperature conditions. The passage of water through Whited Reservoir on the South Fork increases the mean daily stream temperature by as much as 10 °F until the outlet gates are opened in late July or August. During this early part of the irrigation season, flow downstream consists of the warmer water from the top of the reservoir (flow over the spillway). Later, cooler water from the bottom of the reservoir is released causing a large decrease in temperature below the reservoir. Both Whited and Unity reservoirs are somewhat stratified during the irrigation season in terms of water temperature and there can be a significant difference in water temperatures whether water is taken off the top (usually the case at Whited), or the bottom (e.g. Unity) in certain periods during the irrigation season. Since all of the flow in the lower South Fork is diverted for irrigation, the South Fork flow into Unity Reservoir is essentially all irrigation return flows (both surface and subsurface) that are generally cooler than the surface water in the South Fork, especially during the latter part of the irrigation season.

Summary

Processes that Involve the Transfer of Heat Energy

There are six processes that allow heat energy exchange between a stream and its environment: solar radiation, long-wave radiation, evaporation, convection, streambed conduction, and groundwater inflow/outflow. Of these, radiation is by far the most significant.

Solar Radiation

In the summer the main stem Burnt River gains almost all of its heat from radiation, with about half of the gain coming from solar radiation and about half coming from atmospheric radiation. Anything that reduces the amount of a stream that is exposed to solar radiation (vegetation, clouds, topographic features, reduction in width, etc.) will reduce the amount of heat added.

Atmospheric Radiation

There has been confusion over how heat is transferred between air and water. On a typical July day, some heat is transferred to the Burnt River by convection, but over ten times more heat is transmitted from the air to the river by atmospheric radiation than by convection. About half of the heat gained by the river in the summer comes from atmospheric radiation.

Cooling Processes

Heat loss occurs primarily through long-wave radiation from the water back to the atmosphere. Evaporative cooling produces significant heat loss, especially during warm and windy periods.

Groundwater, primarily from irrigation return flows, contributes to cooling the main stem in the late part of the irrigation season.

Stream Characteristics Important to Temperature

Seven stream characteristics were identified as being important to temperature: elevation, aspect, topographic features, flow, channel width and depth, vegetative shade, and reservoirs.

The thermal environment is warmer at lower elevations. Groundwater inputs are warmer and more heat is transferred to streams from warmer air. Air, soil, and water temperatures in the Burnt River subbasin increase about 1 °F for each 250 foot drop in elevation.

Aspect, stream width, and vegetation affect the amount of solar radiation that streams receive. Burnt River tributaries draining north facing basins tend to have higher base flows and lower stream temperatures during the spring and summer than south facing basins. The width of the main stem (average 40 feet) makes it difficult to shade, especially with the predominant native willow species that grow to no more than 15 feet in height. The most heavily shaded section of the North Fork displays lower diurnal swings than other sections. Model runs showed that increasing shade on the main stem would lower stream temperatures, with the greatest effect being on maximum temperatures.

Reservoirs have a significant effect on stream temperatures in the Burnt River. Higher summer flows with Unity Reservoir (90-130 cfs vs. 10-15 cfs without the reservoir) slow the warming process, but outflows are warmer than inflows in August and September. When water is taken off the top of Whited Reservoir, mean daily stream temperatures on the South Fork increase by as much as 10 °F until outlet gates are opened in July or August and cooler water is released from the bottom.

OBJECTIVE 2: TEMPERATURE MANAGEMENT ALTERNATIVES

Objective 2: Utilize the results of Objective 1 to identify and evaluate management practices that might be employed to reduce current temperatures in the Burnt River basin.[4]

Methodology

Reclamation used their calibrated stream temperature computer model[6] to evaluate effects of management practices on the Burnt River reach from Unity Dam to the confluence with Clarks Creek at the head of the Burnt River Canyon. Findings should not be generalized to any other part of the subbasin.

Shade

Site Capability

The main problem with shading the main stem appears to be the average width (about 40 feet) of the channel. The amount of shade is a function of the type of riparian species, how high they grow, where they grow, their density, and their distance from the channel.

Vegetation

Site capability work was performed by OSU[50] with the assistance of the NRCS and peer reviewed by Forest Service and BLM experts agreed to by study participants. The NRCS developed an ecological site description (Willow Riparian) that applies to most of the riparian areas downstream of Unity dam except for a few cottonwood sites below the reach modeled by Reclamation. The overstory of the historic climax plant community in these areas was willows with unknown understory. Many of these areas have been invaded to varying degrees by reed canary grass.

Willows likely would grow in soils and channel types that were normally colonized by the various willow species. It was assumed that the willows would grow 5 feet from the water edge for the majority of the summer, and only grow in alluvial deposits, comprising about one-sixth of a typical river reach. Willows were estimated to average between 5 and 15 feet in height (only the taller height was used in shade computations). In her peer review, Crowe[51] observed that the "vegetation heights are probably higher than the average of even the tallest individuals in populations of these shrub species."[52]

Crowe felt that "[c]ottonwood would be unlikely to occur naturally within the Hereford [modeled] reach of the river."[53] The site capability work did not argue that taller species such as cottonwood could not be grown in areas that are described as willow communities. In a peer review of the site capability work, Leonard[54] pointed out that "[c]ottonwoods may grow in this segment if planted, but it is highly unlikely that there would be recruitment from seed."[55]

The DEQ has pointed out that taller non-native species have been planted in the study reach and survived, and that restoration could be focused on passive regeneration of native vegetation or it could include active planting of willows, cottonwood, or other taller species.

Channel

The site capability work did not address channel changes and their potential effects on shade. Channel changes could affect the distribution of willows and reed canary grass. Crowe suggested that if the stream evolves to more of an E-type channel morphology, the willow stand remnants would be right on the streambank and would provide more shade to the stream.[56] However, she also wondered if movement toward an E-type channel might lead to the reduction of the area available for woody species establishment given the abundance and aggressiveness of reed canary grass in the riparian system. She observed that if the channel is or becomes more of a C-type, areas other than alluvial bars might be potential sites for shrub establishment unless they are too heavily dominated by reed canary grass. Crowe[57] pointed out that gravel transportation and sedimentation has an effect on vegetation and wondered if a decrease in the amount of gravel being transported in the river was contributing to a decline in willow populations.

Crowe[52] and others have wondered if there is a chance that the river is wider than it was before settlement of the valley, and if there is a chance that it could become narrower in the future with changes of management in the riparian areas. Some sections of the river that have been straightened are wider than unstraightened sections. As pointed out above in the discussion of width and depth, a narrower channel would lead to increased shade.

Reclamation Findings

Reclamation investigated the effects of achieving shade potential in the river reach from the Unity Dam to the canyon entrance. Their initial modeling runs were based on estimates of the maximum amount of shade attainable under existing soil and stream conditions provided by OSU.[58] These estimates considered the combined tree, shrub, grass, and bank shade components. The estimates were made for each modeling reach and ranged from 2.8 to 6 percent shade. Shade estimates were based upon the average amount of stream area covered by shadow at the hours of 10:00, 11:00, 12:00, 1:00 and 2:00. In their final report, Reclamation estimated that increasing shade to these levels would have a very slight cooling effect on the stream. The largest difference projected in instream temperatures would be about 0.5 °F for maximum daily temperature at the lowest validation station. The shade effects would be more pronounced at the downstream stations, and would affect the maximum daily water temperatures more than the mean daily water temperatures.

A participant review of the above methodology highlighted the fact that this was a different approach to shade estimates from the effective shade methodology employed by the DEQ. In an effort to provide more consistency, OSU provided new shade estimates[59] to Reclamation for June, July, and August based on taking an average of estimated shade at each hour of the day from 7 a.m. to 5 p.m. The new estimates of average shade were 5.9 percent for June, 6.6 percent for July, and 8.2 percent for August (compared to the 3.6 percent average used in Reclamation's final report).[60] Increasing the estimate of attainable shade from 3.6 percent to 8.2 percent for August led to an estimated decrease of 1.2 °F in maximum daily stream temperature at the lowest validation station as opposed to the earlier projection of a 0.5 °F decrease.[61] The changes would be less for June and July when the sun angle would be higher.

No assessments were done on headwater streams where shade potential would be much greater, nor on the lower reaches of the river that are dominated by midstory shrubs with a very minor cottonwood component.

Irrigation Operations

Reclamation simulated a number of irrigation efficiencies and found that increasing irrigation efficiencies would likely cause stream temperatures to decrease somewhat until about the middle of July, and then warm through the remainder of the irrigation season. In the early part of the irrigation season most of the return flows are warm surface flows. Increasing efficiencies would reduce these flows, lowering stream temperatures. However, reduction in early season recharge of the shallow aquifer could reduce cool late-season groundwater returns. In the later part of the irrigation season more of the return flow is cool groundwater. Increasing efficiencies during this part of the year would decrease cool subsurface return flows, raising stream temperatures. Projected August temperature increases were as high as 2 °F at the site furthest downstream from the Unity Dam. Decreased irrigation efficiencies would tend to lower stream temperatures in late July and August. However, if irrigation efficiencies become too low, there could be an increase in overland return flows leading to higher stream temperatures.

Combining Shade Improvements with Irrigation Efficiency

Reclamation modeled the effects on the upper main stem of combining a 3-6 percent shade increase with an increase of irrigation efficiency from 55 to 70 percent. This combination would likely result in a minor cooling (a maximum of about 1 °F) from Unity dam to Pine Creek. However, in the reach from Pine Creek to the canyon this combination would likely lead to a slight increase in stream temperatures. Adding shade to the simulation would result in reducing stream heating, while increasing irrigation efficiency would lead to an increase in stream temperatures through a reduction in subsurface return flows. Thus, the two options appear to act against each other resulting in very minor stream temperature changes.

OBJECTIVE 3: DEVELOP AND TEST A SURROGATE

Objective 3: Develop and test a concept using riparian and stream characteristics as a surrogate for temperature goals.[4]

Rationale for a Surrogate

One of the objectives of the Burnt River study was to develop a surrogate for the 64 °F criterion[62] in Oregon's water temperature standard.[63] Not meeting the criterion brings about a process that leads to regulation under a water quality management plan. Although the standard can be satisfied without attaining the 64 ºF criterion,[64] many have felt that water quality planning would proceed more smoothly if less attention was given to the criterion and more attention was given to the environmental factors related to temperature. If a surrogate based on desired stream and riparian conditions could be developed, the criterion could be used only to start the planning process and then the focus could shift from achieving the criterion to achieving the field conditions described in the surrogate. This would change the focus from goals that might not be achieved to ones that could be achieved. For example, in the Burnt River, it may not be possible to achieve the 64 °F criterion in all reaches at all times, but it should be possible to achieve the field conditions described in a surrogate.

Ideally, a surrogate would identify conditions that landowners could easily see as problems, and then come up with their own solutions. Advocates of this approach feel that this changed focus would likely receive more support and cooperation from landowners. Surrogates could form the basis of the temperature portion of 1010 plans, and could provide the framework for monitoring plans with which to measure progress. This kind of approach might also more clearly show that certain problems were not the fault of specific landowners.

When the Burnt River study began, some participants felt a surrogate could eventually form the basis of an alternative standard (sometimes referred to as a healthy streams standard), but that has not been a study goal.[65]

Two approaches to a surrogate were discussed: a surrogate that would reflect the temperature standard, and one that would describe the conditions of a healthy stream. It was felt that the latter approach should be considered because the present temperature criterion is in essence already a surrogate for a healthy stream.

Temperature Surrogate

The majority of participants felt that a surrogate could be developed around a description of desired riparian and stream characteristics that could be used as objectives in improving stream temperatures. If those factors are brought to as good a condition as they are capable of achieving, then summer stream temperatures should be as low as can be expected. Most study participants were looking for a simple tool that would show whether or not a stream was functioning as it should. Participants were largely in agreement on the concept of a temperature surrogate, but were unable to develop a process for testing these concepts on the ground.

Definition

Although there was no consensus on a definition, a surrogate was generally perceived as a set of environmental parameters that can be managed to improve water temperature. Much of the discussion involved a perception of surrogates as having two basic elements: (1) components of the major environmental factors that affect temperature, and (2) the process by which goals are set and progress measured.

Components

Component categories (vegetation, flow, and channel morphology) had been defined through the work on the first two study objectives and were generally agreed to. Visions of a healthy stream from a temperature perspective usually included unconstrained riparian vegetation, good surface and groundwater flows, a narrow channel, and a stream that is connected to the flood plain, all determined and based on the site potential. However, participants could not agree on specifics.

There was discussion of a vegetation component related to ecological site descriptions developed by the NRCS. It was agreed that vegetation components affected by management include the establishment, recruitment, and maintenance of vegetation appropriate to existing site conditions.[66] Flow components discussed included stream flows, irrigation return flows (both surface and subsurface), groundwater flows, and factors affecting a watershed's capability to store and release water. Channel structural features affecting stream temperatures discussed included bank stability and improved width/depth ratios, where there is potential to do so. The possibility of including thermal refugia as a surrogate component was discussed but not pursued. The participants recognized that component values will vary across years within climates.

Process

Although participants reached no consensus, they did discuss defining each surrogate component in terms of a process by which goals could be set and progress measured. The following potential elements were identified: (1) existing condition, (2) site potential (the physical maximum that a resource is capable of achieving), (3) inhibiting factors, (4) goals or desired future conditions, based on resource capability (what can be achieved given identified inhibiting factors), (5) prohibited conditions, (6) a monitoring program, and (7) progress assessment and review.

The OSU Rangeland Resources Department developed an estimate of vegetative site potential in their work on Objective 2, and NRCS personnel made a similar independent analysis, but participants did not agree on their findings. In general, participants were not comfortable with determining site potential or defining specific goals. To get around some of these problems, some felt that a surrogate could be defined in terms of improvement in stream characteristics, but no attempt was made to develop that approach.

Healthy Streams Surrogate

Some participants felt that the 64 °F criterion was itself a surrogate and had been developed partly because it can be objectively measured. Some felt that a more appropriate approach would be to develop a surrogate around healthy stream concepts instead of just temperature.[67]

Considerations

The purpose of the temperature standard is to protect aquatic life, but from a fishery perspective the temperature focus can lead to overlooking other factors that could benefit fish. Some of the environmental representative's felt that what was really needed was a healthy stream for aquatic life, not just a low temperature. In the Burnt River below the dam, some felt that through focusing on the 64 °F criterion, minor improvements in temperature might be made with perhaps no effect on the fishery. If the focus were expanded, a better understanding of what could be done to protect the fishery might be obtained.

Another disadvantage of the temperature criterion is that landowners tend to identify less with temperature concerns (especially when they feel that targets can't be achieved) than with the concept of a healthy stream. A focus on a healthy stream instead of just temperature might yield more landowner support and help them better identify problems so they could develop their own solutions.

There was some brief debate over what constitutes a healthy or fully functioning stream, a stream that optimizes resources for fish, for agriculture, or for fish and agriculture. However, most participants felt that a healthy stream surrogate would probably look similar to a temperature surrogate because things that help stream temperature constitute most of the components of a healthy stream.

Possible Additional Components

There was some discussion of adding additional components to a healthy streams surrogate.

Relating Stream Conditions to Aquatic Life

Some participants wanted to help define a healthy stream by doing a survey of aquatic life and linking the findings to various stream and riparian states. For example, do fish fare better under banks lined with willows or canary grass? But there was insufficient support for a survey.

Biological Factors

Adding other factors, such as macroinvertebrates, into a healthy streams effort was also discussed, but adding biological factors to the mix would likely be beyond the State's funding capability as well as landowners' endurance and good will.

A proposal from a group of northwest Forest Service and BLM scientists attempting to develop a biological analog to Properly Functioning Condition (PFC) was discussed. They had suggested two types of assessments: a level 1 assessment that would focus generally on physical factors and a level 2 assessment that would provide more detailed habitat mapping, macroinvertebrate sampling, and assessments of fish communities. Level 2 assessments were suggested only for high-priority streams. The Burnt River study participants concluded that fortunately physical factors related to temperature are also strongly linked to biological factors and can be used to predict the biological factors, and that most streams that are physically healthy are also biologically healthy.

Conclusions

Most participants concluded that although a healthy stream was desirable, defining it and measuring it was very complex and that surrogate development should probably be limited to the physical conditions of streams and riparian areas.

OBJECTIVE 4: 1010 PLAN

Objective 4: Use the results of Objectives 1 through 3 as a basis for development of a SB 1010 plan[2] by the Oregon Department of Agriculture. This plan will be submitted to EPA[68] via DEQ as part of the Burnt River TMDL[69] for removal of the river from the 303(d)[70] list.[4]

Approach: ODA, with the assistance from the Burnt River Technical Committee, will evaluate the work done under the first three objectives in developing a management plan. The plan will be submitted to EPA as part of the TMDL for the Burnt River, and upon EPA's approval, the river will be removed from the 303(d) list.[4]

Conservation Activities

The Burnt River has a long history of having a very active SWCD (Soil and Water Conservation District) that has initiated a great number of successful conservation projects. However, some of the past accepted practices, such as channeling, are now recognized as being detrimental to bank and channel stability, and flood plain connectivity.

Much of the Burnt River is now covered by CRMPs (Conservation Resource Management Plans). These have helped coordinate proposed and ongoing conservation projects and have made local landowners aware of problems in the basin and on their own property. Most landowners were present when the PFC assessment (Properly Functioning Condition) was done on their property as part of the OSU Range Department's portion of the Burnt River study, thus gaining additional understanding of the riparian conditions.

Implementation Problems

During the course of the Burnt River study, landowners have expressed considerable frustration with the implementation of Oregon's standard for stream temperature. The Burnt River study participants felt that making policy suggestions would be inappropriate, but that a summary of the problems encountered may be useful to others who are trying to make the process more effective.

With the involvement local landowners have had in the Reclamation and OSU studies (several served on the Technical Committee) most do not see high stream temperatures as a significant man-caused problem in the Burnt River subbasin.

Three types of problems have been encountered: process, scientific disagreements, and socioeconomic.

Process

Although most landowners are now well-informed of the TMDL and 1010 processes, some of their initial reluctance to address stream temperatures was due to a lack of understanding of the temperature standard and the processes related to it. Some felt that the standard called for all streams in the state to be cooled to 64 °F whether or not that was physically possible. It was sometimes felt that if the 64 °F criterion can't be achieved it is fruitless to make changes solely to improve temperature. Some feel that if they are having a net positive effect on temperatures it's not necessary for them to make additional improvements in temperature.

Many landowners initially did not understand that there are two parts to the temperature standard. In addition to the numeric standard, there is also a narrative standard. The narrative standard provides for a plan to be developed that identifies the reasonable means to address human-caused impacts to water temperature. The 1010 plan meets the requirements of the narrative standard and is recognized as agriculture's contribution to the Burnt River TMDL.

The Burnt River TMDL will be developed similarly to those in other basins. The regulatory portion of the Burnt River 1010 plan for agricultural and rural lands will take into consideration what can be accomplished on the ground given the diversity of conditions. Thus, the goals of the Burnt River TMDL and the 1010 plan are the same with the 1010 plan focusing on how to get to what is reasonable given practical, economic, and social considerations.

Scientific Disagreements

Most environmental interests feel that vegetative shade is the most important factor in lowering stream temperatures. Many Burnt River landowners are not convinced of the importance of vegetative shade and feel that air temperature and other environmental factors have a greater influence, often rendering attempts at lowering stream temperatures with shade ineffective, especially at lower elevations. Landowners believe that main stem flows are cooler with Unity Reservoir (because of greater volume) than they would be without it. However, with extremely low inflow the reservoir is in essence a stagnant pool during the summer with releases (from the bottom of the pool) often exceeding 70 ºF. Most landowners believe that these summertime releases are the primary contributor to main stem temperatures that exceed the temperature standard. They also believe the primary problem on the North Fork is nearly nonexistent flows during the summertime.

Most in the environmental community feel that if mistakes are to be made, one should err on the side of assuming too much potential initially, so as to achieve as much as possible. Some Burnt River landowners fear that when the TMDL is developed for the Burnt River, inhibiting factors will not be taken into account when making estimates of site potential for vegetation and shade. If that happens, they feel that one unachievable goal (the 64 °F criterion) will be replaced by another – goals for vegetation will be developed that are just as impossible to reach as the goals for temperature.

Socioeconomic

Some landowners feel that they are assumed to be guilty of degrading water quality until proven innocent, and the burden of proof rests with them. They feel that they are being told what to do instead of having the freedom of finding their own solutions. They also perceive that they are being asked to achieve a goal that can never be attained, and once they give in to that process they put their financial livelihoods at risk

Use of Surrogates

Although the Burnt River participants could not agree on a temperature surrogate for the Burnt River subbasin, they did agree that surrogates in some form needed to be used in 1010 plans. TMDL's and 1010 plans developed in Oregon to date have dealt with temperature surrogates, not temperature units; however, the conditions discussed in 1010 plans are not commonly called surrogates. The TMDL's developed to date have identified a number of surrogates that could be used in controlling stream temperatures, but only vegetation and its related effective shade has been used in load allocation. The surrogate goals developed in the TMDL process define conditions on the ground that would have to be achieved if load allocations are to be met. The water quality management plan, including the 1010 plan, describes how those conditions will be achieved. ODA believes that 1010 plans should focus on attainable improvements defined in surrogates (leaving the choice of practices to achieve those improvements up to individual landowners); and then whatever temperature results from those improvements would reflect what is reasonable and practical. Some felt that attainable surrogates could be defined with the help of resource sites that could be identified as a standard as well as the use of master ranchers who could demonstrate resource capability.

Study participants discussed the need to translate surrogates into 1010 plan elements such as actions and prohibited conditions, but developed no recommendations. Some agricultural representatives wanted to see prevention and control measures focused on things that could be fixed where landowners could see actual improvements. There was also considerable discussion of the need to make objectives clear and measurable and developed with respect to a specific time frame. However, there was an awareness of landowner resistance to this type of approach in a regulatory environment.

Feasibility

Those contributing to non-point source pollution are responsible for implementing feasible improvements. Feasibility is defined in Oregon Administrative Rule as a function of "…a site-specific balance of the following criteria: protection of beneficial uses; appropriateness to local conditions; use of best treatment technologies or management practices or measures; and cost of compliance."[71] Some study participants felt that if these criteria were followed, increasing shade from 1 percent to the estimated site potential of 5-7 percent on the main stem would not be feasible. This is based on the estimate that a 5-7 percent shade impact on stream temperature would be minimal and would be of little or no benefit to fish. There was no agreement in the group on this issue.

The relationship of feasibility to money and time, and the tradeoff between the two was discussed. Only so many dollars are available at any given time, but given more time, more changes are possible. There was also some discussion of social factors that may limit the achievement of site potential. For example, many individuals in the Burnt River subbasin believe that the majority of stream heating is due to natural factors and that solutions such as shading the stream are not effective. Landowners are also reluctant to take action to improve temperature unless it can be shown that the changes will have a positive impact on aquatic communities. Even some fish biologists argue that if only small amounts of fish are produced in relation to expensive improvements, those improvements may not be justifiable.

Measures of Progress

Study participants discussed means of measuring progress. The DEQ was interested in measures of interim progress, the ODA talked about the need for stepwise approaches to the temperature standard, and OSU thought measures might be developed around vegetative recovery rates. No recommendations were developed.

Burnt River 1010 Plan

The ODA, with the assistance of a local water quality management area advisory committee, is preparing a 1010 plan which they expect to complete in 2002. The 1010 plan will identify conditions associated with agricultural lands that can contribute to water quality problems and outline a strategy that will include education, enforcement, and monitoring, to mitigate those problems. The intent of 1010 is to provide a clear role for ODA to assist and advise producers in watersheds known to have water quality problems, to prevent pollution problems wherever possible, and to alleviate any existing problems.

Typically, 1010 plans are being developed prior to the development of a TMDL because of agriculture's and the state's desire to be proactive. For the Burnt River subbasin, DEQ is scheduled to begin work on the TMDL in 2005. After the TMDL is developed, ODA (with the assistance of the local water quality management area advisory committee) will evaluate the Burnt River 1010 plan in light of the TMDL and make any changes necessary. The 1010 plan then becomes the TMDL agricultural implementation plan and is part of DEQ's overall management plan that describes the strategy for achieving the TMDL for that basin.

FUTURE RESEARCH

Study participants did not develop a set of recommendations for further research in the Burnt River. This section contains suggestions that were made throughout the course of the study that might be pursued in other basins or at some later date in the Burnt River.

Objective 1: Factors Contributing to Stream Temperatures

In general, study participants agreed on the processes that involve the transfer of heat energy and the stream characteristics that are important to temperature. Further investigations that might improve the understanding of these processes are listed below.

Burnt River

- Identify and measure surface return flow sites on the main stem and South Fork.
- Perform flow and temperature analyses with and without Unity Reservoir.
- Study spring water temperatures by elevation to show how source water temperatures change by elevation.

General

- Identify the relationship between PFC and water temperature. Currently measurement techniques are not fine enough to measure differences across short reaches.
- Test the hypothesis that summer stream temperatures cannot be maintained below 64 ºF at elevations below 4500 feet in eastern Oregon unless there are significant cool groundwater inputs.[72]
- Develop regression equations for predicting water temperatures in other watersheds based on hydrology, climate, water quality parameters, elevation, etc.[73]
- Develop heat budgets on tributary streams. Compare these with main stem heat budgets to better assess the impacts of atmospheric radiation.

Tools

- Models
    - Develop performance criteria for temperature models.
    - Compare the Fish and Wildlife Service SNTemp Model with DEQ's Heat Source Model.
    - Compute present and potential shade using DEQ's approach.
    - Use the shade function in the SNTemp Model where there is enough actual or potential shade to justify its use.

- Forward Looking Infrared Technology (FLIR) – Consider using (FLIR to identify areas of stream heating.

Objective 2: Temperature Management Alternatives

Several areas of research associated with potential temperature management alternatives were discussed.

- More research on headwater streams with more shade (narrower channels, more vegetation, less atmospheric heating)

- Riparian Vegetation
  - Map ecological sites.
  - Identify resource sites as standards.
  - Explore the possible introduction of taller species.
  - Study canary grass control.
  - Evaluate reservoir operations for propagating riparian vegetation.

- Irrigation return flows – assess options for
  - Controlling surface return flows.
  - Enhancing cold water inputs.

- Channel
  - Identify areas where width might be reduced with changed riparian management.
  - Gather more cross-section data to show how channelized sections could be changed.
  - Consider effects of evolution to e-type stream, e.g. on willows, reed canary grass.

- Develop a water pollution reduction crediting system.

Objective 3: Develop and Test a Surrogate

The following items were discussed as steps to be taken in the development and testing of candidate temperature surrogates.

- Develop candidate surrogates and test them on site.

- Define feasibility/Develop cost/benefit analyses of management practices.

- Identify/get buy-off on attainable improvements.

- Define surrogates in terms of 1010 plan elements with clear, measurable goals.

- Identify a time frame for accomplishment with measures of interim progress.

BIBLIOGRAPHY

Adams, T. and K. Sullivan. 1989. *The Physics of Forest Stream Heating: a Simple Model.* Weyerhaeuser Research Report. TFW-WQ3-90-007.

Beschta, et al.. 1987. *Stream Temperature and Aquatic Habitat: Fisheries and forestry interactions, pp. 191-232.* In E.O. Salo and T.W. Cundy (eds.). Streamside Management: Forestry and Fisheries Interactions. Institute of Forest Resources Contribution No. 57. University of Washington, Seattle.

Beschta, R. L. and R. L. Taylor. 1988. *Stream Temperature Increases and Land Use in a Forested Oregon Watershed.* Water Resources Bulletin. February. Vol. 24, No. 1: 19-25.

Bliss, Tim. 2001. *Burnt River Water Quality Study Final Report Review Comments.* Wallowa Whitman National Forest. Baker City, Oregon.

Boyd, Matthew S. 1997. *Thermodynamic Stream Relationships and Management Practices. Oregon Department of Environmental Quality.* Portland.

Boyd, Matthew and Debra Sturdevant. 1997. *The Scientific Basis for Oregon=s Stream Temperature Standard: Common Questions and Straight Answers*. Oregon Department of Environmental Quality. Portland.

Brazier, J. R. and G. W. Brown. 1973. *Buffer Strips for Stream Temperature Control.* Research Paper 15. Forest Research Laboratory. School of Forestry. Oregon State University. Corvallis.

Brown, G. W. and J. T. Krygier. 1967. *Changing Water Temperatures in Small Mountain Streams.* Journal of Soil and Water Conservation. November-December. Pp. 242-244.

Brown, G. W. and J. T. Krygier. 1970. *Effects of Clear-cutting on Stream Temperature.* Water Resources Research. Vol. 6, No. 4: 1133-1139.

Brown, G. W., G. W. Swank, and J. Rothacher. 1971. *Water Temperature in the Streamboat Drainage.* USDA Forest Service. Research Paper PNW-119.

Crowe, Elizabeth. 2001. *Comments on Vegetative Site Capability for Burnt River Water Quality Study*. Deschutes National Forest. Bend, Oregon.

Crowe, Elizabeth and R. Clausnitzer, 1997. *Midmontane wetland plant associations of the Malhuer, Umatilla and Wallowa-Whitman National Forests.* USDA Forest Service. R6-NR-ECOL-TP-22-97.

Donato, Mary. 2002. *An Empirical Predictive Stream Temperature Model for the Salmon and Clearwater River Basins, Idaho.* U.S. Geological Survey. Water Resources Investigation Report 2002-xxxx (in press)

Duncan, David. 1999. *Defining a Surrogate*. David Duncan and Associates. Boise, Idaho.

Edinger, J. E., D. K. Brady, and J. C. Geyer. 1974. *Heat Exchange and Transport in the Environment. Report No. 14.* Electric Power Research Institute. Publication No. 74-049-00-34.

Hidore, J.J., and J. E. Oliver. 1993. *Climatology – An Atmospheric Science.* Macmillan Publishing Company. New York, New York. Pp. 23-65.

Independent Multidisciplinary Science Team. 2000. *Influences of Human Activity on Stream Temperatures and Existence of Cold-water Fish in Streams with Elevated Temperature: Results of a Workshop – Technical Report 2000-2.* Corvallis, Oregon.

Jaindl, Ray. 2001. *Recommendation to Burnt River Steering Committee at their September 21 meeting.* Salem, Oregon.

Larson, Larry and Michael Borman. 2000a. *Use Attainability Assessment (Temperature Standard), Burnt River Watershed*. Rangeland Resources Department. Oregon State University. Corvallis.

Larson, Larry and Michael Borman. 2000b. Use *Attainability Assessment (Temperature Standard), Burnt River Watershed – Appendix A – Burnt River Shade, Soil Temperature, and Groundwater Recharge Estimates, A First Approximation*. Rangeland Resources Department. Oregon State University. Corvallis.

Larson, Larry and Michael Borman. 2000c. *Use Attainability Assessment (Temperature Standard), Burnt River Watershed – Appendix B – Elevation, Thermal Environment, and Stream Temperature on Headwater Streams in Northeastern Oregon*. Rangeland Resources Department. Oregon State University. Corvallis.

Larson, Larry and Michael Borman. 2001. *Summary Document, Burnt River Research 1998-2000.* Rangeland Resources Department. Oregon State University. Corvallis.

Leonard, Stephen G. 2001. *Burnt River Site Capability Review.* National Riparian Service Team. Bend, Oregon.

McRae, G. and C. J. Edwards. 1994. *Thermal Characteristics of Wisconsin Headwater Streams Occupied by Beaver: Implications for Brook Trout Habitat.* Transactions of the American Fisheries Society. 123:641-656.

Mangelson, Kenneth. 2000a. *Burnt River Basin Water Temperature Modeling Study. Draft Final Report.* U. S. Department of the Interior, Bureau of Reclamation Technical Service Center. Denver.

Mangelson, Kenneth. 2000b. *Burnt River Basin Correlation Tables*. U. S. Department of the Interior, Bureau of Reclamation Technical Service Center. Denver.

Mangelson, Kenneth. 2000c. *Summary Description of Burnt River Modeling Runs to Assess the*

Impacts of Variations in Air Temperatures and Solar Radiation. U. S. Department of the Interior, Bureau of Reclamation Technical Service Center. Denver.

Mangelson, Kenneth. 2001a. *Burnt River Basin Water Temperature Modeling Study. Final Report*.
U. S. Department of the Interior, Bureau of Reclamation Technical Service Center. Denver.

Mangelson, Kenneth. 2001b. *Technical Memorandum: Water Temperature Computer Modeling Runs for Different Global Shade Estimates than were used in the Final Report.* U. S. Department of the Interior, Bureau of Reclamation Technical Service Center. Denver.

Neiburger, Morris, James G. Edinger, and William D. Bonner. 1982. *Understanding our Atmospheric Environment*. W.H. Freeman. San Francisco.

Nichols, Richard. 2001. *DEQ Review Comments of Draft Final Report, Dated April 2001.* Department of Environmental Quality. Bend, Oregon.

Risley, John, Edwin Roehl, and Paul Conrads. *Estimating maximum Water Temperatures in Small Streams in Western Oregon Using Neural Network Models.* U.S. Geological Survey. Water Resources Investigation Report 2002-xxxx (in press).

Shortley, George, and Dudley Williams. 1961. *Elements of Physics for Students of Science and Engineering*. Prentice-Hall. Englewood Cliffs, N. J.

Ward, J.V. 1985. *Thermal Characteristics of Running Waters.* Hydrobiologia 125:31-46.

NOTES

[1] MOU Participants: Oregon Dept. of Environmental Quality, Oregon Department of Agriculture, Burnt River Irrigation District, Powder Basin Watershed Council, Bureau of Reclamation Snake River Area Office, Oregon State University College of Agricultural Sciences, Environmental Defense, Oregon Farm Bureau Federation, Oregon Department of Fish and Wildlife, Natural Resources Conservation Service, Wallowa Whitman National Forest, Bureau of Land Management Vale District, Oregon State University Extension Service, Oregon Water Resources Department, Oregon Water Resources Congress, Burnt River Soil and Water Conservation District. Most of the participating agencies and organizations provided members for a steering committee and a technical committee that were established for oversight.

[2] In 1997 the Oregon Legislature adopted Senate Bill 1010 authorizing the Oregon Department of Agriculture to develop and carry out an agricultural water quality management area plan for agricultural and rural lands where a water quality management plan is required by state or federal law. Local water quality management area advisory committees are established to participate in the development and ongoing modifications of the plan. These plans, "for the prevention and control of water pollution from agricultural activities and soil erosion in a management area…"(OAR 603-095-0010(5)) are commonly referred to as "1010 plans". ODA administrative rules (OAR 603-090-0030) state that 1010 plans "…shall describe a program to achieve the water quality goals and standards necessary to protect designated beneficial uses related to water quality, as required by state and federal law."

[3] MOU: Bureau of Reclamation MOU No. 1425-8-MU-10-02170. MOU objectives listed in italics at the beginning of each section of the current report.

[4] Technical Reports: Larson, Larry and Michael Borman. 2000a, 2000b, 2000c, 2001. Mangelson, Kenneth. 2000b, 2001a, 2001b.

[5] Environmental Defense Statement: The Burnt River Water Quality Study (BRWQS) was initiated in 1998 in an attempt to identify consensus-based actions to improve stream temperature conditions in the Burnt River Basin. Environmental Defense=s principal interests in agreeing to participate as a MOA signatory in the BRWQS initiative were in the exploration of alternatives to the temperature standard that could yield better stream health results; in the identification of alternative ways that landowners' management activities could enhance stream health; and in implementing acceptable and low cost incentives for encouraging such land management activities.

During the ensuing nearly three years of the BRWQS=s process, Environmental Defense expressed concerns about the lack of appropriately structured peer reviews of research and studies, and the lack of linkages of the project=s research to problem-solving policies and actions. Nevertheless, the BRWQS=s direction of work became progressively more narrowly focused than the directions indicated by the goals of the MOA signed by the participants in 1998. These goals related to the identification of a surrogate for the temperature standard and the incorporation of the BRWQS project=s work into the agricultural water quality management planning process (1010 plans) for the Burnt and, by example, the 1010 planning process for other Oregon river basins with temperature problems.

While some discussion of these goals did occur in BRWQS meetings, the BRWQS=s focus became a set of loosely connected technical studies, with an ongoing and ad hoc set of reviews. These reviews benefited from the experience and expertise of a number of knowledgeable individuals, some of who are employed by state or federal agencies. At the same time, many of these agencies are also stakeholders in the policy-related issues and problems that were to be addressed by the BRWQS. In such cases, compliance with one criterion for credible research peer reviews -- that reviewing entities have disinterested third-party status -- was problematic.

Many of the studies conducted as part of the BRWQS=s process addressed relevant issues. At the same time, Environmental Defense did not envision as a MOA signatory that these studies were to become the principal product of the BRWQS project. Environmental Defense continues to support research efforts, but we expect such efforts to be undertaken to produce some utility in or to have applicability to the implementation of problem-solving actions. In our judgment, the BRWQS project has not identified significant and tangible directions or recommendations that will be useful in problem solving with regard to temperature problems in the Burnt River or in other river basins in Oregon or elsewhere.

Environmental Defense views the BRWQS project as having produced some interesting exchanges of views and information, but at the same time falling short of achieving its main objectives.

[6] Reclamation modeled a main stem reach from Unity dam to the head of the Burnt River canyon using the SNTEMP stream temperature model originally developed for and maintained by the U. S. Fish and Wildlife Service. Reclamation assessed model performance based on predictions of stream temperature at the validation stations on the Burnt River during the calibration and verification tests given measured climatological and flow data. Findings: (1) The pattern

and magnitude of ditch diversions and return flows were critical in calibrating the computer model. Initial estimates of the timing and rates of irrigation diversions and return flows were modified in the model applications in order to accurately predict instream temperatures. (2) The calibrated model performed very well in predicting mean daily water temperatures in comparison with the measured temperatures but the predicting of maximum daily instream temperatures was not as accurate. (3) Prediction of maximum daily instream temperatures was improved through the development of regression equations. Regression equations were developed using climatic variables, flows, and mean daily instream temperatures computed by the calibrated model runs and were found to accurately predict maximum daily instream temperatures thoughout the modeling reach except for the stream reach near the dam which is most affected by reservoir outflows.

[7] The organization of this section and much of the theoretical discussion is based on Boyd and Sturdevant, 1997.

[8] Based on Mangelson, 2001a, Figures B-8, D-7, and E-4.

[9] Based on Mangelson, 2001a, Figures B-14, D-9, and E-6.

[10] Based on Mangelson, 2001a, Figures B-13, D-8, and E-5.

[11] Independent Multidisciplinary Science Team, 2000, p. 8.

[12] Independent Multidisciplinary Science Team, 2000, p. 23.

[13] Independent Multidisciplinary Science Team, 2000, p. 21. Quote taken from Beschta, et al., 1987.

[14] Boyd and Sturdevant, 1997.

[15] Neiberger, Edinger, and Bonner, 1982, p. 65.

[16] Mangelson, 2001a, p. iii; Boyd and Sturdevant, 1997, p. 6.

[17] Based on Boyd and Sturdevant, 1997, p. 7 and Mangelson 2001a, Figure 15, ff. p. 47.

[18] Data, equations, and graphs for other July days are reported in Mangelson, 2001a, Appendix L.

[19] Actual shade values were not measured but are somewhat higher. Therefore the values for both solar and atmospheric radiation are very slightly overestimated.

[20] Mangelson, 2001a, Appendix L. Burnt River Hourly Heat Flux for Station BR-CP near Durkee, for July 14, 1999.

[21] Based on Mangelson, 2001a, Appendix L. Burnt River Hourly Heat Flux for Station BR-CP near Durkee, for July 14, 1999.

[22] Mangelson, 2001a, Appendix C; Mangelson, 2000b.

[23] Mangelson, 2001a, Appendix L. The equation for atmospheric radiation is $H_A = (1-S_A)(1+0.17\bullet C_L^2)(3.36+0.706\bullet(R_h\bullet 1.064T_A)^{1/2})(10^{-8}\bullet(T_A+273.16)^4)$ where H_A = atmospheric radiation (J/m^2/sec), S_A = atmospheric shade factor (decimal), $C_L = (1-S/So)^{3/5}$ = cloud cover (decimal), S = actual sunshine, S_o = optimal sunshine, S/So = sunshine ration (decimal), e_a = vapor pressure = $R_h\bullet(6.60\bullet(1.064T_A))$(mb), R_h = relative humidity, T_A = air temperature. S and S_o were estimated based on weather station solar and rainfall data. All other parameters are based on actual weather station data.

[24] Mangelson, 2000c. These findings are based on taking real temperature data and varying them hypothetically while keeping all other variables constant – a condition that would not occur in nature. The air temperatures modeled would not occur on a regular basis in nature.

[25] Mangelson, 2001a, Appendix L.

[26] Reclamation felt attaining 50 percent shade was not possible given the width and soil conditions on the main stem, but some participants did not agree.

[27] Brown et al., 1971, Beschta and Taylor, 1988, Brown and Krygier, 1967 and 1970, and Brazier and Brown, 1973.

[28] Brown et al., 1971.

[29] Adams and Sullivan, 1989.

[30] McRae and Edwards, 1994.

[31] Mangelson, 2000c. These findings are based on taking real solar radiation data and varying them hypothetically while keeping all other variables constant – a condition that would not occur in nature. The solar radiation modeled would not occur on a regular basis in nature.

[32] Data collected by the Forest Service in 1990-91 showed North Fork Burnt River temperatures “mirroring air temperature – about 68-70 °F in cool, cloudy, misty weather, and about 78 °F in warm, clear weather.” (Bliss, 2001)

[33] Mangelson, 2001a, Appendix L. Burnt River Hourly Heat Flux for Station BR-CP near Durkee, for July 14, 1999.

[34] Shortley and Williams, 1961, p. 347.

[35] Boyd and Sturdevant, 1997, p. 7.

[36] Data collected by Art Kreger (Wallowa-Whitman National Forest soil scientist) showed mean summer soil temperatures at 20 inch depth in the Burnt River subbasin varying from 38 to 48 °F above 5000 feet on north slopes and above 6000 feet on south slopes. Mean soil temperatures were between 54-64 °F below 3000 feet on north slopes and

4000 feet on south slopes. (Bliss, 2001)
[37] Ward, 1985.
[38] Adams and Sullivan, 1989.
[39] Ward, 1985
[40] Independent Multidisciplinary Science Team, 2000, p. 21.
[41] Mangelson, 2001a, p. iii.
[42] Boyd and Sturdevant, 1997, p. 16.
[43] Reclamation felt that narrowing the channel by 30 percent would not practically occur, but some participants felt the channel might be narrowed appreciably from its present width if allowed to evolve toward its potential.
[44] Boyd and Sturdevant, 1997, p.13.
[45] Leonard, 2001, p.2, Crowe, 2001, p. 2.
[46] Crowe, 2001, p.1. Leonard (2001, p.2) also states that "[t]he Burnt River from near Unity Reservoir to the canyon near Bridgeport does not exhibit characteristics conducive to cottonwood regeneration."
[47] Leonard (2001, p.2) points out that "[c]ottonwoods may grow in this segment if planted, but it is highly unlikely that there would be recruitment from seed.
[48] Based on Mangelson, 2001a, Figures B-7 and D-8.
[49] Based on Mangelson, 2001a, Figures B-8 and D-9.
[50] Larson and Borman, 2000, pp. 3-10
[51] Crowe, 2001, p. 2. At the time of her review Elizabeth Crowe was an Area Ecologist with the Central Oregon Interagency Ecology Group. She had previously been an ecologist with the Wallowa Whitman National Forest and had extensive experience in the Burnt River. She has published a guide to the plant communities of the Blue Mountains (Crowe and Clausnitzer, 1997).
[52] Three types of willow species are found in Burnt River riparian areas (Coyote, Booth, and Yellow). Leonard (2001) provided two estimates of Coyote Willow heights (2-3 meters and an average of 8.7 feet). Crowe (2001) found Coyote Willow to grow to 6 feet in the Blue Mountains and Central Oregon. Leonard (2001) provided two estimates of Booth Willow height (2-4 meters and 3-5 meters). Crowe (2001) estimated Booth and Yellow willow to grow to heights between 8 and 13 feet in the Blue Mountains, and 7 to 7.5 feet in Central Oregon.
[53] Crowe, 2001, p.1.
[54] At the time of his review Steve Leonard was a Bureau of Land Management ecologist on the National Riparian Service Team. Leonard participated in the 1998 interagency Proper Functioning Condition Assessment of the Burnt River.
[55] Leonard, 2001, p.2.
[56] Crowe, 2001, p. 3.
[57] Crowe, 2001, p.4.
[58] Estimates are contained in Mangelson, 2001b, p. 5. Methodology is discussed in Larson and Borman, 2000, pp. 3-10.
[59] Mangelson, 2001b, p. 5.
[60] DEQ staff have done quick estimates of effective shade for the modeled reach "…that include low end estimates similar to those reported here and high end estimates up to 50 percent." (Nichols, 2001, p.5).
[61] Mangelson, 2001b, p. 3.
[62] When surface water temperatures exceed 64 °F (on a seven day average maximum) in streams where salmonid fish rearing is designated as a beneficial use, no measurable surface water temperature increase from human activities is permitted without a DEQ-approved temperature management plan (Oregon Administrative Rules 340-41-725(2).
[63] Oregon's stream temperature standard is made up of two components: (1) the numeric criteria (which includes the 64 °F criterion for salmonid rearing) identified in basin standards which trigger actions to be taken when stream temperatures rise above these criteria, and (2) the rule language which puts the criteria in context and explains what constitutes a violation and what needs to happen when a violation occurs. The water temperature standard for the Burnt River is described in Oregon Administrative Rules (340-41-765).
[64] The temperature standard can be satisfied by having an approved water quality management plan in place even if the plan shows that the 64ºF criterion cannot be met.
[65] The Burnt River study addressed temperature only and did not take into consideration any other parameter such as sediments, nutrients, or bacteria, nor did it evaluate the effect of a decline in existing riparian vegetation on water quality.
[66] Jaindl, 2001.

[67] At the beginning of the study agricultural interests were interested in pursuing a prototype healthy streams standard, but they abandoned that effort because they felt that the U. S. Environmental Protection Agency would not support it.
[68] U. S. Environmental Protection Agency.
[69] The Total Maximum Daily Load (TMDL) is the total amount of pollutant that can enter a water body without violating water quality standards. The TMDL process assesses what is causing temperature standard exceedances (point, non-point, and background sources) and determines what pollutant loadings must be met to achieve standards. (OAR 340-41-026 (3) (a)(D)(ii).
[70] If a temperature criterion is not being met in a given stream, section 303(d) of the Clean Water Act (CWA) requires that the state place that stream on a 303(d) list of water quality limited steams, and complete a TMDL. The main stem below Unity Dam and the North Fork are currently listed on DEQ's 303(d) list as water quality limited for temperature.
[71] OAR 340-41-026(3)(a)(D)(ii).
[72] Recent studies done by the U.S. Geological Survey in cooperation with the Oregon and Idaho Departments of Environmental Quality (Donato, 2002; Risley, et al., 2002) have used elevation to estimate "natural" water temperatures.
[73] The U.S. Geological Survey and the Idaho Department of Environmental Quality (Donato, 2002) have developed regression equations to predict stream temperatures in the Salmon and Clearwater basins of Idaho. Grand averages have been developed using watershed area, elevation, and slope; and then daily averages have been predicted using a seasonal adjustment factor and air temperature.

APPENDIX A --PARTICIPANT COMMENTS

Objective 1: Factors Contributing to Stream Temperatures

Environmental Defense

Objectives Achieved

- Identified physical conditions influenced by human activities (vegetation, surface and groundwater flows, channel shape, sinuosity, entrenchment/flood plain connection, structures such as reservoirs and diversion dams.)

- Surveyed literature and other water quality planning in Oregon to identify three important factors (stream surface shading, flow volume, channel width and depth) for managing instream water temperatures.

- Commenced with development of a modeling system (Stream Network Temperature Model plus input data and assumptions) for use in evaluating the relative sensitivity of water temperatures to changes in physical conditions (e.g., channel shape, surface shading).

Objectives Not Achieved

- Did not identify the relationship between properly functioning conditions (PFC) assessments and water temperature management.

- Did not develop performance criteria for the modeling system or to conduct a performance evaluation of the modeling system.

Objective 2: Temperature Management Alternatives

Environmental Defense

Objectives Achieved

- Commenced with development of a modeling system (Stream Network Temperature Model plus input data and assumptions) for use in evaluating the relative sensitivity of water temperatures to changes in physical conditions (e.g., channel shape, surface shading) and management practices (e.g., surface flow reduction, vegetation propagation).

- Assessed the potential for increasing stream surface shade through vegetation management.

Objectives Not Achieved

- Did not develop performance criteria for the modeling system or to conduct a performance evaluation of the modeling system. Consequently, no scenarios (i.e., variations of physical conditions and management practices) were developed to model and conduct both local and global sensitivity analyses to estimate the relative effectiveness (in terms of costs versus benefits) of changing physical conditions through management practices to reduce peak instream temperatures.

- Did not determine what management practices are feasible by building consensus on the definition of feasible and evaluating the potential utility of management practices deemed feasible in terms of the anticipated costs versus benefits.

- Did not consider or develop a water pollution reduction crediting system for landowners voluntarily implementing management practices.

Objective 3: Develop a Surrogate

Environmental Defense

Objectives Accomplished

- Discussed a conceptual definition of a surrogate in terms of measures of physical conditions and management practices, including vegetation, irrigation return flows, instream flows, cold water refugia, channel width, sinuosity, and PFC assessments.

- Discussed defining a surrogate in terms of a Healthy Streams Standard.

- Developed a seven-part surrogate definition and implementation process that includes (1) establishing the existing physical conditions of each measure; (2) defining the peak potential of each measure; (3) identifying factors inhibiting ultimate attainment of peak potential: (4) establishing goals that incorporate peak potential and inhibitions; (5) defining existing conditions or actions that would be prohibited: (6) implementing a monitoring program; (7) reviewing all goals, definitions and conclusions based on information gathered during implementation.

Objectives Not Accomplished

- Did not reach a consensus on the feasibility of any candidate temperature surrogates.

- Did not propose one or more “pilot” temperature surrogate applications at suitable sites to test the concept in on-the-ground situations.

Objective 4: 1010 Plan

Environmental Defense

Objectives Achieved: Developed a Final Report summarizing the lack of consensus on procedural, scientific, and socioeconomic considerations pertaining to the design of a 1010 plan in the Burnt River Basin.

Objectives Not Achieved: Did not produce a Final Report with uniformly credible scientific findings and feasible management actions for consideration and possible incorporation into a 1010 plan for the Burnt River Basin or for guidance in the design of temperature control policies and actions in other river basins in Oregon and elsewhere.

APPENDIX B

SUMMARY DOCUMENT

BURNT RIVER RESEARCH
1998-2000

Larry Larson & Michael Borman
Rangeland Resources Department
Oregon State University

April 4, 2001
Final report
(revised July 19, 2001)

INTRODUCTION

Thermodynamic laws state that the temperature of an object will spontaneously trend toward the temperature of the surrounding thermal environment (Halliday and Resnik 1988). Temperature difference and exposure time influence this process. In the study of water temperature the concept of an equilibrium temperature is used to describe the response of water temperature to meteorological conditions (Edinger et al. 1968). The equilibrium temperature is a dynamic number that reflects change in the sum of the radiation, conduction, and evaporation processes, primarily at the water-air interface.

Studies were undertaken to evaluate factors that could influence how fast stream temperatures approach thermal equilibrium and influences that could occur after a thermal equilibrium was achieved. The studies provide a description of vegetation site potential, and associations between headwater, elevation, weather, and land use to observed patterns of stream temperature.

VEGETATION SITE POTENTIAL

A study was conducted to provide an initial estimate of the shade potential along the Burnt River. The following is an illustration of the geomorphic, soil, and vegetation patterns that occur along the river between Unity Reservoir and Bridgeport.

Geomorphic, Soil, and Ecological Site Complex

Four ecological sites (Laird et al. 1988) dominate the river reach between Unity Reservoir and Bridgeport (wet meadow, meadow, loamy bottom, and sodic meadow). Their occurrence upon the landscape is closely associated with geomorphic surfaces and soils (figures 1-3). The youngest geomorphic surface in the Burnt River valley is called Horseshoe. It forms the lowest flood plain and is subject to annual flooding. The surface includes channel, point bars, channel fillings, and abandoned meanders. The Horseshoe surface is the primary zone of scouring and deposition and is subject to rapid landscape changes due to the abandonment of older channels, lateral migration of meanders, and downstream movement of alluvial deposits. The soil survey describes these young surfaces as Riverwash, Fluventic and Fluvaquentic Haploxerolls. The next floodplain, Ingram, is slightly higher than the Horseshoe. The soils are more developed and ecological sites have been described within the current soil survey. Ingram provides an undulating surface that defines over-bank channeling during flood stage. Textures within the Ingram surface will tend to become finer as you move upslope away from the channel. Annual flooding is common on the Ingram surface and soils tend to be moist for extended periods forming wet meadow communities over Cumulic Haplaquolls (Boyce and Wingdale soils) in lower areas and meadow communities over Fluvaquentic and Pachic Haploxerolls (Balm and Wingville soils) on elevated surfaces. Localized areas within this zone are affected by salt accumulation that has occurred over geologic time. These salt-affected surfaces form Typic Haplaquepts (Baldock and Haines soils) which support sodic meadow communities. The oldest surface associated with the Burnt River flood plain is called Winkle. The surface forms a series of benches and terraces that are remnants of abandoned flood plains. Winkle is an undulating surface that provides a variety of local elevation differences.

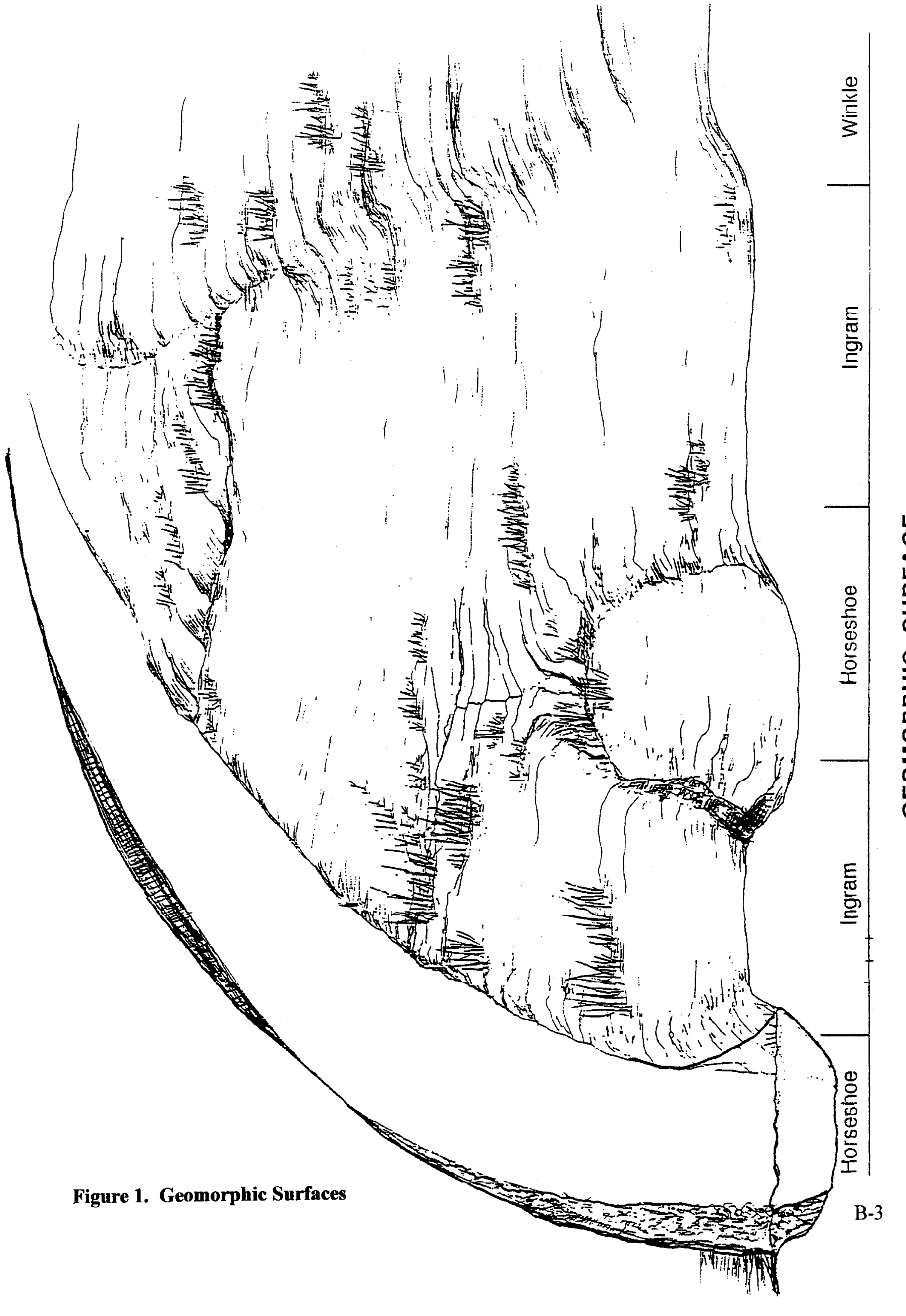

Figure 1. Geomorphic Surfaces

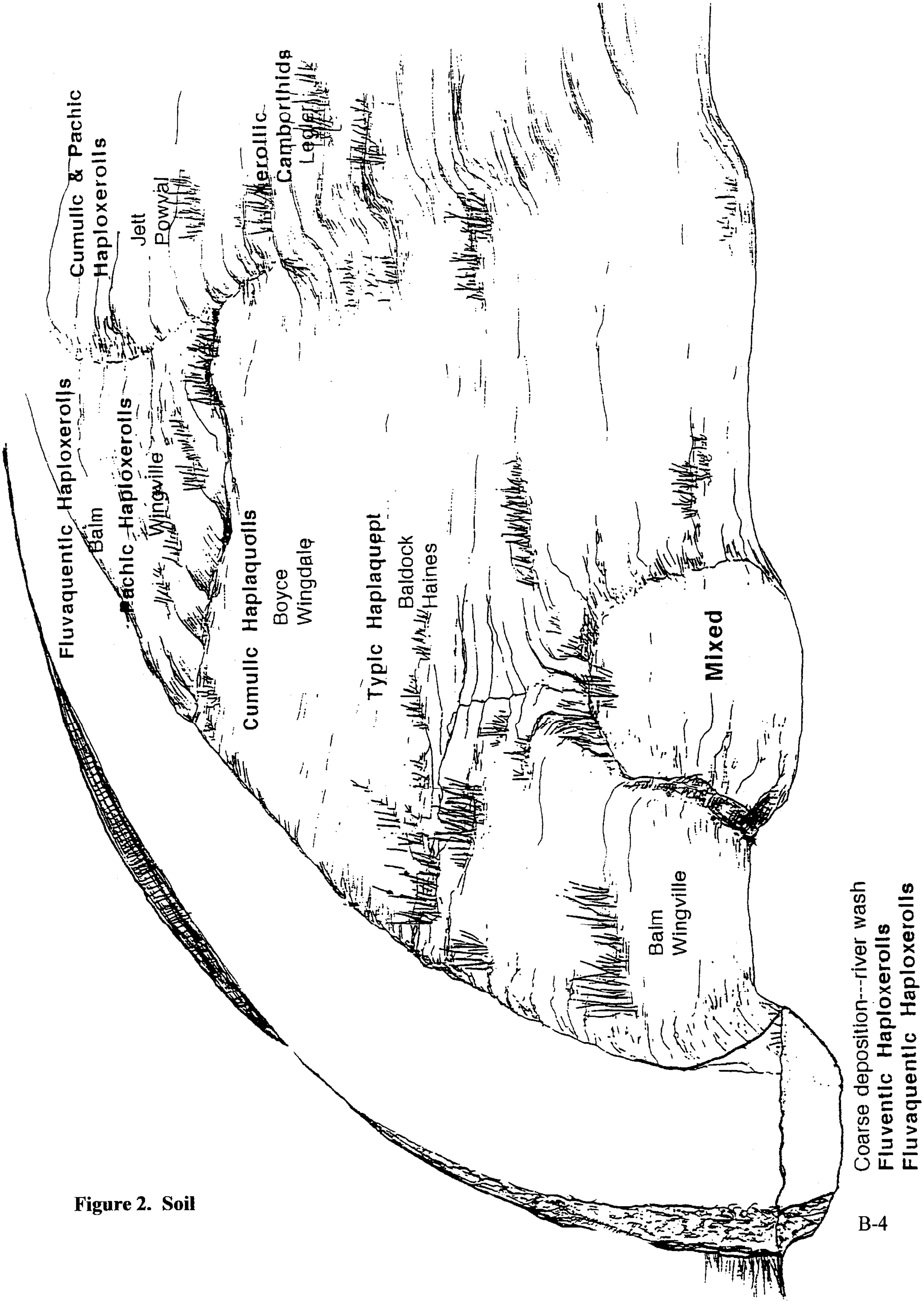

Figure 2. Soil

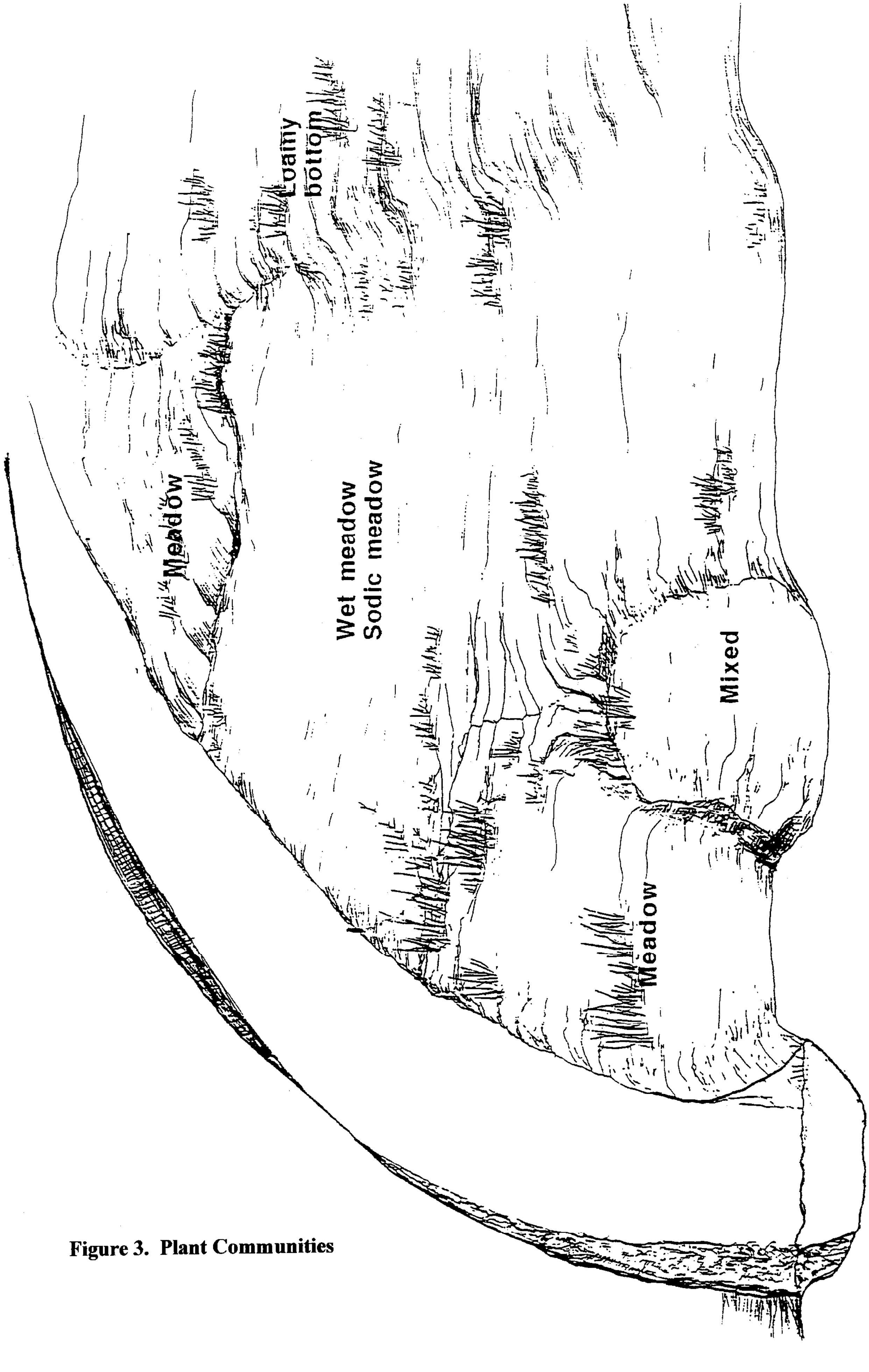

Figure 3. Plant Communities

Flooding in this zone varies from common to infrequent reflecting the elevation pattern of the surface. Soils formed on these surfaces tend toward Cumulic and Pachic Halpoxerolls (Jett and Powval soils) or Xerollic Camborthids (Legler soil) which support Loamy bottom communities.

The Occurrence of Willow

A fifth ecological site (NRCS 2000) called willow riparian (Booth willow) also occurs within the Hereford reach. The willow riparian site forms linear galleries within the Horseshoe surface and localized inclusions within the other ecological sites. Dominant willow species for this ecological site include Booth, yellow, and coyote willow. Each species is described as an obligate wetland indicator, tolerating some but not prolonged flooding above the root crown, and being associated with a water table that drops during the growing season but remains within reach of the root system (Crowe and Clausnitzer 1997). Booth and yellow willow are root crown sprouters that produce a multi-stem tree/shrub that is typically less than 15 feet in height. Coyote willow sprouts from a creeping root system forming a thicket of single stemmed shrubs. Thicket height typically ranges from 5-10 feet. Establishment (seed) for each of these species is closely associated with river channel scouring and deposition. Booth and yellow willow will tend to be associated with fine sand and silt deposition. Soils supporting these species generally contain redoximorphic features several feet below the soil surface. Coyote willow, on the other hand, is normally associated with sandy to skeletal deposits and sites that lack redoximorphic features. Seedling establishment, for all three species, is closely associated with the exposure of fresh mineral deposits that are free of competition and remain moist during initial establishment. In addition to seed establishment these species may also become established through the burial of detached limbs and the deposition of plants dislodged from upstream locations during flood events.

Integration

Channel scouring and deposition is the principal means by which colonization sites are created for willow in the Hereford reach. Substrate size as well as the timing and patterns of substrate deposition will greatly influence willow establishment. The Horseshoe surface provides the greatest opportunity for scouring, deposition and colonization. Additional colonization may occur within the Ingram surface if the deposition remains moist and free of competition during seedling establishment. Suitable Ingram surfaces currently support sedge, rush, and grass communities that rapidly re-colonize areas of deposition following flooding.

The majority of the river in the Hereford reach has evolved into an E channel (Rosgen 1996). Its flat gradient and flood plain are dominated by wet meadow and meadow communities. In most areas fine sediment deposits are a minimum of 3 feet deep. This can generally be interpreted to mean that the channel is no longer recruiting large amounts of gravel into this portion of the valley. Lateral channel movement continues to rework existing deposits, exposing them, and providing sites for plant colonization. Alluvial bars are being formed from materials ranging in size from silt and fine sand to gravel. Herbaceous colonization increases as the texture of these bars tends toward finer particle sizes. Conversely, bars dominated by gravel tend to provide a greater opportunity for colonization by species such as coyote willow. Overflow channels, swales and depressions that occur in the immediate vicinity of the channel may accumulate deposits of silt and fine sand that are of sufficient depth and size to slow re-colonization by herbaceous species. When this occurs, the potential for establishing Booth and yellow willow is increased.

Findings

The following river shade estimates reflect the availability of substrates commonly associated with the colonization of woody species in riparian areas. For the purposes of this study, percent shade is defined as the percent of water surface over which direct solar radiation is intercepted by vegetation between 10:00 a.m. and 2:00 p.m.

APPROXIMATE AMOUNT AND RIVER SHADING ALONG THE MAINSTEM COMMUNITIES OF THE BURNT RIVER

	Hereford [2]		**Durkee[3]**	
COMMUNITY [1]	MILES	% SHADE	MILES	% SHADE
Wet meadow/meadow (no gravel)	21.4	3-4	1.5	2-3
Loamy bottom	0.6	2-3	13.0	1-2
Wet meadow/meadow (gravel)	4.5	4-5	3.0	4-5
Riverwash			2.3	13
Channelized				
Meadow (no gravel)	1.5	1-2		
Sodic meadow	1.5	1		
Sodic meadow	0.7	1		

[1] Community refers to NRCS ecological site description
[2] Hereford refers to the Burnt River between Unity Reservoir and Bridgeport
[3] Durkee refers to the Burnt River between the canyon mouth above Durkee downstream to Lime. The canyon between Bridgeport and Durkee is not included in this table.

HEADWATER

A number of literature references indicate that headwater sources reflect the temperature of the thermal mass from which they originate (Ward 1985, Meisner et al.1988, Raphel 1962, Adams and Sullivan 1989, McRae and Edwards 1994). When headwater sources contribute significant cold or cool water to a stream, their contribution will depress the diurnal range of stream temperature. In addition, these waters typically show a higher rate of temperature change due to large differences between equilibrium and headwater temperatures.

Study Results – Headwater

Average soil temperature at 1-ft depth in August at 6,000 ft is 50 F.

Headwater data (August 1999) - Barney and Stevens Creeks[1]

	Barney	Stevens
Elevation	7,150 ft	6,600 ft
Source temp.	37.5 F	40 F
Distance to 6,000 ft elev.	6,200 ft	2,450 ft
F increase/500ft distance	1.0	0.9
F increase/hr	1.6	1.3
Average Velocity	0.2 f/s	0.2 f/s
Average depth	3.5 in.	3.0 in.
Exposure time	8.5 hr	3.4 hr
6,000 ft temperature	51.5 F	44.5 F

[1] Water temperatures at source and 6,000 ft are rounded to the nearest 0.5 F

Elk Creek headwater source was not studied. However, side channel data and field observations note that side channels enter the main stream at 5,900 and 5,600 ft elevations. Their combined contribution is equal to ½ of the stream flow and enters the stream approximately 3 F cooler then the main channel. Field notes indicate that saturated soils and seeps occur in several locations downstream and are more frequent than on any other stream studied.

Findings

Based upon headwater temperatures, Barney and Stevens Creeks appear to originate from snowmelt that has moved subsurface to the spring sources. Barney Creek springs are located at about 7200-ft elevation and temperatures ranged from 37.4 to 38.5^{o}F. Stevens Creek spring is at nearly 6700-ft elevation and temperatures ranged from 38.8 to 41.7^{o}F. To reach the spring source from snowmelt, water traveled further subsurface to reach Stevens Creek than to reach Barney Creek. The thermal environment of the soil appears to have been warmer than the initial snowmelt temperature of the water and to have had a warming effect.

Water temperature differences between Barney and Stevens Creeks at the 6000-ft elevation appear related to exposure time differences. Barney Creek exposure time was 2.5 times longer than Stevens Creek. At 6000-ft elevation, average monthly mean water temperatures were

49.3°F (July 1999) to 54.3°F (July 1998) for Barney Creek and 43.0°F (July 1999) to 45.3°F (July 1998) for Stevens Creek.

ELEVATION

Elevation differences exert a strong influence on the thermal regime of running water (Ward 1985, Meisner et al. 1988, Raphel 1962, McRae and Edwards 1994, Larson and Larson 1997). Air density decreases with increasing elevation, which decreases the insulating effect of air at the Earth's surface. Lower air temperatures and water vapor pressure reduce the influence of long-wave radiation at higher elevations. As a result of these interactions, the thermal environment at higher elevations is characterized by more rapid thermal cycling and less warming. Waters observed at different elevations reflect these characteristics. Waters flowing down an elevation gradient are subject to temperature equilibrium regimes that are warmer than where they originate.

Study Results – Elevation

Tests were performed to determine if there was an association between elevation and mean air, soil, and water temperature. Results from these tests showed a strong association between elevation and mean daily air, soil, and water temperatures. Mean daily air, soil, and water temperatures increased with each 500-ft drop in elevation.

Water Data - August 1999 Example

	Barney	Stevens	Elk
6000-ft temperature ± range	51 ± 5 F	45 ± 2 F	45 ± 3 F
4500-ft temperature ± range	58 ± 8 F	57 ± 8 F	50 ± 4 F
Thermal Gradient @			
6000 ft	7.8 F	10.4 F	10.8 F
4500 ft	4.4 F	3.9 F	8.8 F
Exposure Time (hr)	7	11	4.5
Temperature Change (F)	7	12	5

Findings

Mean daily air, soil and water temperature increased with each 500-ft drop in elevation. The pattern was similar to the adiabatic rate of air temperature change, which is 3 - 5 F (1.7 – 2.8 C) for every 1000 ft (300 m) drop in elevation.

* Two years of water temperature data from the four headwaters streams suggested that streams that lack significant cold-water inputs will exceed the water temperature standard at about the 4500-ft elevation during July and August.

* The convergence of mean daily air and mean daily water temperature indicated that Barney and Stevens Creeks were approaching equilibrium as they dropped in elevation. As an example, the mean air and water temperature differences (air temperature minus water temperature) during August 1999 were 7.7, 6.8, 5.0, and 4.5^{o}F on Barney Creek and 10.4, 8.6, 7.6, and 4.0^{o}F on Stevens Creek at 6000, 5500, 5000, and 4500-ft elevations respectively.

* Total exposure time (spring sources to 4,500-ft elevation) for Barney and Stevens Creeks were similar and likely accounted for much of the similarity in the average monthly mean and maximum temperatures at 4500-ft elevation. Barney (58 and 67 ^{o}F, Aug. 1999) had a total exposure time of 15.5 hr. Stevens (57 and 64 ^{o}F, Aug. 1999) had a total exposure time of 14.4 hr.

* Elk Creek was delayed in reaching thermal equilibrium with its thermal environment. Cold water from the side channels, a shorter exposure time (greater stream velocity), and an apparent input of ground water (not measured but based on observed saturated soils along much of the creek) contributed to this delay. Additional data collection would be required to determine if thermal equilibrium is achieved on Elk Creek before it joins the flow of the mainstem of South Fork Burnt River.

WEATHER INFLUENCE

Water temperature follows but lags behind air temperature (Stefan and Preud'homme 1993, McRae and Edwards 1994, Walker and Lawson 1977, Larson and Larson 1997, Mosheni and Stephan 1999). The similarity between mean air and water temperatures increases as the equilibrium temperature is approached (Adams and Sullivan 1989). At that point daily mean air temperature will be near daily mean air temperature. Local air temperature is identified as the single most important parameter influencing daily mean stream temperature (Sinokrot and Stefan 1994, Lewis et al. 2000). The air mass is large and exhibits significant temperature swings that can occur on daily, seasonal, regional, and local bases. These two characteristics exert a strong influence on the equilibrium temperature.

Study Results – Headwaters

Tests were performed to determine if a relationship could be determined between monthly air and water temperatures. Monthly air temperature differences were associated with significant changes in water temperature. Water temperature patterns followed air temperature patterns and reflected the cumulative effect of annual, monthly, and daily patterns of atmospheric conditions on the equilibrium temperatures of July and August.

Further analysis determined that the pattern of monthly temperature differences was not repeated in 1998 and 1999. The lack of a repeated pattern between the two years suggests that monthly atmospheric variation had a greater influence on water temperature than did fixed solar patterns.

Year	Mean Air Temperature	Mean Water Temperatures
1998	July 2-4 F > August	July 0.4-3 F > August*
1999	August 1 F ≥ July	August 0-3 > July

* An exception occurred at 5500 ft elevation on Stevens Creek where mean water temperature was 0.2 F cooler in July than in August 1998.

Study Results – Mainstem

Mean daily air, water, and soil temperatures were determined during July and August in 1998 and 1999 between Unity Reservoir and Clarks Creek. Peak air and water temperatures occurred daily between 3 and 4 pm unless climatic conditions disrupted the daily cycle of heating. Peak energy accumulation occurs several hours after peak solar radiation. When we divided the daily pattern of heating into three 4 hour units, air heated most rapidly (30 F) during the first 8 hours of the day (6:00 a.m. - 2:00 p.m.). Water heated most rapidly between 10 a.m. and 2 p.m. At that time water temperatures generally increased 7 F. Water temperatures continued to heat until 3 or 4 p.m., but the heat accumulation occurred at a slower rate. If air temperature accumulation during the first 4 hrs did not approach 14 F, then daily water temperature patterns lacked a strong heating pattern. Peak soil heating at 1-ft occurred at midnight.

Mean July/August temperatures for 1998/99

Mean ± range (F)

	1998	**1999**
Air	66 ± 19	65 ± 20
Water	66 ± 7	65 ± 7
Soil	61 ± 2	61 ± 2

Findings

* Monthly water temperature differences in 1998 and 1999 were strongly associated with air temperature differences. Water temperature patterns followed air temperature patterns. Air and water temperatures were warmer in July vs. August 1998; and, conversely, air and water temperatures were warmer in August vs. July 1999.

* Water and soil temperatures lagged behind air temperatures. Air temperature lagged behind peak solar radiation.

Air heated most rapidly during the first 8 hrs of the day. Water heated most rapidly between 10:00 am and 2:00 pm. When air temperature accumulation did not approach 14°F during the first 4-hr period of the day along the mainstem Burnt River, daily water temperature patterns lacked a strong heating pattern.

River temperatures between Unity reservoir and Clarks Creek were near thermal equilibrium. Mean air and water temperatures were nearly equivalent. Mean air and water temperatures during July and August were 66°F (1998) and 65°F (1999). Water temperatures typically ranged 7°F above and below the mean and air temperatures ranged 19-20°F above and below the mean.

RIVER SEGMENT COMPARISONS

The influence of land use was evaluated by comparing segments of the mainstem that are managed for a specific land use. In this case, segments of the river approximately 1 mile (1.6 km) in length were monitored for changes in temperature accumulation in the air, water, and soil. Replicates (2 in 1998, 3 in 1999) were monitored during July and August of land managed for 1) hay production followed by winter grazing, and 2) grazing using a summer rotation pattern. Data collection within each segment of the river was designed to measure the pattern of energy accumulation that took place during 1 hour flow periods.

Differences in stream temperature that can be associated with land use should be detectable in the temperature accumulation that occurs within a treatment and the extension of the daily temperature range of the water. The data indicated that the water flowing through these treatments had similar ($P<0.05$) amounts of temperature increase (Table 9). No significant difference could be detected in the amount of energy accumulated at the time of daily maximum water temperature, the magnitude of the daily water temperature range, nor the daily mean water temperature between the treatments compared. The accuracy of thermister technology limits data collection to $\pm$ 0.4 F (0.2 C). This means that although an energy accumulation was detected within each mile segment of the river, it is not possible to provide an accurate measure of the energy accumulation because it falls below the level of equipment accuracy.

Results from this study indicated that each segment of the river accumulated similar amounts of energy regardless of the treatment. It is appropriate to state that since no significant differences were observed between river segments, land use had minimal effect (non-significant) on the rate of energy accumulation.

Findings

Water flowing through hay meadow and summer grazing treatments had similar ($P<0.05$) amounts of temperature increase.

Study results indicate that each segment of the river accumulated similar (non-significant) amounts of energy regardless of the treatment.

* Shade potential for most of the mainstem Burnt River ranges between 3 and 6%.

		Land Use		
		Hay meadows/ Winter grazing	Grazing: Summer Rotation	
Maximum Temperature				
1998				
	July	0.7	0.5	NS
	August	0.2	0.3	NS
1999				
	July	0.6	0.6	NS
	August	0.4	0.4	NS
Temperature Range				
1998				
	July	0.7	0.4	NS
	August	0.5	0.5	NS
1999				
	July	0.7	0.5	NS
	August	0.5	0.5	NS
Mean Temperature				
1998				
	July	0.4	0.3	NS
	August	0.2	0.1	NS
1999				
	July	0.3	0.2	NS
	August	0.2	0.3	NS

Table 9. Comparison of differences (F) during approximately 1 hour flow time in maximum temperature, temperature range, and mean temperature during July and August of 1998 and 1999.

LITERATURE CITED

Adams, T. and K. Sullivan. 1989. The physics of forest stream heating: a simple model. Weyerhaeuser Research Report. TFW-WQ3-90-007.

Crowe, E. A., and R. R. Clausnitzer. 1997. Mid-Montane Wetland Plant Associations of the Malheur, Umatilla and Wallowa-Whitman National Forests. USDA Forest Service. Pacific Northwest Region. Technical Paper R6-NR-ECOL-TP-22-97.

Edinger, J. E., D.W. Duttweiler, and J. C. Geyer. 1968. The response of water temperatures to meteorological conditions. Water Resources Research. 4:1137-1143.

Halliday, D. and R. Resnick. 1988. Fundamentals of physics. 3rd ed. John Wiley & Sons Inc., New York.

Laird, W. E., M. H. Fillmore, G. D. Macdonald, and D. P. Christenson. 1988. Soil survey of Baker County area, Oregon. USDA, NRCS. US Gov. Print Office, WA, DC.

Larson, L. and P. A. Larson. 1997. The natural heating and cooling of water. Rangelands 19:6-8.

Lewis, T. E., D. W. Lamphear, D. R. McCanne, A. S. Webb, J. P. Krieter, and W. D. Conroy. 2000. Regional assessment of stream temperatures across Northern California and their relationship to various landscape level and site-specific attributes. Forest Science Project. Humbolt State University Foundation, Arcata, CA. pp.420.

McRae, G. and C. J. Edwards. 1994. Thermal characteristics of Wisconsin headwater streams occupied by beaver: implications for brook trout habitat. Transactions of the American Fisheries Society 123:641-656.

Meisner, J. D., J. S. Rosenfeld, and H. A. Regier. 1988. The role of groundwater in the impact of climate warming on stream salmonines. Fisheries 13:2-8.

Mosheni, O. and H. G. Stefan. 1999. Stream temperature/air temperature relationship: a physical interpretation. Journal of Hydrology 218:128-141.

NRCS. 2000. Ecological Site Descriptions. Oregon.

Raphael, Jerome M. 1962. Prediction of temperature in rivers and reservoirs. J. of the Power Division, Proceedings of the American Society of Civil Engineers 88:157-181.

Rosgen, D. 1996. Applied river morphology. Pagosa Springs, CO. Wildland Hydrology p 352.

Sinokrat, B. A. and H. G. Stefan. 1994. Stream water-temperature sensitivity to weather and bed parameters. J. Hydraulic Eng. 120:722-735.

Stefan, H. G. and E. B. Preud'homme. 1993. Stream temperature estimation from air temperature. Water Resources Bulletin 29:27-45.

Walker, J. H. and J. D. Lawson. 1977. Natural stream temperature variations in a catchment. Water Research 11:373-377.

Ward, J. V. 1985. Thermal characteristics of running waters. Hydrobiologia 125:31-46.