Stream Temperatures, Riparian Vegetation, and Channel Morphology in the Upper Grande Ronde River Watershed, Oregon

by

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Robert L. Beschta

The Upper Grande Ronde River Watershed in northeastern Oregon is considered important habitat for threatened stocks of chinook salmon (Oncorhynchus tshawytscha). Documented reductions in channel complexity and riparian vegetation within the watershed have increased concern over loss of viable habitat. An important component of salmonid habitat is stream temperature during critical summer periods. In general, annual maximum stream temperatures and diurnal fluctuations in the Upper Grande Ronde River were found to reflect local reach characteristics, position in the drainage, and large-scale changes in valley shape. Stream temperatures on the Grande Ronde River at a distance of 71 km from the watershed divide exceeded 14°C, the "upper preferred temperature" for chinook salmon, more than 90% of time in July of 1991 and in July and August of 1992. While the occurrence of temperatures above 14°C were less common in the headwaters of the Grande Ronde River, downstream of a large meadow (i.e., Vey Meadow) (29 km from the divide) 14°C was exceeded at least 60% of the time during the same three month period. Seven-day maximum stream temperatures on the Upper Grande Ronde River ranged between 17.9°C and 26.6°C in 1991 and between 19.1°C and 26.7°C in 1992. Diel fluctuations on the mainstem were greatest immediately below Vey Meadow (about 12°C) but tended to

stabilize at approximately 8°C at distances of over 49 km from the divide.

Maximum stream temperatures in tributaries of the Upper Grande Ronde River varied by as much as 11°C (during 1992), reflecting large differences in stream cover, aspect, and flow. The timing of annual maximums seemed to be strongly linked to aspect during 1992. In addition, the high-elevation, forested tributaries had annual maximum stream temperatures and diel fluctuations which were 3°C lower than those associated with more open, low-elevation sites.

Relationships between stream temperatures, riparian vegetation, and channel morphology characteristics were evaluated for 11 tributary reaches. Differences in stream cover, average flow velocity, bankfull depth and percent undercut bank were found to be significantly ($p < 0.1$) related to maximum stream temperatures and/or average August diel fluctuations based on linear regression models.

A stream temperature prediction model (i.e., TEMP-86) was found to be an accurate predictor of average hourly stream temperatures through short 250-m long reaches. An average WSTAT (a measure of model accuracy) of -0.18°C was calculated based on 11 reaches though two reaches led to consistent over- and under-predictions of downstream temperatures. A series of temperature simulations using TEMP-86 and combinations of wetted width and percent stream cover suggest that lower maximum daily stream temperatures would be observed through altered reaches if concurrent changes in both parameters occurred.

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INTRODUCTION

The populations of many salmon species (and stocks) are at critically low levels throughout the Pacific Northwest; this decline is directly attributable to upstream and downstream passage problems, alterations of fresh water habitat, over-fishing, hatcheries, water use, and ocean conditions. In the Upper Grande Ronde River Watershed in northeastern Oregon (Figure 1), the location of this study, one of the most immediate and important challenges facing resource managers is the evaluation and restoration of existing fresh water habitat. The role and significance of stream temperature in determining suitable fish habitat for salmon species is well known (Hicks et al, 1991) and it is precisely those factors which influence stream temperature, namely those associated with riparian vegetation and channel morphology, which are addressed in this study.

The Upper Grande Ronde River (UGRR) Watershed comprises 18% of the area of the Grande Ronde Basin. Historically the watershed contained over 25% of the total spring chinook salmon escapement of the basin and 5-7% of the total Snake River run (UGRRTWG, 1992). As late as 1957, the spawning escapement for spring chinook salmon (Oncorhynchus tshawytscha) was estimated to be over 12,000 within the basin; however, by 1990 the estimated escapement was only 725 chinook salmon (UGRRTWG, 1992). Conditions downstream from the Grande Ronde/Snake River confluence, namely dams, ocean harvest and ocean mortality, have apparently been the principal catalysts for the decrease in population, but wide scale habitat degradation within the UGRR Watershed throughout the last 50 years or more has apparently accelerated this decline (McIntosh, 1992; NWPPC, 1990).

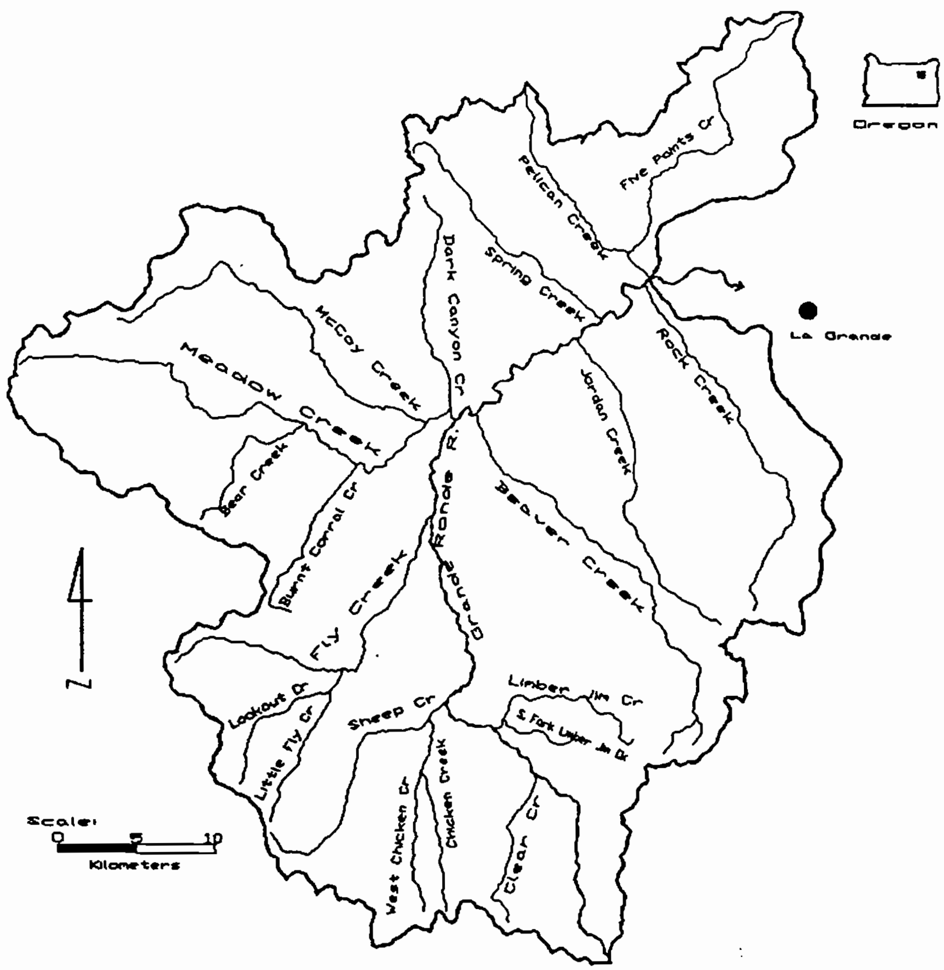


Figure 1. Project study area. Upper Grande Ronde River Watershed in the Blue Mountains of northeastern Oregon.

In response to declining fish populations, which were further impacted by the Tanner Gulch Wildfire in 1989, the "Upper Grande Ronde River Anadromous Fish Habitat Protection, Restoration, and Monitoring Plan" was developed (UGRRTWG, 1992). This plan, which established early action plans, management guidelines, and research needs, also identified specific tasks related to the inventorying and monitoring of resources. Task five, involving water quality (stream temperature) monitoring at 30 locations, provided the basis for this study.

Throughout the UGRR Watershed, widespread reductions in riparian vegetation have been observed since the late 1800's. However, the degree to which changes in riparian vegetation have led to basin-wide elevated stream temperatures is not known. Given this situation, stream temperature monitoring sites were established across the watershed to identify sites of significant thermal loading and the local factors governing this process. Because the complexity of channel features and diversity of plant species within undisturbed stream reaches create a highly heterogenous system, understanding the role of individual components in the riparian system is critical if rehabilitation projects are to be effective over a long period of time. The magnitude of the stream temperature problem, and the vast area over which it occurs, also necessitate providing resource managers with guidance in deciding where to focus their attention.

Study Objectives

The overall goal of this study is to characterize summer stream temperature patterns and factors which influence them within the UGRR Watershed. This study has three primary objectives:

1) describe the daily summertime stream temperature patterns, namely maximum temperatures, diel fluctuations and duration of maximum temperatures, for the UGRR and its tributaries;

2) determine the relationship between stream temperature patterns and environmental parameters such as channel morphology, discharge, and type and extent of vegetative stream cover;

3) determine the accuracy with which TEMP-86 predicts average hourly stream temperatures.

LITERATURE REVIEW

As with many water quality parameters, the temperature of a stream reflects an integration of numerous physical and biological factors. The relationships between many of these factors and stream temperature have been addressed in recent research. A discussion of this research includes the mechanisms involved in heat exchange, the environmental variables important in mediating this process, how the relative influence of these variables on stream temperature changes along a longitudinal gradient, and the effect of altered stream temperatures on chinook salmon.

Heat Exchange Processes in Streams

As water is an excellent absorber and retainer of heat, understanding stream thermal regimes requires the consideration of heat and energy fluxes both in and out of the system as well as changes in storage (i.e., temperature changes). An energy budget for any open body of water therefore needs to include the following energy transfer terms: net radiation, evaporation, conduction, convection, advection, and change in storage (Brown, 1983). For streams with little vegetative cover, the primary source of heat during clear sky conditions is shortwave (solar) radiation, whereas heat dissipation occurs via evaporation, convection, and conduction. Cooling from evaporation and convection reflect the temperature and vapor pressure gradients which exist between the air-water interface, while conduction between the stream and streambed is determined by the temperature gradient (Beschta et al., 1987; Oke, 1987).

Advection, which occurs via the mixing of waters with different temperatures, is closely associated with discharge. It is an important component which takes place primarily at the confluence of streams and along reaches where a net gain or loss of flow due to subsurface flow is observed. Brown (1969) observed that the resultant water temperature below the confluence of two streams is simply equal to the temperatures of the two streams weighted by their respective discharges (i.e., a simple mass balance calculation).

Riparian Vegetation and Stream Temperature

The combination of long days, high sun angles, clear skies, warm air temperatures, and low stream discharges results in maximum stream temperatures during the summer months in North America. Given this situation, riparian vegetation plays an important role in dampening both diurnal, and to a lesser extent, seasonal temperature fluctuations by intercepting incoming shortwave radiation during the day and limiting nighttime longwave radiational cooling (Beschta et al., 1987). The removal of vegetation surrounding low order streams is known to increase summer daily maximum temperatures (Brown and Krygier, 1970; Rishel et al., 1982; Holtby, 1988), the magnitude of summer diurnal fluctuations (Brown and Krygier, 1970), and both the frequency and duration of events during which summer stream temperatures rise above the lethal limit for many salmonids (Lynch et al., 1984). Sullivan and Adams (1990) observed that diel stream temperature fluctuations as large as 90% of diel air temperature fluctuations are possible in exposed reaches lacking vegetation.

The importance of streamside vegetation is apparent in a simple comparison of clearcuts versus patchcuts with buffer strips; Brown and Krygier (1970) estimated solar radiation additions for streams flowing through clearcuts to be 10 times greater than those flowing through forested reaches. No change in maximum stream temperature was observed due to harvesting when buffer strips were employed along several streams in the southern Cascade Mountains and the Oregon Coast Range (Brazier and Brown, 1973). A linear relationship between the amount of heat blocked (W/m^2) and angular canopy density, namely that portion of the canopy that shades a stream from direct solar radiation, was found when densities ranged between 20 and 80%. However, streams within broad, flat valleys were omitted from the analysis due to the occurrence of significant levels of side lighting which entered the streams without directly passing through the canopy. In Ontario, Barton (1985) found a stream, which was within an anomalously broad valley relative to others in his study, for which aspect was more important than percent canopy cover in affecting high stream temperatures.

In Barton's (1985) Ontario study, the influence of riparian vegetation cover in moderating downstream maximum temperatures was significantly reduced beyond one kilometer; a maximum of 52% of the variation in maximum temperatures was accounted for by the percentage of forested streambank for the kilometer above the temperature monitoring site. This result is in agreement with Sullivan and Adam's (1990) work which suggests that temperatures of downstream rivers are more responsive to local environmental conditions, and the underlying basin geomorphic relationships that control them, instead of riparian conditions in distant headwaters.

The removal of riparian vegetation has also been observed to alter the timing of maximum daily stream temperatures. Lee and Samuel (1976) report that following clearcutting of small forested streams in West Virginia, daily peak temperatures occurred at 15:00 hours, solar time, while in a neighboring control stream peak temperatures occurred at 20:00 hours. Although weekly average diel fluctuations were 3 to 4 times greater following clearcutting, there was no significant change in summer minimum temperatures. These observations suggest that removal of vegetation can significantly alter both the timing and duration of elevated stream temperatures.

In western Oregon streams, Brown (1969) found little cooling occurred when previously heated streams (from streamside harvest of vegetation) flowed through downstream forested reaches. Brown attributed this lack of cooling to the very small vapor pressure and temperature gradients (hence low rates of evaporative and convective cooling) as well as minor inputs of direct and diffuse solar radiation near the surfaces of small forested streams. Cooling rates of headwater streams following heating in clearcuts were also evaluated by Andrus (1993). Results indicated that low gradient headwater streams cooled the quickest, an observation attributed to slower travel times and thus more time for heat transfer to occur between the water and air. However, even in these low gradient tributaries, streams needed to flow at least 300 m, distances greater than those within the clearcuts, through a downstream forested reach before the heat gained within the upstream clearcut was dissipated. Andrus also attributed groundwater dilution to be an important component in the cooling process. In semi-arid regions where low relative humidities are common, such as may exist in northeast Oregon, evaporative energy loss stemming from steep vapor pressure gradients may facilitate quicker cooling than within streams in more humid regions.

Channel Morphology and Stream Temperature

Channel characteristics such as wetted width, average depth, water velocity, channel complexity (including the amount of intergravel and subsurface flow), substrate type, and gradient can affect stream temperature patterns in so far as they influence energy transfers to or from a stream. The following equation by Brown (1970), which predicts stream temperature increases following canopy removal (for small streams in western Oregon), demonstrates the relationship between these channel characteristics and changes in stream temperature:

$$\Delta T = \frac{Nh*A*k}{Q} = \frac{Nh*L*k}{D*V}$$

where Nh = net rate of heat per unit of area (Watts/m^2)
A = total stream surface area (m^2)
Q = stream discharge (m^3/s)
k = coefficient to convert heat load to a change in temperature
L = stream length (m)
D = stream depth (m)
V = stream velocity (m/s)

For a given discharge, Brown's equation predicts that a wide, shallow stream will heat up faster than a deep, narrow one. Sullivan and Adams (1990) have also indicated that stream temperature increases are inversely related to channel depth. Additionally, they found strong correlations (for streams with comparable discharge), between decreases in channel depth and increases in diurnal fluctuations. The greater response of smaller streams to heat inputs stems from the smaller mass of water per unit of surface area heated.

In 1972 Brown made further changes to his stream temperature prediction model to account for the influence of substrate. Brown (1972) noted that the amount of bedrock and substrate greater than 0.25 m in diameter in the active channel can influence stream temperatures in a number of ways. He found that between 15-20% of the net incoming radiation was absorbed by bedrock and decreased the magnitude of daily temperature fluctuations. Once heated, bedrock also serves to increase minimum daily stream temperatures that typically occur in the early morning hours.

The relationships between geomorphic characteristics of a channel and stream temperatures have not been extensively studied; this situation is (at least in part) attributable to the subtle and complex nature of riparian systems. An example of this complexity is indicated in the relationship between aggrading reaches of a stream in western Oregon, which Lyons and Beschta (1983) found to cause widening of a channel, and daily maximum stream temperature fluctuations. According to Brown's equation, stream temperature would be expected to increase in response to this widening. However, McSwain (1987) noted that local channel widening (caused by extensive sediment and debris loading from mass valley wall failures) produced a decrease in maximum daily stream temperatures. McSwain's observations indicated that a large proportion of flow was subsurface. In addition, Andrus (1993) observed a 4.1°C decrease in maximum daily stream temperatures through a 245-m long clearcut on Phillips Creek, a small, headwater stream in northeast Oregon. Apparently the clearcut included a segment at which about 66% of the streamflow went subsurface. The impact of these cooler subsurface inflows on stream temperature regimes can be quite significant, particularly during the summer months when mean daily stream temperatures are greatest and base flows are at their lowest (Adams and Sullivan, 1990).

Bilby (1984) identified four types of cool water sources along Thrash Creek, a fifth-order stream within the Coast Range of western Washington: lateral seeps, pool bottom seeps, cold tributary mouths and flow through bed. Lateral seeps were the most common, accounting for 64% of the cool water sources, though they comprised only 2.9% by volume of the 3.5 km reach. However, he noted that seeps were potentially limited as a thermal refuge for aquatic organisms due to depressed levels of dissolved oxygen (relative to ambient surface water) found within the seeps. Thermal stratification was not observed in any of the deep pools where seeps were absent.

In addition to Bilby's (1984) work, a survey of cool water seeps along Joseph Creek in the Wallowa Mountains in northeast Oregon found thermal stratification associated with pool and seep types comparable to those described by Bilby (J. Ebersol, Department of Fish and Wildlife, Oregon State University). The greatest stratification was found in pools of low gradient reaches where maximum temperature differences of 3.8°C to 6.4°C were observed. These pools were generally, by volume, the largest units in the system and received relatively small inflows (thus low turbulence). Additionally, Ebersol found diel fluctuations between two cold pools varied considerably with respect to the diel fluctuations in the mainstem. In one pool, diel fluctuations of 1 to 2°C were observed while in the mainstem fluctuations were above 20°C. However, in the second pool, diel fluctuations were approximately 10°C and hourly temperatures closely tracked those in the mainstem. Ebersol attributes the extreme dampening of diel fluctuations in the first pool to a large groundwater signature.

Longitudinal Trends in Stream Temperature

In general, stream temperatures increase with increasing distance from a watershed divide (Ward, 1985). For large watersheds in Washington's western Cascades, a specific distance from the headwaters at which mean air temperatures equal mean stream temperatures, termed the "threshold distance", has been observed (Sullivan and Adams, 1990). Below this location, air temperature is thought to be the most influential environmental factor regulating stream temperatures. In headwater streams, Sullivan and Adams (1990) indicate stream temperatures are strongly regulated by riparian vegetation and influxes of subsurface flow. However, riparian vegetation provides progressively less shade with increasing distance from the divide due primarily to stream widening, and the greater volume of water present in large rivers makes small influxes of cool subsurface water less thermally important. A model developed by Adams and Sullivan (1990) uses four primary environmental parameters, namely changes in stream depth, relative contribution of groundwater, amount of exposure to shortwave radiation, and mean air temperature to explain much of the variation in stream temperatures.

In Washington's western Cascades, Sullivan and Adams (1990) suggest that threshold distances correspond to average stream depths of approximately 0.6 to 1 m or distances of 40 to 60 km. However, the threshold distance is not static in a watershed and is susceptible to alterations stemming from land use activities and natural variations in climate. For instance, during drought years when decreases in channel depth are observed due to lower flows, a slight downstream shift of the threshold distance might be expected.

Land Use and Stream Temperature Changes

The effect of various land use activities on stream temperatures is largely site-dependent and often difficult to assess. Activities such as road construction and logging, which sometimes cause sedimentation, may affect channel width, water depth, and water velocity which in turn alter the solar radiation loading per unit mass of water for a particular reach of stream. Historical road construction within riparian corridors has also reduced riparian vegetation occurring within right of ways and in some cases has constricted the water to a single channel. Given such scenarios, it is easy to appreciate the complex nature of management disturbances, particularly historical practices, and their multiple effects on stream temperatures.

Beschta and Taylor (1988) found a positive correlation between an index of cumulative harvesting effects and maximum stream temperatures. Their index incorporated watershed harvest records and a relationship (developed by Summers (1983)) between the angular canopy density removed during clearcut harvesting and the rate of canopy recovery following harvest. Between 1955 and 1984, maximum daily stream temperatures (averaged over the 10-warmest days) increased at least 6°C while minimums increased 1 to 2°C . However, maximum stream temperatures decreased on Salmon Creek after 1980. Decreased levels of harvest activity since 1972 and the recovery of streamside vegetation facilitated by an absence of major flow events were offered as possible reasons for the decrease.

In a study on Steamboat Creek in southwest Oregon, Holaday (1991) found significant decreases in maximum stream temperatures in tributaries which had a high proportion (>20%) of the stream length adjacent to harvest units. Only one creek, Boulder Creek, exhibited a slight (though non-significant) increase in maximum stream temperatures between 1969 and 1990. As this stream was the only tributary where logging was absent, the decreases in maximum stream temperatures found in other tributaries are thought to be the result of the re-establishment of riparian vegetation and the implementation over the past 20 years of a wide range of management guidelines designed to protect and maintain riparian vegetation.

Land use activities which incur changes in soil temperature may also alter stream temperatures. In the eastern United States, increases in soil temperature stemming from the removal of upslope vegetation, namely timber harvesting or grazing, may function to elevate the temperature of subsurface flow and water contained in shallow storage areas (Swank and Vose cited in Bermann and Quinn, 1991). The affect of these activities on stream temperatures, therefore, is contingent on the hydrologic pathways which connect hillslopes to streams.

Significant alterations to stream temperatures have also been observed associated with dams. Ward (1985) noted dramatic changes from natural thermal conditions were observed in reaches below large dams. Large, deep reservoirs that release water from the hypolimnion can markedly decrease annual and diel temperature ranges, producing warm winter and cool summer conditions and altering natural thermal periodicity patterns. At a smaller scale, natural beaver dams can also influence stream temperatures. On Bridge Creek in central Oregon, Lowry (1993) observed a three month lag time between stream temperatures in a beaver pond and groundwater temperatures below the dam. As a consequence, during warm summer months the relatively cooler groundwater associated with late-winter aquifer recharge near the pond may represent a localized "cool water" source to the stream below the dam.

Biological Effects of Stream Temperature Change

All fish are poikilotherms or cold blooded organisms and thus have metabolic rates which are directly affected by ambient stream temperature. Therefore, large and long-term deviations from a normal thermal regime are potentially physiologically stressful and may cause irreversible damage to such organisms (Bjornn and Reiser, 1991). While preferred temperatures for fish vary with species, "Unsuitable temperatures can lead to disease outbreaks in migrating and spawning fish, altered timing of migration, and accelerated or retarded maturation" (Bjornn and Reiser, 1991).

One conventional way for quantifying fish tolerance to thermally stressful conditions defines upper and lower lethal limits as the temperatures at which 50% of the species die after 1000 minutes (16.7 hours) of exposure under controlled conditions. These Incipient Lethal Temperatures (ILT) were first determined by Brett (1952). For chinook salmon, the upper and lower lethal limits are 25.1°C and 0.8°C, respectively. An alternative upper value, termed the Critical Thermal Maxima, which is arrived at by the slow heating of fish until a point where avoidance behavior (via swimming) is no longer feasible, is 27.6°C (Becker and Genoway, 1979). Preferred rearing temperatures for chinook salmon, determined by observing the stratum within a vertical temperature gradient where individuals tended to congregate, are thought to be between 12 to 14°C (Brett, 1952).

Observations at three streams which experienced virtually complete elimination of riparian vegetation due to the 1980 eruption of Mount St. Helens (Martin et al., 1986) suggest that the death of coho salmon during the summer of 1981 stemmed from the length of time spent in water over 25°C (where stream temperatures did not exceed 28°C). Mortality was also strongly correlated with maximum diel stream temperatures during August within eight study sites where riparian vegetation was reduced. These findings suggest the importance of both maximum stream temperatures as well as the range of diel fluctuations in affecting fish populations.

Additional temperature requirements concerning spawning and incubation as well as time of emergence and migration have also been studied for different salmonid species. In a summary of the current knowledge of salmonid habitat requirements, Bjornn and Reiser (1991) report that adequate spawning and incubation temperatures for fall chinook salmon and for winter and spring chinook salmon range from 5.6 to 13.9°C and from 5 to 14.4°C, respectively. As temperatures during embryo incubation may be the primary evolutionary factor that has determined the time of spawning (Heggberget 1988, from Bjornn and Reiser, 1991), the extent to which current stream temperatures deviate from the natural range can be an important factor affecting fisheries. For chinook salmon, the time to emergence following fertilization was 192 days in 6°C water and only 85 days in 12°C water (Bjornn and Reiser, 1991). Within the Carnation Creek drainage in British Columbia (Holtby et al., 1988) an early emergence of fry was observed following logging of riparian vegetation. In eastern Oregon streams, however, winter temperatures are more likely to decrease following harvesting of riparian vegetation as a result of a loss of insulation and increases in radiative cooling (loss of longwave radiation) so that emergence may be later.

The behavior and ability of salmon to utilize different habitat types (namely pools and riffles) are also broadly determined by stream temperatures. Utilization of cool water pockets in a reach of the John Day River increased greatly when stream temperatures rose above 24°C (H. Li, Department of Fish and Wildlife, Oregon State University). Similarly, an aggregation of coho salmon was observed at a cool water plume in Schultz Creek, a tributary of the Green River near Mount St. Helens, where surface water temperatures climbed above 22°C (Bisson et al., 1988). In a much larger system, namely the Columbia River, Bermann and Quinn (1991) observed spring chinook salmon during the summer of 1989 holding for long periods near islands (reflecting possible sites of cool water seeps). This study suggests the importance of summer thermal refuges for spring chinook salmon since it is only shortly before spawning that these fish leave for their respective spawning grounds. Additionally, Bjornn (1978) observed high densities and normal growth rates of juvenile chinook salmon and steelhead (*Salmo gairderi*) in streams with daily maxima of up to 24°C for periods of less than one hour. In larger Idaho streams, however, Bjornn reports (from Mabbot, 1982) that where maximums ranged from 24 to 26°C and minimums between 15 to 16°C, most juveniles moved upstream into tributaries.

Conclusions

Much of the current research on stream temperatures in the western United States has focused on small forested streams. As a result of this research, many commonly used stream temperature prediction models have been developed for low-order (<5) streams. The assumptions upon which these models are based, namely that stream temperatures are largely determined by local reach features, continues to be debated (Adams and Sullivan, 1990). Downstream of a threshold distance, mean stream temperatures may be largely regulated by mean air temperatures. Though elevated temperatures in headwater streams do not necessarily result in elevated downstream temperatures, studies evaluating the longterm effects of land use activities on summertime stream temperatures (Beschta and Taylor, 1988; Holaday, 1991) indicate that human influences throughout a watershed can have significant affects on elevated stream temperatures.

DESCRIPTION OF STUDY AREA

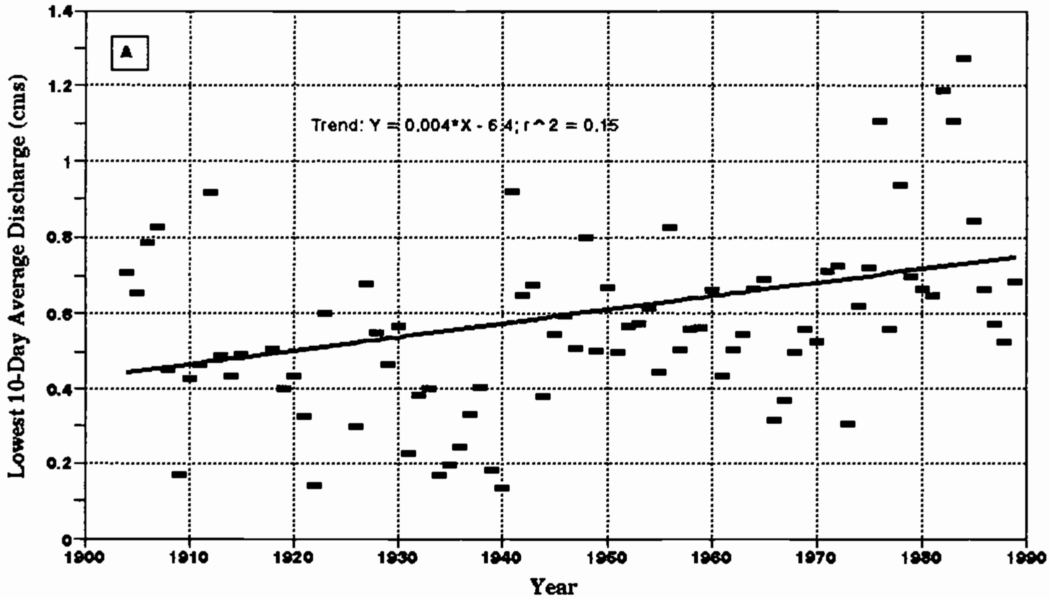
Location

The Grande Ronde River, a major tributary of the Snake River, is located in northeast Oregon and extends 342 km from the headwaters to the mouth. The Upper Grande Ronde River Watershed, the area of focus in this study (Figure 1), extends 71 km from the watershed divide. The watershed is 1750 square kilometers in area and is located in the Blue Mountains west/southwest of La Grande, Oregon. The watershed is mountainous and widely timbered, though broad valleys with open meadows are common in unconstrained reaches.

Hydrology and Low Flows

Runoff in the watershed is primarily derived from snowmelt, with peak flows typically occurring in the spring. The mean annual discharge of the Grande Ronde River at La Grande (station number 13333000), which has drainage area of 1750 km^2, is 10.87 m^3/s based on 81 years of record. Springs, which are scattered throughout the UGRR Watershed, generally occur at lower reaches of creeks and in the northern part of the subbasin which is underlain by the basaltic lava rocks (Hampton and Brown, 1964).

Low flows of the Grande Ronde River at La Grande average of 0.538 m^3/s, ranging between a high of 1.274 m^3/s in 1984 and a low of 0.110 m^3/s in 1940. Regression analysis of USGS data from La Grande (#13319000) for the years 1904 to 1988 suggests that baseflows have been increasing by 0.002 m^3/s per year since 1904 (Figure 2). The mean Julian day of the low flow is 245 or September 2nd. Additionally, the timing of low flows, as shown in Figure 2, seems to have a slight increasing trend since 1904, suggesting that present low flows occur 20 days later than in 1904. Widespread



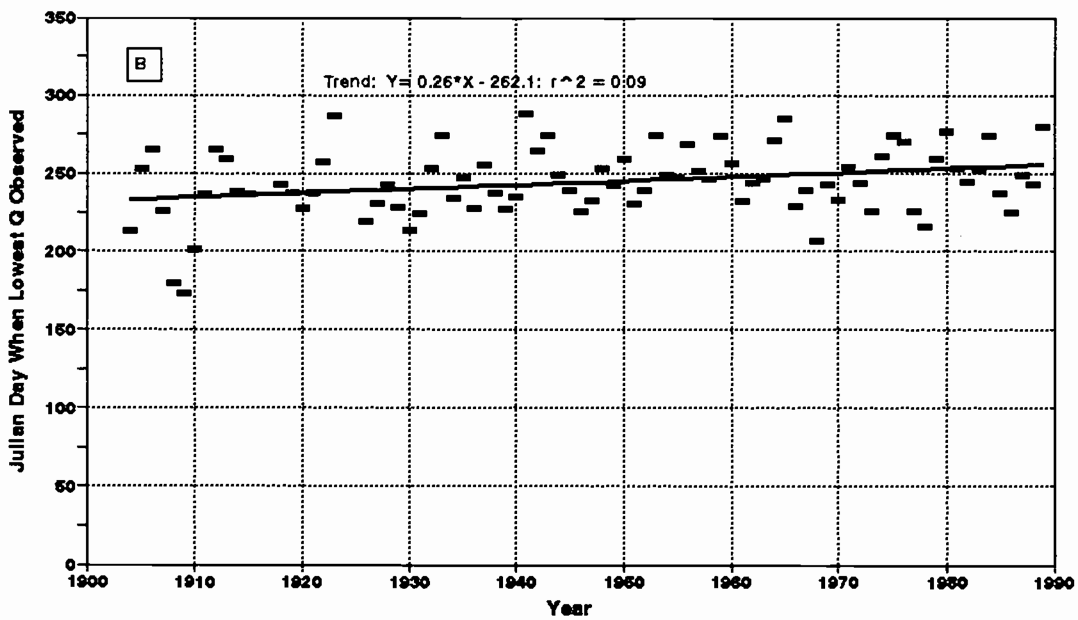


Figure 2. Linear regression of (A) lowest 10-day average discharge (measured in m^3/s (cms)) and (B) timing of 10-day low flow for the Upper Grande Ronde River at La Grande regressed on years 1904-1990.

reductions in foliage resulting from the combined effects of timber harvesting, insect defoliation, and livestock grazing may have reduced transpiration losses from the watershed during the period of record. Larger baseflows can buffer streams by providing a greater amount of thermal inertia, while their occurrence later in the season, when inputs of solar radiation are declining, also facilitates lower stream temperatures (Beschta et al., 1987). Both of these trends would tend to moderate or reduce summer maximum stream temperatures in the basin.

Low flows during the summers of 1991 and 1992, here represented by annual 7-day minimum values, were 0.496 m^3/s and 0.411 m^3/s and occurred on September 22 and August 16, respectively (Table 1). Additionally, the probability of lower flows occurring during 1991 and 1992 are 33% and 23%, respectively. As shown in Table 2, mean monthly flows during the months of June through September in 1991 were close to the long term means for every month except September. This contrasts with 1992 in which June exhibited the lowest mean flow on record. Additionally, the three months following June of 1992 had probabilities of occurrence less than 17% and consequently represent a period of unusually low flow. Estimates of mean flows at La Grande for the months of June to September were calculated by regressing Rondowa data (USGS #13332500) against La Grande (USGS #13319000) for the years between 1926 to 1988.

Climate and Precipitation

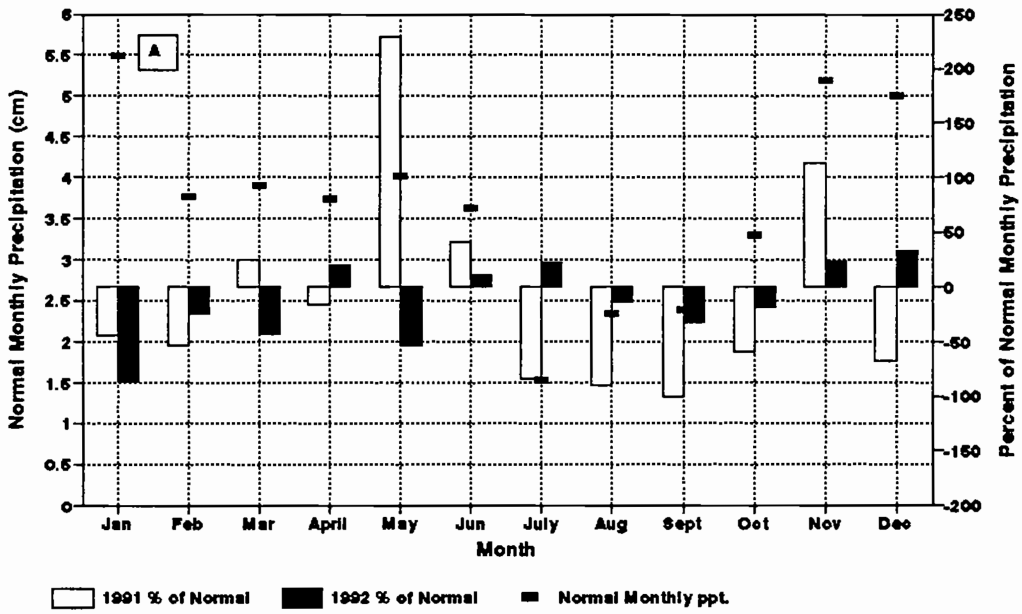
The UGRR Watershed receives an average of 40 centimeters of precipitation annually, approximately 95% of which is relatively evenly distributed over the months of October to June. By June of the average water year, 85 to 90% of the precipitation has fallen. As Figure 3 indicates, monthly precipitation was largely below

Table 1. Probability of occurrence of 1991 and 1992 annual low flow and the timing of the minimum 7-day low flow for the Upper Grande Ronde River at La Grande.

Year	Low Flow (m^3/s)	Probability of Occurrence	Timing of Low Flow (Julian Day)	Probability of Occurrence
1991	0.496	33.4%	9/22 (234)	30.5%
1992	0.411	23.2%	8/16 (197)	2.4%

Table 2. Probability of occurrence of summer mean flow for 1991 and 1992 for the Upper Grande Ronde River at La Grande.

Month	1991 Mean Flow (m^3/s)	Probability of Occurrence	1992 Mean Flow (m^3/s)	Probability of Occurrence
June	9.486	43.9%	4.276	11.5%
July	2.690	57.0%	1.671	31.0%
August	0.765	51.0%	0.680	34.0%
September	0.595	17.7%	0.736	50.0%



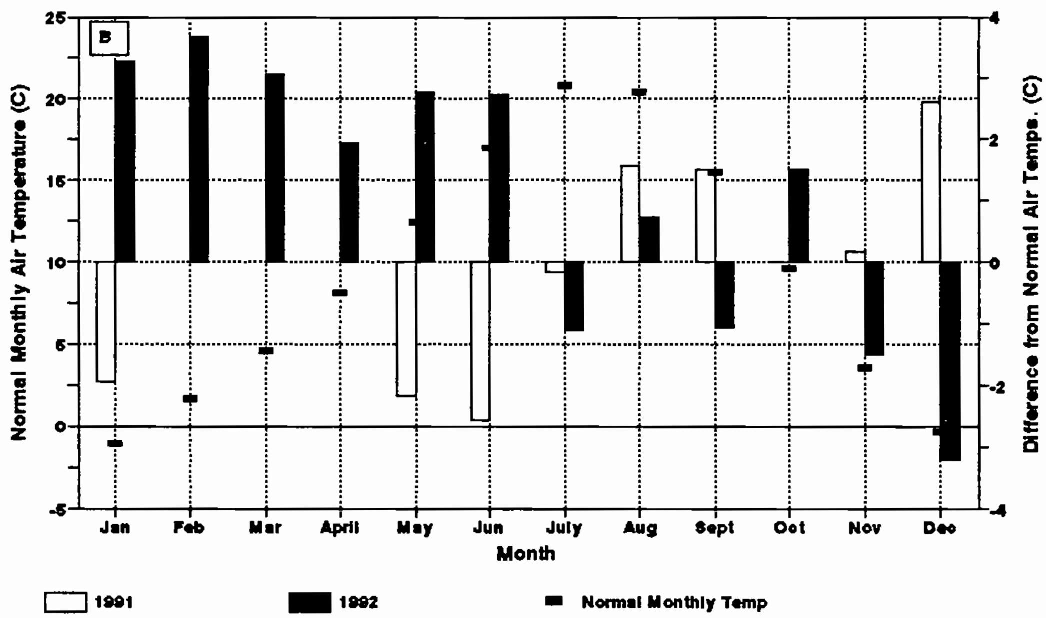


Figure 3. Normal monthly (A) precipitation and (B) air temperatures at La Grande, 1965-1992.

average during the winters of both 1991 and 1992. An evaluation of mean annual precipitation (measured in La Grande) since 1900 indicates a slight decreasing trend (Figure 4) while average yearly snow depth, based on April 1 water equivalents, reveals a rather pronounced downward trend between 1939 and 1990. The recent drought period, which began in 1985, is also apparent when looking at mean annual precipitation since 1985 (Figure 4).

Summers in the Upper Grande Ronde Watershed are generally hot and dry, with day time highs around 30°C and lows near 12°C. July is typically the warmest month of the year, having a monthly mean of 20.8°C (69.4°F) (Figure 3b) while January is the coolest, with a mean of -1.1°C (30.1°F). In 1991, average monthly temperatures during the months of May, June and July were 2.2°C, 2.6°C, and 0.2°C below average, respectively. August and September, however, were 1.6°C and 1.5°C above normal, respectively. The first six months of 1992, however, were all more than 1.9°C above normal, with May and June being nearly 2.8°C greater than average. The months of July and September were both approximately 1.1°C below normal, while August was 0.7°C above the monthly average. In general, 1992 was characterized by consistently high air temperatures until July, at which time a series of several major storms moved through the region and kept air temperatures relatively cool.

Topography and Geology

The elevation of the UGRR Watershed ranges from a low of 909 m (2982 ft) below Hilgard Junction (on Interstate 84) to a maximum of 2377 m (7800 ft) in the Elkhorn Range. The entire northern slope of the Elkhorn Range flows into the Upper Grande Ronde River within the prominent east-trending downwarp called the Grande Ronde Syncline. The syncline or trough is a prominent feature of the Grande Ronde from La Grande, where it is buried by recent river-washed alluvium,

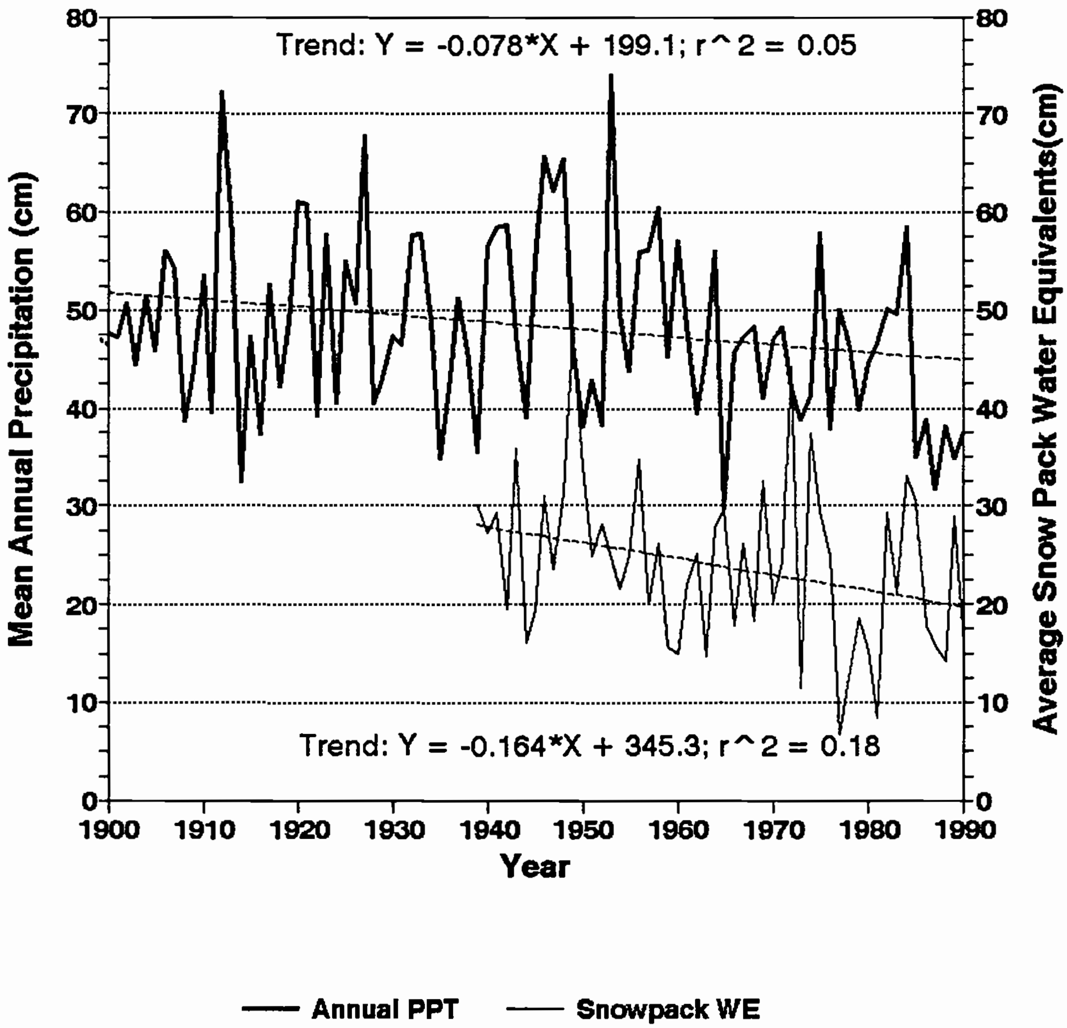


Figure 4. Linear regression of mean annual precipitation at La Grande (1904-1990) and April 1 snowpack water equivalents, for the Upper Grande Ronde River Watershed at Beaver Creek (1941-1990).

to the confluence with Meadow Creek (approximately 29 km upstream), at which point it underlies Meadow and Burnt Corral Creeks (Hampton and Brown, 1964). The Columbia River Basalt is the main bedrock unit in the watershed which broadly consists of basal basalt flows and platy andesite flows. The Bald Mountain Batholith, an intruded igneous rock having granular texture, can be found throughout the headwaters in the southwestern part of the watershed. The intrusive rocks in the batholith contain approximately 25% dark minerals, namely biotite and horneblende, which typically weather into a sandy soil less than 1.5 m thick. The rock itself is tight and poorly permeable. Additionally, a highly permeable conglomerate of sand, silt and clay, upwards of 76 m thick and approximately eight kilometers in area can be found near Starkey. This tertiary rock, called a Fanglomerate, overlies the Columbia river basalt and represents deposition during faulting along the Grande Ronde Syncline. The syncline is also intersected by many northwest trending faults, the frequency and intensity of which increases with distance away from the Elkhorn Range.

In general, creeks which drain the older, metamorphic and igneous rocks have a dendritic pattern while those draining the layered tertiary volcanic rocks have a trellis pattern. During periods of low flow, most streams that drain the older metamorphic and intrusive igneous rocks of the Elkhorn range are dry. Streams draining areas where tertiary volcanic rocks overlie the older metamorphic and igneous rocks maintain a rather constant though small flow. According to Hampton and Brown (1964),

> "the alluvial fill found in both the Beaver Creek and Spring Creek valleys is derived, in part, from the Fanglomerate unit and forms small ground-water reservoirs of potential importance."

Vegetation

According to the species zonation of Franklin and Dyrness (1973), the Upper Grande Ronde Watershed contains principally two vegetation zones, namely grand fir (Abies grandis) and ponderosa pine (Pinus ponderosa). The grand fir zone is found primarily in mid-slope locations between 1500 to 2000 m and in environments commonly characterized by moderate soil moisture and temperature regimes. In contrast, the ponderosa pine zone, common between 900 to 1500 m in elevation, frequently occupies relatively dry forest sites with well drained sandy soils, large diel air temperature fluctuations and minimal summer precipitation. Besides ponderosa pine and grand fir, the two zones consist primarily of lodgepole pine (Pinus contorta), white fir (Abies concolor), Engelmann spruce (Picea englemannii), western larch (Larix occidentalis), and Douglas-fir (Pseudotsuga menziesii). Mountain meadows, which are most common to the grand fir zone, typically occur along stream courses with gentle gradients.

The valley bottoms tend to be covered with scattered conifers as well as the following deciduous trees and shrubs: thinleaf alder (Alnus incana), aspen (Populus tremuloides), black cottonwood (P. trichocarpa), willow species (Salix eastwoodia, S. bebbiana, S. scouleriana, S. geyeriana, S. lasiandra, S. exigua exigua, S. melanopsis var exigua, S. rigida, S. sitchenis, and S. drummondii), chokecherry (Prunus virginiana), hawthorn (Crataegus columbiana), dogwood (Cornus nuttallii), shiny-leaf spiraea (Spiraea betufolia), snowberry (Symphoricarpos albus), little wood rose (Rosa gymnocarpa), western serviceberry (Amelanchier alnifolia) and numerous species of currant (Ribes spp.).

Land Use History

The magnitude of human disturbance within the UGRR Watershed has been intensive and varied. The employment of splash dams, sheep and cattle grazing, mining, timber harvesting, and encroachment of roads in riparian areas have all contributed to significant local, as well as large scale, modifications to channels.

The two earliest documented activities were the use of splash dams and livestock grazing, though reductions in beaver populations as a result of beaver trapping may have occurred prior to both of these activities. Splash dams, temporary structures built to capture large quantities of water which were then used to flush logs down channels, were used from the late 1800's to 1919 along the tributaries of Dark Canyon Creek, Meadow Creek and Fly Creek as well as on the Grande Ronde River below Vey Meadow and Perry (McIntosh, 1992). McIntosh reports that overgrazing by sheep and cattle may have occurred by as early as the 1880's. Since 1911, however, livestock grazing has apparently decreased by approximately 78%. However, increases in the Elk population since the 1950's have led to rather stable levels of total grazing activity (51,000 Animal Unit Months in 1990).

Significant road construction in the UGRR Watershed began in the 1950's (Figure 5), in conjunction with a greater demand for timber. The Grande Ronde Lumber Company harvested prior to the 1950's, but before 1941 averaged only 36 million board feet per year (McIntosh, 1992). Levels of timber harvest, according to Grande Ronde Lumber Company records, averaged 98 mmbf/year between 1941 and 1990. Road construction reached a peak between 1978 and 1989 when the length of road doubled from 7240 to 16,000 km.

Dredging for gold in the headwaters of the Grande Ronde, between approximately kilometers 10 to 20 from the watershed divide, occurred during the early 1900's (McIntosh, 1992). Large portions

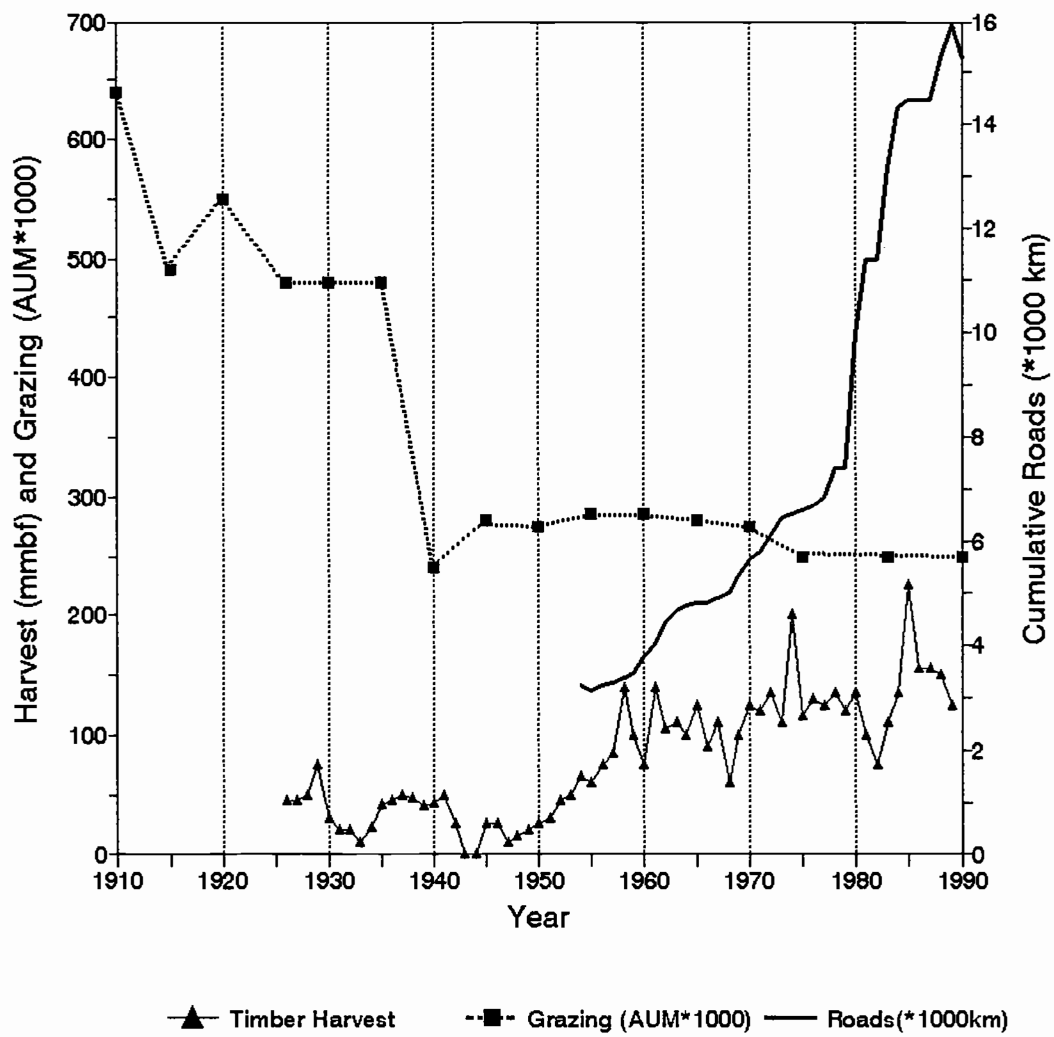


Figure 5. Trends in volume of timber harvest, livestock and elk grazing (Animal Unit Month) and road construction in Wallowa-Whitman National Forest (McIntosh, 1992).

of the floodplain and active channel were dredged and mine tailings, composed of large boulders, cobble, and gravel are still present and serve as a reminder of the extent to which this activity has altered and constrained channels. Channelization has also occurred along McCoy Creek just above its confluence with Meadow Creek. This activity, which occurred following the major flood of 1964, created a single, deeply incised channel. In general, however, mining and channelization were limited to these 2 reaches.

Outbreaks of forest disease, frequently brought on by prolonged drought and widespread mortality, have been prevalent since the early 1900's. Mountain Pine Beetle outbreaks in particular have been a rather continuous occurrence since the early 1900's, with an epidemic infestation in the 1970's.

The UGRRTWG (1992) suggest that the above human influences and disease outbreaks have led to an estimated 52% reduction in stream shade in the watershed. Given the importance of streamside shade in moderating stream temperatures (Beschta et al., 1987), the occurrence of widespread increases in summer stream temperature may reflect the watershed's long history of land use activities. Human influences are also thought to be largely responsible for an average reduction in number of pools of 65% in Rock Creek, Five Points Creek, Jordan Creek, Meadow Creek, Sheep Creek, McCoy Creek, Beaver Creek and the Grande Ronde River between 1941 and 1990 (McIntosh, 1992). In light of the importance of pools during periods of elevated stream temperatures, human influences in the watershed have contributed to a significant reduction in viable salmon habitat during thermally stressful conditions.

METHODS

Instrumentation

Starlog Data Loggers, programmed to scan every five seconds and record average, minimum and maximum hourly values, were used in conjunction with temperature probes, weather stations, and pressure transducers. Temperature probes, accurate to ±0.2°C, were placed within well mixed sections at each temperature site, typically in the thalweg of riffles and glides and out of direct exposure to sunlight. Weather stations were used to collect relative humidity, incoming solar radiation and air temperature. Stations were placed between one and two meters above the ground and within two meters of the streambank. Pressure transducers were used in conjunction with weather stations to measure average and maximum hourly water depths (stage). In addition, periodic discharge measurements near individual sensors were made using a Marsh-McBirney current meter and standard USGS protocols.

Site Selection and Description

Thirty data loggers were utilized during the summers of 1991 and 1992[1] within the UGRR Watershed (Figure 6 and Table 3). Data loggers were deployed over a broad area in order to characterize the thermal patterns of both the Grande Ronde River along a longitudinal gradient as well as its principal tributaries. Six data loggers were deployed on the main stem of the Grande Ronde River above Five Points Creek (Site 2). As is shown in Figure 6, Site 25, at an elevation of 1389 m and 15.4 km from the drainage divide, represents the upper-most site on the Grande Ronde River. Additional loggers

[1] In 1992 one additional data logger was used (to monitor temperatures at Site 32) while the logger at Site 11 was removed (due to the presence of an ODFW logger in the same reach) and placed at Site 31.

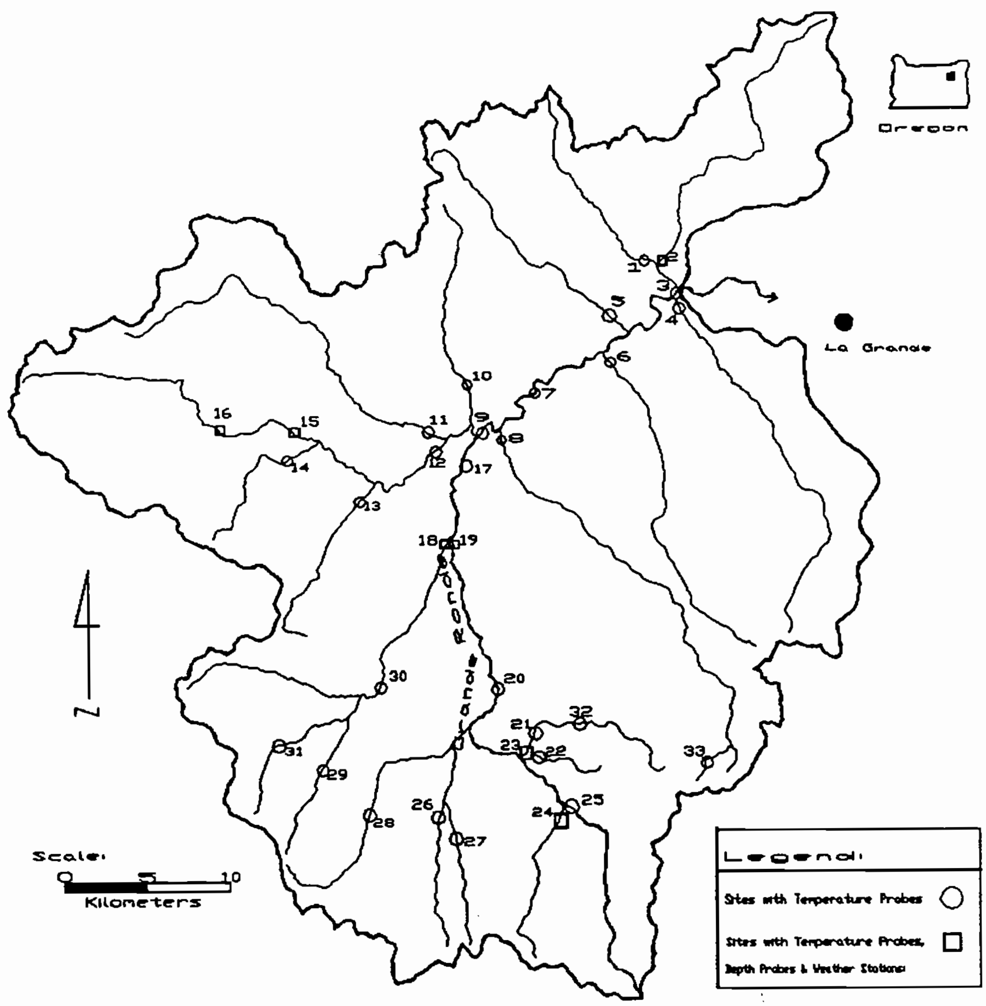


Figure 6. Stream temperature monitoring sites in the Upper Grande Ronde River Watershed during the summers of 1991 and 1992.

Table 3: Site description of temperature monitoring sites in the Upper Grande Ronde Watershed (* = 1992 only; ** = only two day record in 1992).

Site	Site Location	Drainage Area (km^2)	Gradient (percent)	Elevation (meters)	Aspect (deg)	Stream Order
1	Pelican Creek	73.1	2.4	933	132	3
2	Five Points Creek	106.2	1.6	933	207	3
3	Grande Ronde @ Five Points Ck	1563.4	0.3	905	55	5
4	Rock Creek	127.2	1.4	908	325	3
5	Spring Creek	62.1	1.4	942	132	4
6	Jordan Creek	50.2	1.4	942	343	3
7	Grande Ronde @ Red Bridge S.P.	1180.8	0.5	966	30	5
8	Beaver Creek	154.0	1.3	991	316	4
9	Grande Ronde @ Meadow Creek	1008.5	0.5	1000	17	5
10	Dark Canyon Creek	42.1	2.4	1049	175	3
11	McCoy Creek	147.0	0.8	1036	129	3
12	Meadow Creek near road 2137	268.5	0.6	1024	94	4
13	Burnt Corral Creek	35.6	1.9	1100	29	3
14	Bear Creek	28.6	0.9	1167	43	2
15	Meadow Creek near road 2120	128.3	0.5	1128	111	3
16	Meadow Creek 3 mi above 2120	114.4	0.5	1177	115	3
17	Beaver Pond near Starkey store	740.0	0.5	1010	17	5
18	Fly Creek @ Grande Ronde	129.8	1.4	1061	25	4
19	Grande Ronde @ Fly Creek	372.0	1.5	1058	344	5
20	Grande Ronde below Vey Meadow	324.6	0.5	1219	336	5
21	Limber Jim Creek above S. Fork	34.4	1.7	1323	282	3
22	South Fork Limber Jim Creek	9.6	7.6	1311	290	2
23	Limber Jim Creek below S. Fork	46.0	1.6	1305	275	3
24	Clear Creek	28.5	1.5	1389	15	3
25	Grande Ronde @ Clear Creek	69.3	0.5	1389	342	3
26	West Chicken Creek	21.8	1.7	1317	0	2
27	Chicken Creek	24.7	2.5	1335	344	2
28	Sheep Creek	47.3	1.2	1332	37	3
29	Little Fly Creek	23.3	1.5	1396	23	3
30	Fly Creek below Fly Valley	64.0	0.6	1308	95	4
31**	Lookout Creek	9.6	0.9	1454	15	2
32*	Limber Jim above N Fork	21.4	2.4	1390	294	2
33**	Beaver Meadow on Beaver Creek	4.3	2.4	1530	32	1

were placed below Vey Meadow (29 km), above the confluence with Fly Creek (40.7 km), below the confluence with Meadow Creek (49 km), at Red Bridge State Park (56 km) and just above Five Points Creek (70.9 km). The Grande Ronde at Five Points Creek is at an elevation of 905 m and has a northeast aspect of 55°. Tributary sites included mostly second or higher order creeks. In some instances, private land ownership and difficult access limited the placement of data loggers. Table 3 lists all of the locations at which a data logger was deployed during at least one of the two years of the study. Weather stations and pressure transducers were deployed at Sites 2, 15, 16, 18, 19, 23 and 24 (denoted by squares in Figure 6).

1991 Field Season

The primary objective of the 1991 field season was the selection of sites for monitoring stream temperatures. The Starlog Data Loggers and sensors were deployed and initial discharge measurements were made between July 27 and August 1. Between September 25 and October 1, data loggers at all sites except those with weather stations and depth probes were removed and discharge measurements were repeated.

1992 Field Season

The 1992 field season, which continued the stream temperature monitoring of 1991, began June 22 with the downloading of data from data loggers deployed over winter. Following this, data loggers at all other sites were deployed, with the last logger installed on June 30. Data loggers were checked between July 10 and July 15 to assure proper functioning and the first of two discharge measurements were made at that time. Removal of the data loggers, again with the exception of the same over-winter sites, and final discharge measurements were made between September 2 and September 6.

A second objective of the 1992 field season was to conduct reach surveys on sites representing a range of forest and meadow systems. The channel morphology and riparian vegetation data was collected for the 11 reaches briefly described in Table 4. The data collection procedures are addressed below.

Data Collection

In order to evaluate the relationship between stream temperature patterns and numerous environmental characteristics, 11 reaches with comparable discharges and elevations were surveyed. The surveyed reaches varied greatly in type and density of riparian vegetation (Table 4) and consequently in the magnitude of maximum stream temperatures. Where possible, reach surveys were performed upstream of the stream temperature monitoring site. Numerous channel morphology and riparian vegetation characteristics were measured with the frequency indicated in Table 5.

Channel morphology. A point between 0 and 20 meters from the data logger was randomly chosen and from this point a 250-m reach survey was started. Within this reach a station was established every 10 m. At each station thalweg depth, wetted width, bankfull width, bankfull height, percent stream cover and percent substrate were measured using a stadia rod, a 10-meter tape and a canopy densiometer. In addition, thalweg depth was measured every two meters between stations and the percent undercut bank was estimated for both banks for the ten meters between sampling stations. For the area five meters above and below the station, ocular estimates of substrate particle size were made. Substrate size categories (using the Wentworth scale) were defined as follows: sand: <0.2 cm; gravel: 0.2 to 6.4 cm; cobble: 6.4 to 25.6 cm; boulder: >25.6 cm.

Table 4. General description of reach survey sites within the Upper Grande Ronde River Watershed (McIntosh, 1992).

Site	Location	Distance to Drainage Divide km (mi)	Riparian Vegetation	Land Use History
11	McCoy Creek	28.0 (17.4)	Meadow (Grasses, scant willow)	Grazing, Channel-ization
12	Lower Meadow Creek	35.8 (22.3)	Meadow (Willow and alder)	Grazing, Splash dams
15	Mid-Meadow Creek	22.3 (13.8)	Meadow/ Forest (Conifer, alder, few willow)	Grazing, Splash dams, Timber harvesting
16	Upper Meadow Creek	17.4 (10.8)	Meadow (Few willow, alder, scattered conifers)	Grazing, Timber harvesting, Splash dams
23	Lower Limber Jim Creek	12.6 (7.8)	Meadow (Grasses and Sedges with scant willow)	Grazing and Timber harvesting
26	West Chicken Creek	8.1 (5.1)	Meadow/ Forest (Grasses with scant willow and conifers)	Grazing and Timber harvesting
30	Fly Creek (below Fly Valley)	15.3 (9.5)	Meadow (Grasses with scant alder and conifers)	Grazing, Splash dams
33	Beaver Meadow (Beaver Ck)	1.3 (0.8)	High Meadow (Grasses, few conifers, alder)	Elk grazing
24	Clear Creek	12.1 (7.5)	Forest (Conifers, alder)	Mining, Timber harvesting
31	Lookout Creek	4.8 (3.0)	Forest (Conifers, alder)	Recreation
32	Upper Limber Jim Creek	8.7 (5.4)	Forest (Conifers, alder)	Timber harvesting

Table 5. Measurement interval for channel morphology and riparian vegetation parameters included in reach surveys, Upper Grande Ronde River Watershed.

Measurement Interval				
Continuous	2 meters	10 meters	30 meters	Up & Down-Stream
Volume of large woody debris	Thalweg	Cross-sectional area	Belt transect: trees and shrubs	Gradient
Percent undercut bank	Channel unit demarcation	Bankfull width	Line transect: shrubs	Discharge
		Height of fluvial surfaces	Solar Pathfinder measurement	
		Percent substrate		
		Percent over-hanging vegetation		

Channel unit demarcations and volumes of large woody debris (LWD) greater than 10 cm at its smallest diameter and within the four zones of influence (Robison and Beschta, 1990) were inventoried throughout the reach. Channel units included pools, riffles, glides and log steps (falls) (Bisson et al., 1982).

At the top and bottom ends of each reach, discharge and slope measurements were made. Twenty individual velocity measurements were attempted to assure accurate discharge calculations, though the combination of very narrow channels and the inability to measure intervals smaller than 0.15 m frequently resulted in fewer observations. Channel gradient was measured with a clinometer projected along the reach to a stadia rod held at the channel edge.

Riparian vegetation. At every third sampling station (every 30 m), 15-m line intercept transects were run perpendicular to the wetted channel (on both sides of the stream) to determine percent cover of shrub species. The transect intercept of each individual shrub species was recorded according to species and three height classes, namely 0 to 0.5 m, 0.5 to 2 m, and >2 m tall. A 15-m long by 5-m wide belt transect (measured upstream of the line intercept transect) was used to quantify tree basal areas with respect to distance from the channel. Within this belt, tree species, diameter at breast height and distance from the wetted channel were recorded. Finally, a Solar Pathfinder was used, set in the channel approximately 10 cm above the surface, to supplement canopy densiometer measurements of stream cover.

TEMP-86 evaluation data. TEMP-86 is a reach-level stream temperature prediction model developed by Beschta and Weatherred (1984). In order to evaluate how well TEMP-86 predicts temperature changes through 250-m long reaches, an additional logger and temperature probe were deployed, roughly concurrent with the timing of the reach surveys, 250 m upstream from the bottom of each reach for at least 48 hours. Temperature probes were then run side-by-side for one day and regression equations were developed to adjust the downstream temperatures with respect to the upstream temperatures. Weather stations, when available, were also deployed at the top of each reach. Barring availability of weather stations, which were needed to measure hourly air temperature and relative humidity, data was obtained from the nearest site with comparable levels of cover. Additional data needed to run TEMP-86 included average topographic and vegetative shade angles facing southeast, south, and southwest, as well as the left and right streambanks. These angles were obtained by standing in the center of the channel and projecting to the tops of vegetative and topographic shade features in each direction with a clinometer.

Analysis

Description of stream temperature patterns. Descriptions of stream temperature patterns for the Upper Grande Ronde River Basin and its tributaries were developed based on maximum, the highest average of 7-consecutive daily maximums, and average diurnal fluctuations corresponding to the 7-warmest consecutive days as well as to the months of July and August. In addition, a frequency analysis based on hourly average stream temperatures was performed to evaluate the percent of time hourly temperatures were above 14, 20, 24 and 26°C. Maps were also drawn to illustrate general basin-wide trends in relation to the above stream temperature variables.

Relationship between site parameters and stream temperature patterns. Simple linear regression was used to evaluate relationships among channel characteristics (eg. thalweg depth, wetted width, bankfull width, bankfull depth, discharge, percent overhanging vegetation, and percent boulders) and various temperature parameters.

Non-metric Multidimensional Scaling, an ordination technique developed by Kruskal (1964), was also used to evaluate relationships between the 11 surveyed reaches and 14 reach characteristics. This multivariate technique, which is addressed more fully in Appendix B, reduced the 11 by 14 matrix (reaches by variables) into three dimensions which best represent the information in the original data set. The subsequent construction and interpretation of axes drawn through this three-dimensional data swarm helped to identify which sites were most similar and which variables accounted for the greatest amount of variability between reaches. Additionally, ordination scores, which determined each sites position on a particular axis, were used in linear regression analysis to evaluate the correlation between the first and third axes' and various stream temperature variables.

Evaluation of TEMP-86. The accuracy and precision with which TEMP-86 predicts average hourly stream temperatures through 250-m long reaches was determined. Repeated failure of either the up or downstream data logger at Reach 12 (lower Meadow Creek), however, resulted in its exclusion from the model evaluation. Using reach survey data to drive the model, predicted average hourly stream temperatures were compared to those observed. Model accuracy, referred to as the WSTAT, was calculated for each reach using the following equation:

$$\text{WSTAT} = \frac{\Sigma(\text{Predicted} - \text{Observed hourly temperature})}{\text{n (\# of observations)}}$$

Bias was evaluated by regressing the WSTAT against both stream cover and channel morphology variables. Finally, repeated runs of TEMP-86 were made using data from Reach 30, a relatively degraded section of Fly Creek. A comparison of predicted maximum daily stream temperatures through this reach which might occur under combinations of different wetted width and percent stream cover values was made to assess the effect of both independent and concurrent changes in these variables upon maximum daily stream temperatures during warm summer days.

RESULTS AND DISCUSSION

1991 and 1992 Stream Temperatures

Given the enormity of the study area (1750 km^2), there was a surprising degree of uniformity in stream temperature patterns among reaches. For example, variations in stream temperature track each other very closely at Sites 20 and 24 (shown in Figure 7a), suggesting that major changes in stream temperature patterns were largely dictated by basin-wide weather patterns rather than more localized conditions. As shown in Figure 7b, periods of elevated daily summer maximum stream temperatures occur during times of low flows and high air temperatures, indicative of warm, clear days. Relative depressions in maximum daily stream temperatures were generally associated with basin-wide precipitation which raised water levels, decreased amounts of incoming solar radiation, and decreased air temperatures. In general, while the magnitude of maximum stream temperatures varied considerably within the watershed, the timing of annual and weekly maximum stream temperatures was rather uniform.

Maximum Stream Temperatures

Grande Ronde River. Maximum stream temperatures in the UGRR Watershed occurred between July 26 and August 19 during 1991 and 1992. For the six sites on the Grande Ronde River, maximum stream temperatures occurred on August 19 in 1991 and August 13 in 1992. Maximum stream temperatures at Site 25, 15 km from the watershed divide, were 18.9°C (66°F) and 20.8°C (69.4°F) during 1991 and 1992, respectively (Figure 8a and Table 6). Below Vey Meadow (Site 20), however, maximum stream temperatures of 25.4°C (77.7°F) and 26.8°C (80.2°F) were observed during the same two years, reflecting

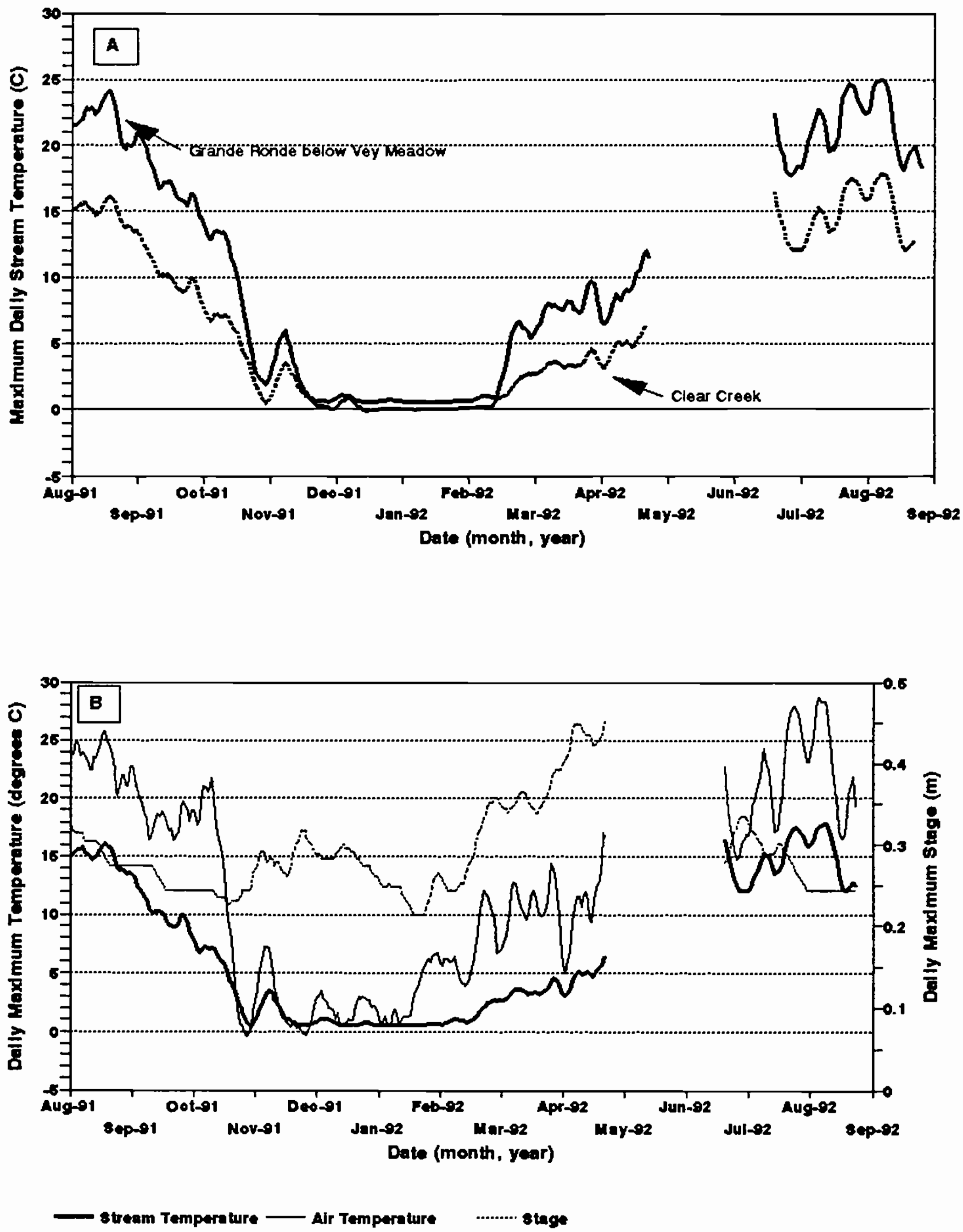
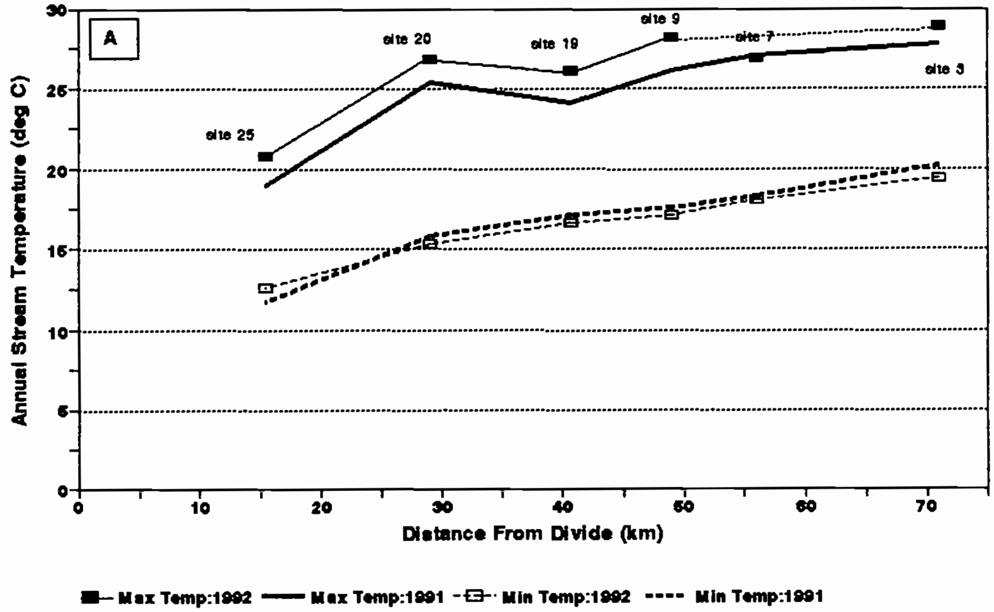


Figure 7. Seven-day moving mean of daily maximum (A) stream temperatures on Clear Creek (Site 24) and the Grande Ronde River below Vey Meadow (Site 20) and (B) stream temperatures, air temperatures, and stage at Clear Creek.



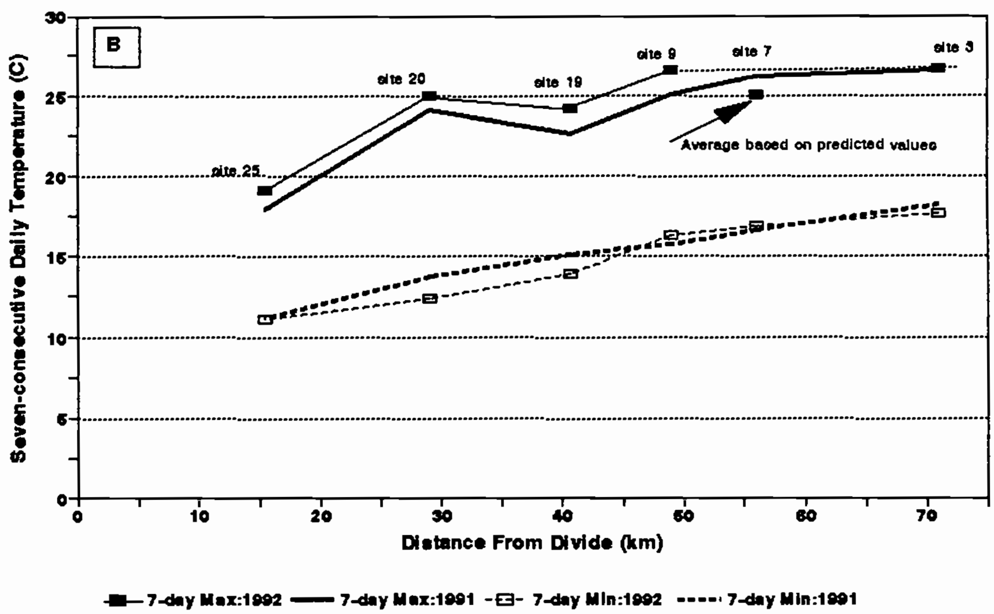


Figure 8. (A) Annual maximum (and associated minimum) and (B) highest average of seven-consecutive daily maximum (and associated 7-day minimum) stream temperatures versus distance from the watershed divide in the Upper Grande Ronde River during 1991 and 1992.

Table 6: Selected 1991 and 1992 summer stream temperature values (°C) in the Upper Grande Ronde River Watershed.

Site	1991					1992					
	Annual max	7-day max	7-day min*	Mean August	Average August diel	Annual max	7-day max	7-day min*	Mean July	Mean August	Average August diel
1	27.5	25.9	12.0	dry	dry	22.9	20.8	11.9	15.0	dry	dry
2	26.1	25.1	15.3	18.1	11.1	28.2	26.9	13.9	17.4	18.1	13.0
3	27.8	26.6	18.2	20.7	8.7	28.9	26.7	17.6	19.6	19.8	8.5
4	27.8	26.3	16.3	19.4	10.3	29.3	28.4	14.3	18.4	18.1	14.1
5	23.2	21.7	14.9	16.8	7.6	24.4	23.3	13.3	16.4	15.5	10.1
6	27.8	26.2	14.4	dry	dry	27.5	25.7	12.7	17.9	dry	dry
7	27.1	26.2	16.6	19.3	9.9	26.9	25.1	16.8	18.0	18.0	8.1
8	22.6	21.9	12.9	15.9	9.1	24.8	22.6	12.6	15.5	14.8	10.2
9	26.1	25.1	15.7	18.3	9.7	28.2	26.6	16.3	17.6	17.8	10.2
10	21.7	20.7	14.3	15.7	6.7	24.8	23.7	14.3	16.1	15.6	9.3
11	29.0	27.5	7.4	nd	19.4	28.8	27.3	12.4	17.8	17.1	14.9
12	27.8	26.9	16.3	19.8	10.9	28.1	26.4	14.0	18.6	18.1	12.4
13	26.1	20.0	13.9	15.3	6.2	22.6	21.7	14.7	14.8	14.7	7.0
14	22.3	21.3	13.6	16.2	7.7	28.2	26.5	14.7	16.0	16.4	11.8
15	24.8	23.8	15.7	18.2	8.3	27.5	25.8	14.7	17.9	17.4	11.1
16	24.1	22.6	13.7	16.5	9.2	24.8	23.4	12.0	15.8	14.8	11.3
17	19.7	19.1	17.4	18.1	1.6	24.4	22.9	20.0	18.2	18.8	2.2
18	23.2	22.1	15.2	17.1	6.8	24.4	23.1	13.6	16.3	16.3	9.5
19	24.1	22.6	15.1	17.3	7.5	26.1	24.2	13.9	16.5	16.6	9.4
20	25.4	24.1	13.7	17.0	10.3	26.8	25.0	12.4	15.8	16.5	12.2
21	19.1	18.4	11.2	13.0	7.4	22.9	21.4	11.3	13.0	13.4	9.8
22	21.1	20.1	11.7	14.2	8.6	22.6	21.3	10.3	13.6	13.9	9.7
23	22.6	21.4	11.4	14.3	10.1	23.5	21.9	10.3	13.9	14.3	9.8
24	17.1	16.1	11.5	12.3	4.8	18.9	17.8	11.4	11.7	12.4	6.1
25	18.9	17.9	11.2	13.0	6.8	20.8	19.1	11.1	11.9	13.0	7.9
26	22.6	21.3	11.5	14.9	9.8	24.8	22.7	11.6	14.5	15.1	10.0
27	15.6	14.9	11.4	12.0	3.8	17.8	17.2	11.6	11.6	12.2	4.9
28	23.5	22.2	11.8	15.1	10.4	25.8	24.6	10.7	15.1	15.4	12.7
29	21.9	20.7	11.9	14.8	8.8	23.2	22.7	10.4	14.2	14.3	11.1
30	26.1	24.8	14.8	17.8	10.2	27.1	25.8	12.7	17.3	16.6	12.4
32	nd	nd	nd	nd	nd	18.9	17.8	11.8	12.9	12.7	5.3

nd = no data

* 7-day minimum temperatures measured on the corresponding dates of the 7-day Maximum temperatures.

increases of 6.5°C and 6.0°C over a distance of 14 km (or rates of maximum temperature increase of 0.48°C/km and 0.44°C/km)(Figure 8a).

Between 29 km and 41 km from the divide, however, both the maximum and seven-day maximum stream temperatures on the Grande Ronde River (Figure 8a-b) decreased from those observed upstream. These decreases are synchronous with a narrowing of the valley floor and an increase in channel constraint and reflect an increase in shade from both topography and vegetation. Maximum temperatures at Site 19 were 24.1°C (75.4°F) and 26.1°C (79°F) during 1991 and 1992, respectively, resulting in rates of temperature decrease of 0.11°C/km and 0.06°C/km (Table 6). Below Site 19 on the Grande Ronde River, maximum stream temperatures gradually increased (at an average rate of 0.1°C/km) with the exception of Site 7 during 1992.

It should be noted that the decrease in maximum stream temperatures found at Site 7 during 1992 likely stems from data logger failure early in the season (July 11) and the regression model consequently used to estimate average hourly temperatures for this site. Average hourly stream temperatures at Site 7 for June 27 through July 11 were regressed on Site 19 data (16 km upstream) to develop the linear model from which Site 7 stream temperatures were calculated for the remainder of the summer. While there was a strong correlation (r^2 = 0.85) between the sites (for the period between June 27 and July 11), the relationship between the two sites likely changes later in the summer in response to gradual changes in discharge and solar angles. In addition, since maximum temperatures did not occur until mid-August, the predicted values are outside of the range of the regression equation and thus have an unknown amount of error.

<u>Minimum stream temperatures in the Grande Ronde River.</u> In contrast to maximum and seven-day maximum stream temperatures, the associated minimum and seven-day minimums indicate a continuous,

increasing trend from Site 25 and Site 3 on the mainstem (Figure 8a-b). Similar to maximum stream temperatures, the associated minimums increased between 15 and 29 kilometers from the divide and much more gradually below Site 19 (41 km from the divide). However, below Vey Meadow (29 km from the divide) annual maximums decreased while the associated minimums increased. This observation is important in so far as it indicates that while the constrained reach may be functioning to reduce daily maximum stream temperatures, it does not reflect a cooling reach.

Maximum stream temperatures in the tributaries. Seven-day maximum stream temperatures varied greatly among tributaries of the Grande Ronde River (Figure 9, Table 6). Values exceeding 26°C (79°F) were common at sites below broad, unconstrained valleys. Sites downstream of extensive meadow systems such as Site 30 (Fly Creek), 12 (lower Meadow Creek), and 11 (McCoy Creek) had seven-day maximum stream temperatures of 24.8°C (76.7°F) or higher in 1991 and 25.8°C (78.5°F) or higher in 1992. However, higher elevation, forested tributaries experienced much lower seven-day maximum stream temperatures during both years. Seven-day maximum stream temperatures in Chicken Creek (Site 27), Limber Jim Creek (Site 21), South Fork Limber Jim Creek (Site 22), Clear Creek (Site 24) and Little Fly Creeks (Site 29) were at or below 21.4°C and 22.7°C during 1991 and 1992, respectively. In addition to the extensive cover and high elevations associated with the coolest streams, Chicken Creek and Clear Creek also had northerly aspects.

Five Points Creek (Site 2), a forested, low elevation tributary with a southerly aspect, had seven-day maximum stream temperatures of 25.1°C and 26.9°C in 1991 and 1992, respectively. These relatively high temperatures (approximately 5°C in comparison to north-facing tributaries higher in the basin) may reflect not only greater relative inputs of solar radiation and slightly higher

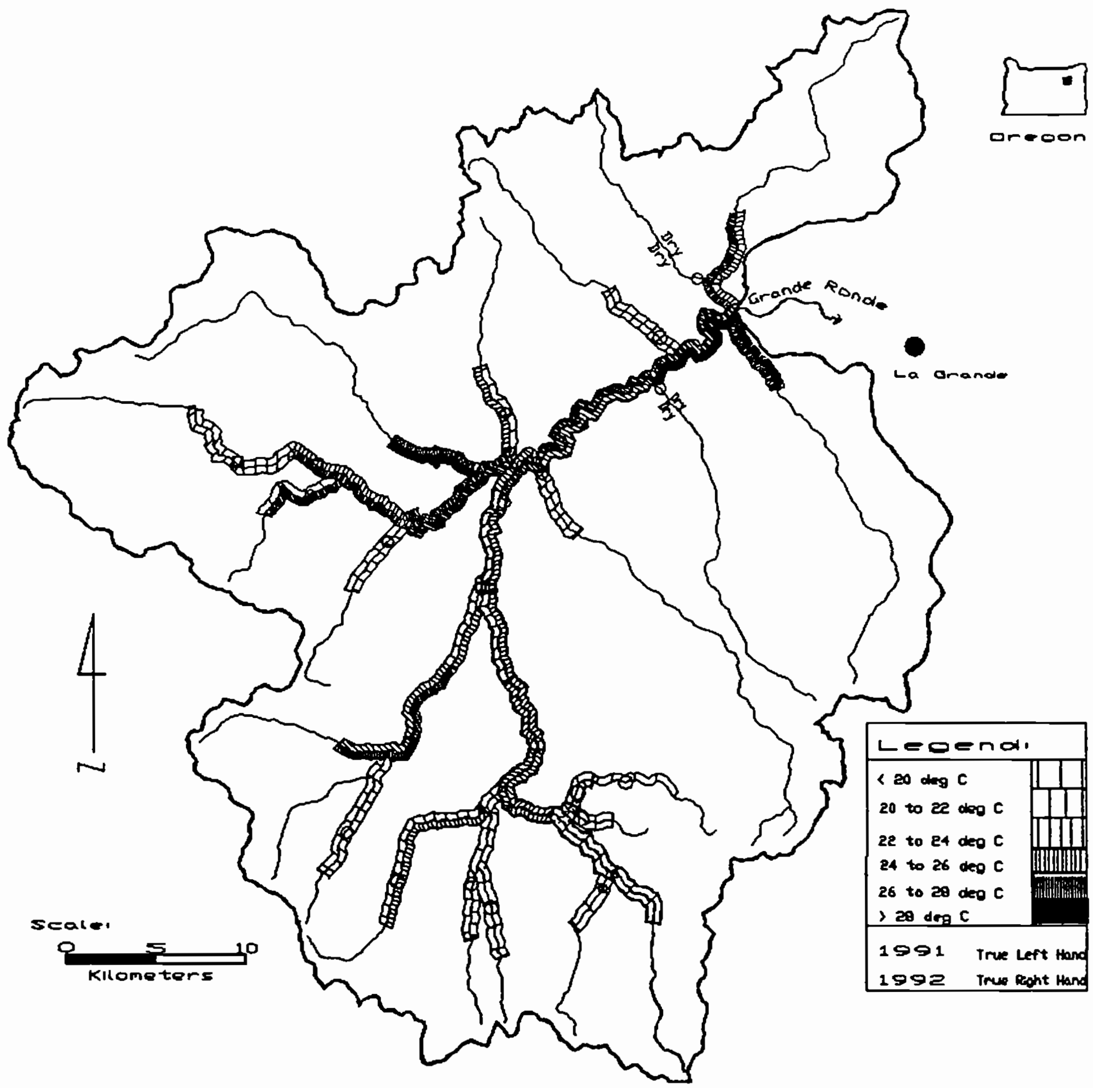


Figure 9. Highest seven-consecutive maximum daily stream temperatures in the Upper Grande Ronde River Watershed, 1991 and 1992.

mean daily air temperatures, but also earlier depletions of subsurface flow in south-facing drainages. A comparison of lowflows per square kilometer of drainage between Sites 2 and 27 indicates nearly an order of magnitude difference, 0.0002 and 0.001 m^3/s per km^2, respectively. Northern exposures may facilitate reduced evapotranspiration, thus longer retention of soil moisture, resulting in greater delivery of subsurface flow later in the summer.

While location within the basin has important implications with regard to stream temperatures, the extent to which riparian vegetation and topography provide cover is also critical. A comparison of maximum stream temperatures between two adjacent headwater streams, namely Chicken Creek (Site 27) and West Chicken Creek (Site 26), provides an example of the importance of vegetative cover and channel complexity. Seven-day maximum stream temperatures on Chicken Creek were 14.9°C and 17.2°C during 1991 and 1992, respectively. In contrast, West Chicken Creek's seven-day maximum stream temperatures were 7°C higher than Chicken Creek during both years. While aspect, elevation and discharge were comparable (within 16°, 18 m, and 0.017 m^3/s of each other, respectively), differences in riparian vegetation and channel complexity were appreciable. West Chicken Creek flows through a broad meadow with few trees or shrubs and a shallow channel with bare streambanks. Chicken Creek, in contrast, is well covered (forested) and has undercut and well vegetated banks.

Diel fluctuations

Grande Ronde River. The daily range or diel fluctuation in stream temperatures is shown in Figure 10 for two sites on the Grande Ronde River during the warmest week of 1992. The daily range in temperatures at Site 20, about 12.5°C, is greater than that

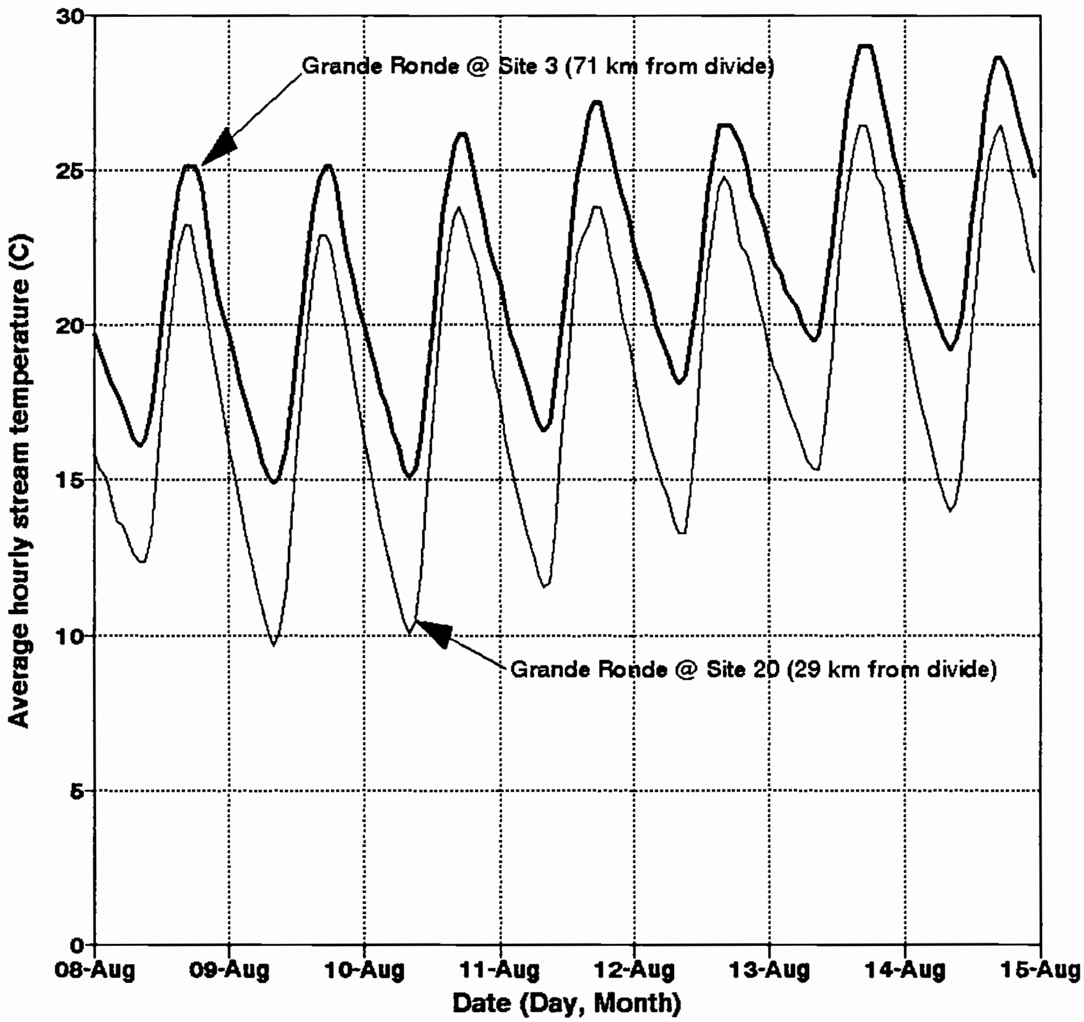


Figure 10. Average hourly stream temperatures during the 7-consecutive warmest days in 1992 at Sites 3 and 20 on the Upper Grande Ronde River.

observed at Site 3, where an average temperature range of 8.5°C was observed during the warmest week. In general, diel fluctuations in the Grande Ronde change rather dramatically with distance from the divide, reflecting abrupt changes in the landscape as well as reach characteristics. As shown in Figure 11, marked increases in average diel fluctuations during the seven-consecutive warmest days occurred between 15 km (Site 25) and 29 km (Site 20) from the watershed divide, an open reach characterized by Vey Meadow. In this reach, average diel stream temperature fluctuations were 3.5°C (6.3°F) and 4.3°C (7.7°F) greater during 1991 and 1992, respectively, than those observed at Site 25. Smaller average diurnal fluctuations were observed at Site 19 (Figure 11), stemming from marked increases in topographic and vegetative shade. One expression of this difference is the valley width-to-depth ratio, which ranged from 19.2 for the Vey Meadow reach to 5.4 within the constrained reach immediately downstream. While these ratios should not be used as direct indices of shade, they are at least suggestive of the reductions in solar radiation provided by topography below Vey Meadow. Between Sites 19 and 9, a distance of 8.8 km along the Grande Ronde River, the valley again widens and increases in diel fluctuations of 2.2°C and 0.8°C were observed during 1991 and 1992. Below Site 9, average seven-day diel fluctuations (Figure 11 and Table 6) remain near around 10°C until Site 7 and then decrease slightly as increases in flow and stream depth function to increase the thermal inertia of the system (Sullivan and Adams, 1990).

Tributaries. Average August diel stream temperature fluctuations were between 0.5 and 1.0°C greater in 1992 than 1991 at all sites, regardless of elevation or stream size. Average diel stream temperature fluctuations during the seven warmest days of more than 10°C were common in many tributaries associated with open meadows such as Fly Creek (Site 30), Sheep Creek (Site 28), McCoy

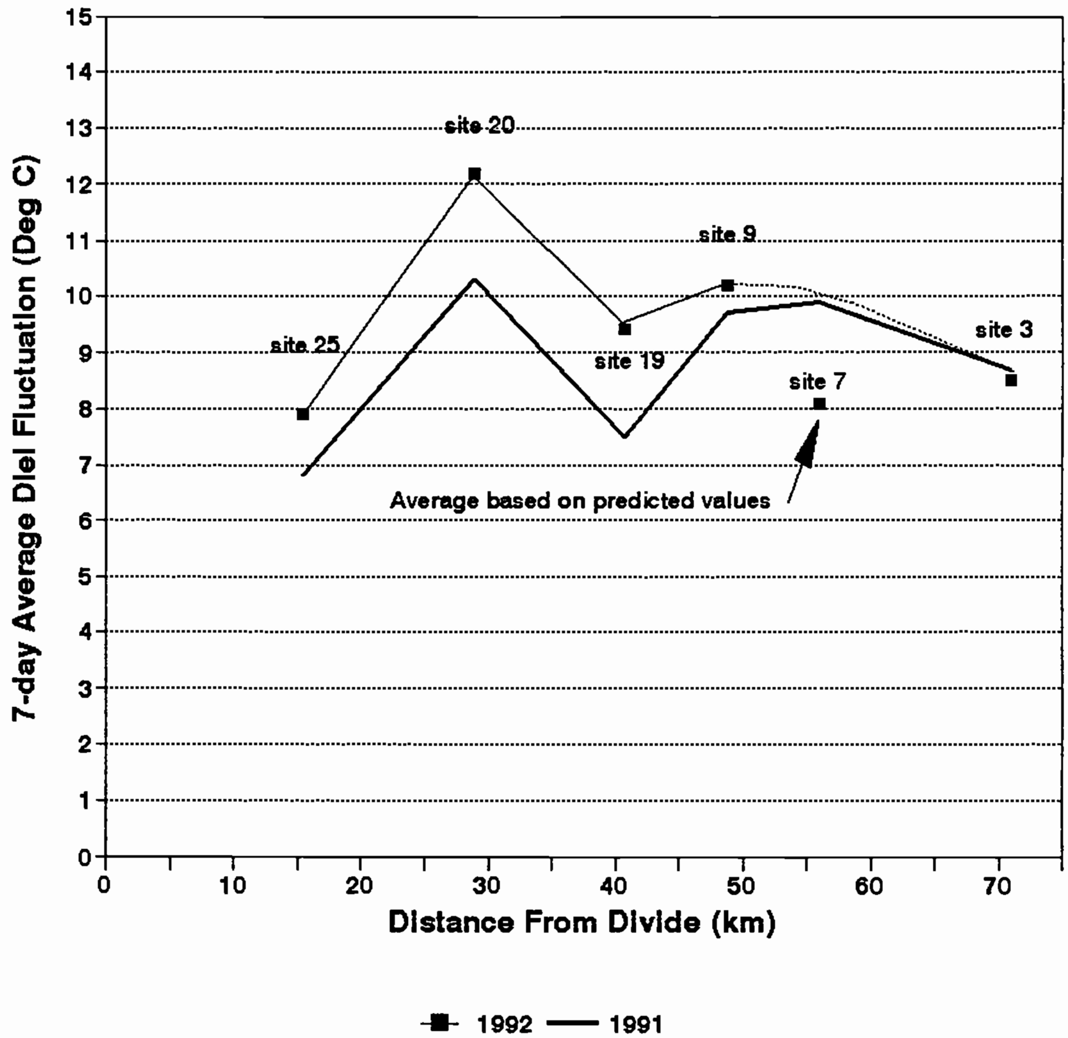


Figure 11. Seven-day average diel stream temperature fluctuations during the warmest seven-consecutive days versus distance from the watershed divide on the Upper Grande Ronde River during 1991 and 1992.

Creek (Site 11) and lower Meadow Creek (Site 12) during 1991 and 1992 (Figure 12 and Table 6). Of these, McCoy Creek had the most wildly fluctuating temperatures with a seven-day average of 19.4°C (34.9°F) and 14.9°C (26.8°F) during 1991 and 1992, respectively. Channelization following 1964 coupled with very little stream cover are perhaps the two key factors responsible for the variable stream temperature regime of Site 11.

Only four of the 31 sites monitored in 1992 exhibited average August diel stream temperature fluctuations below 5°C. Three of these sites, namely Clear Creek (24), Chicken Creek (27) and upper Limber Jim Creek (32), are all densely forested tributaries with relatively undisturbed channels. The combination of diminished quantities of incoming solar radiation and normal inputs of subsurface flow (suggested by the presence of less disturbed hydrologic flow paths) likely to result from riparian systems less influenced by human activity are probably the two biggest reasons for smaller daily stream temperature fluctuations. The fourth site (Site 17), with an average August diel fluctuation of only about 2°C during both summers, however, is a beaver pond near the mainstem of the Grande Ronde River. Given the large (4.5°C) difference in average diel fluctuations between July and August of 1992 in the beaver pond (compared to an average of approximately 2°C for all other sites), and the comparably very low average fluctuations in August of both years, one plausible explanation is that rather pronounced thermal stratification occurred in the beaver pond during August of both years. If the temperature probes were below the epilimnion or upper-most layer of more widely fluctuating water temperatures, the stratification may explain the extreme thermal stability and low average diel fluctuations. Another explanation may involve probe burial or increased levels of turbidity. Under the latter scenario, perhaps

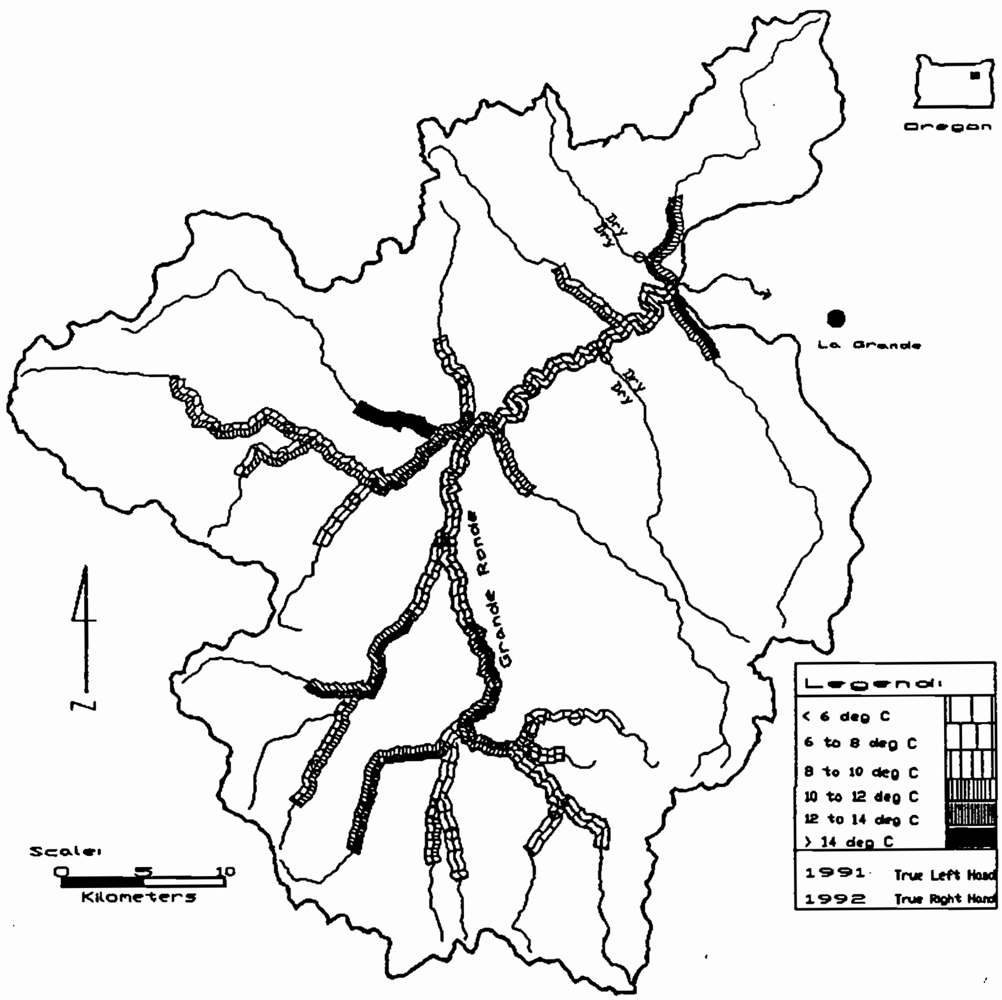


Figure 12. Average diel stream temperature fluctuations during the highest average of seven-consecutive maximum daily stream temperatures in the Upper Grande Ronde River Watershed during 1991 and 1992.

suspended particles would function to impede penetration of solar radiation (and reduce the pond's albedo) thereby reducing the energy available below the pond's surface (Wetzel, 1983).

Maximum stream temperatures versus diel fluctuations. The relationship between the seven-warmest consecutive daily maximum stream temperatures and the corresponding diurnal fluctuations is shown in Figure 13. In general, sites with high maximum temperatures tend to have large diurnal fluctuations. More specifically, a 5°C difference in seven-day maximum stream temperature corresponds to a 3.4°C difference in diurnal fluctuations. Sites with somewhat higher diel fluctuations than predicted reflect generally more open reaches with moderate to sparse amounts of riparian vegetation. One distinct group with lower than predicted diel fluctuations represent high elevation forested streams. These sites, 24, 27, and 32, while small headwater streams, have greater than 75% cover (percent cover for site 27 was visually estimated but not measured). One final observation is that the two lowest sites on the Grande Ronde River (3 and 7) had diel fluctuations nearly 4°C less than would be expected from the regression model. As these sites have the two largest baseflows in the watershed, and discharge has been shown to be inversely proportional to temperature change in a stream following canopy removal (Brown, 1969), the data support the general principals represented in Brown's (1969) temperature model.

Timing of Maximum Stream Temperatures

The timing of both the maximum and the highest average of the seven consecutive daily maximum stream temperatures during 1991 occurred between August 16 and August 22 (Julian days 228 to 234) for all but two stations (Figure 14). Stream temperature stations

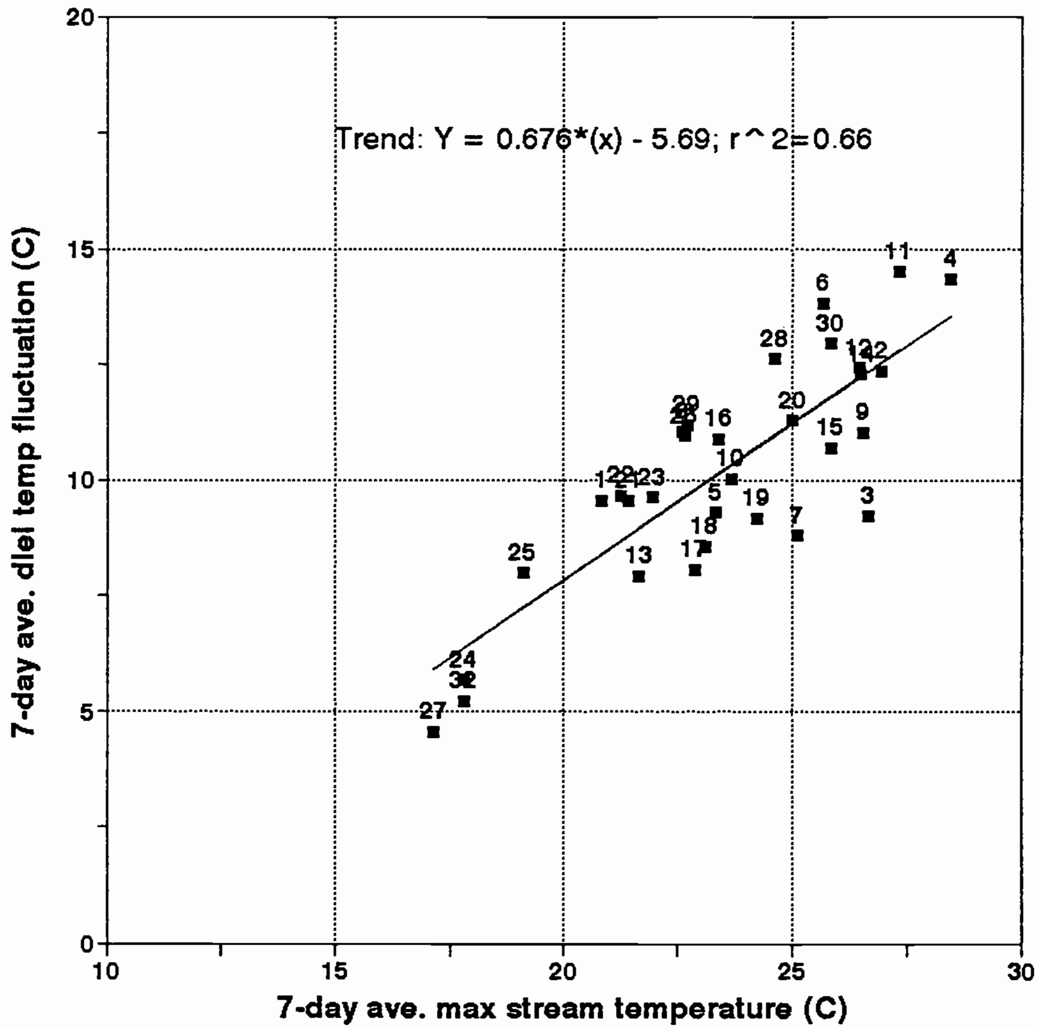


Figure 13. Seven-consecutive daily maximum stream temperatures versus the corresponding seven-day average diel fluctuations for all sites in the Upper Grande Ronde River Watershed in 1992. Site numbers are listed above the corresponding data point.

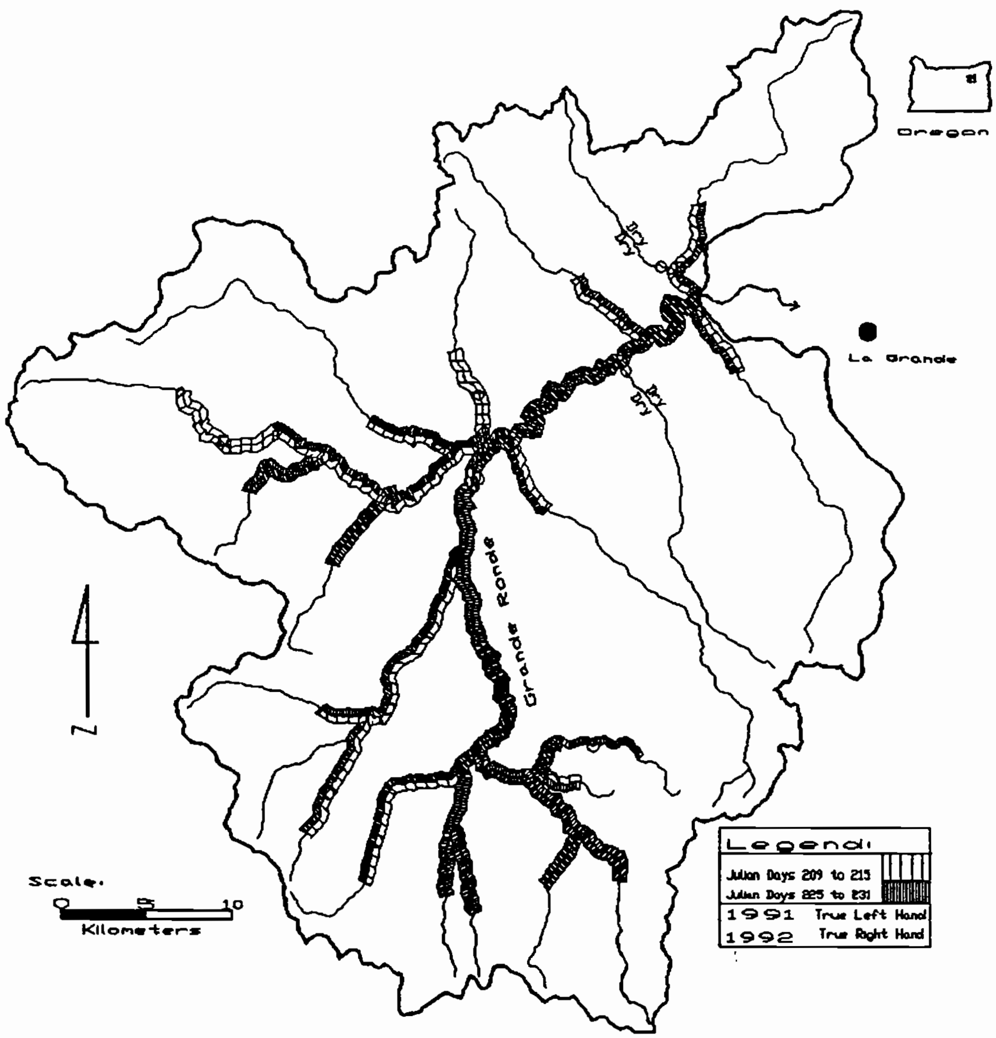


Figure 14. Timing (median Julian day) of the seven-consecutive daily maximum stream temperatures in the Upper Grande Ronde River Watershed during 1991 and 1992.

along upper Meadow Creek and Dark Canyon Creek, both of which have south to southeast aspects, had seven day maximum stream temperatures between August 1 to 7 (Julian days 213 to 219) in 1991. In 1992, however, the highest average of seven consecutive daily maximum stream temperatures occurred during one of two seven day periods, namely July 25-31 (Julian days 209 to 215) and August 10-17 (Julian days 222 to 228)[2]. Additionally, the correlation between the timing of the seven day high and stream azimuth was much more pronounced in 1992.

The timing of the peak stream temperatures in 1992 seems strongly linked to azimuth (Figure 15). All sites with southerly aspects had a median Julian day of the highest average of seven-consecutive daily maximum stream temperatures between 211 and 213. However, for sites with northerly aspects, 14 of 20 (70%) had a Julian date between 225 and 227. The remaining six north-facing sites had an early Julian date; however, three of these reaches were low elevation sites and the early Julian dates may reflect tributaries within which an early depletion of subsurface flow, and consequently early low flows, occurred.

Assuming maximum stream temperatures did not occur prior to logger deployment in late July of 1991, an issue which will be addressed shortly, an explanation for the seemingly stronger linkage between aspect and timing of peak stream temperatures in 1992 can be found by evaluating the magnitude and timing of low flows in the basin. A frequency analysis based on the median day of the average of ten lowest consecutive flows (Table 1) shows that 1992 had the

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[2] During the last week of June in 1992 maximum stream temperatures at Sites 15 and 16 were equal to or greater than those observed later in the season. Given that the deployment of all data loggers was not complete until June 30, however, the period of record for data analysis began July 1. Observations at these two sites, however, support the trend between the timing of peak temperatures and aspect.

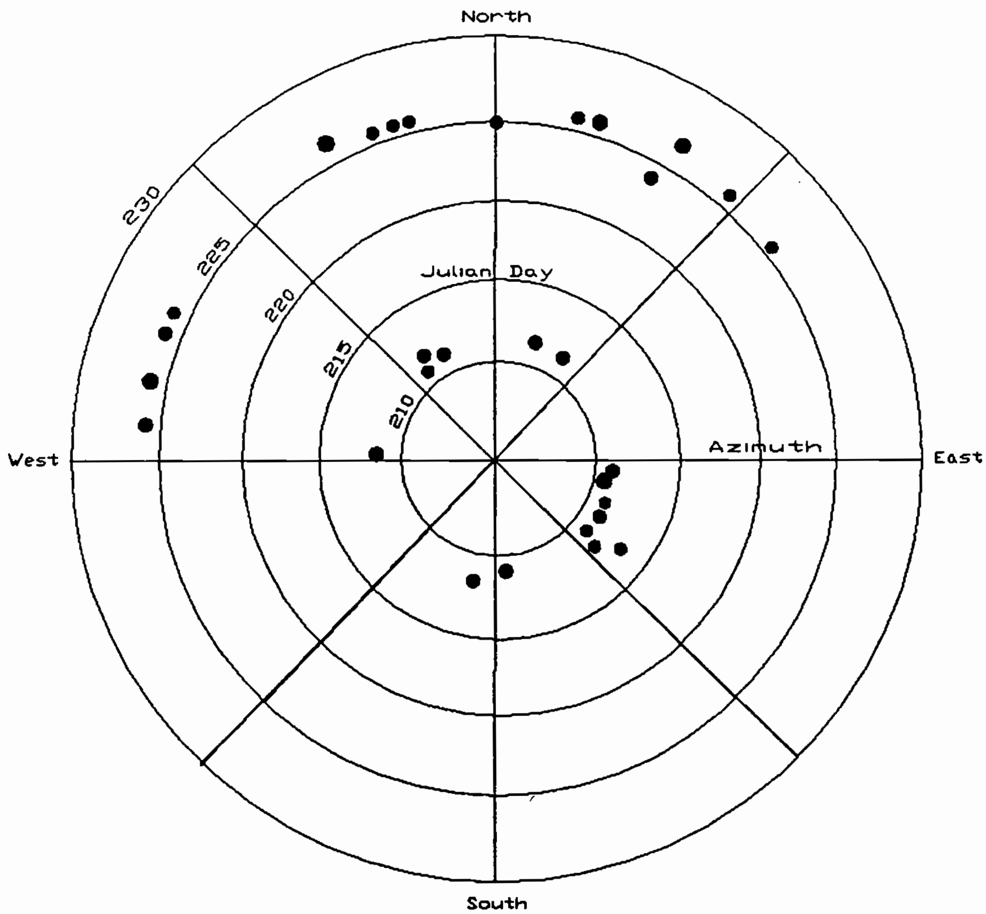


Figure 15. Azimuth plot. Site azimuth versus Julian day of seven-consecutive daily maximum stream temperatures in 1992, Upper Grande Ronde River Watershed.

earliest low flow on record, August 16 (Julian day 228), resulting in a 2.4% probability of occurrence. In contrast, the 1991 10-day average low flow occurred on September 22 (Julian day 265) and had a probability of occurrence of 30.5%. Additionally, the 1992 low flow (Table 2) was slightly less than that observed in 1991, with values of 0.411 m^3/s and 0.496 m^3/s, respectively (observed at La Grande). Given the above trends, the combination of lower than normal low flows, and their occurrence earlier in the year, when solar angles are highest, may account for the stronger linkage between aspect and timing of peak stream temperatures during 1992.

To assess the likelihood that maximum stream temperatures may have occurred during July of 1991, prior to the installation of the data loggers, an inspection of flow records and climate records is necessary. The majority (70%) of the sites in the UGRR Watershed had maximum stream temperatures during August of 1992. This fact has relevance when we consider the following observations: 1) the July mean flow during 1992 at La Grande (1.67 m^3/s, with a 31% probability of occurrence) was less than the 1991 July mean flow (2.69 m^3/s, with a 57% probability of occurrence); and 2) low flows occurred much earlier in 1992 than in 1991 (Table 1). The occurrence of higher flows in July of 1991 reduces the likelihood of early peak temperatures. This reduced likelihood of early temperatures would only be expected given comparable inputs of solar radiation. Climatic records at La Grande indicate that in 1992 mean monthly air temperatures (recorded at La Grande) in July were 1.1°C below normal while in 1991 they were only 0.2°C below normal (Figure 3b). Furthermore, mean monthly precipitation during 1992 was 25% higher than the norm (15 mm) whereas July of 1991 was 80% below normal (Figure 3a). Based on these considerations, the existing data are inconclusive as to whether the 1991 peak temperatures occurred in July or August.

Potential Biological Significance of Elevated Stream Temperatures

Grande Ronde River. To determine the percent of time which Chinook Salmon were potentially exposed to physiologically stressful conditions during 1991 and 1992, a frequency analysis of average hourly stream temperatures was performed. Four temperatures, namely 14°C, 20°C, 24°C and 26°C, were used in the analysis, with 14°C representing the "upper preferred temperature" and 26°C the approximate Upper Lethal Limit for Chinook Salmon (Brett, 1952). The percent of time above these temperatures during the seven consecutive warmest days along the Upper Grande Ronde River is shown in Figure 16. Each site is graphed according to its distance from the divide.

At the upper-most station (Site 25), the upper preferred temperature (14°C, 57.2°F) was exceeded 66% of the time during 1991 and 1992. After flowing through Vey Meadow, however, these percentages increased markedly to 92% at 29 km from the divide. In addition, while the percent of time during which the preferred temperature is exceeded increases slightly in the downstream direction, the percent of time above 20°C and 24°C decreases between 35 and 45 km from the divide during both 1991 and 1992. An interpretation of this pattern is that during peak stream temperatures within the constrained section of the Grande Ronde River (between 29 an 41 km from the divide), physiologically threatening stream temperatures are not as common, even though the preferred temperature is nearly always exceeded.

Downstream of Site 9 (at 49 km) on the Grande Ronde River, the upper preferred stream temperature for Chinook Salmon was always exceeded during the seven warmest consecutive days. In addition, the lowest station on the Grande Ronde River (Site 3 at 71 km) had stream temperatures above the 14°C for the entirety of August in 1991 and July of 1992 (August of 1992 exceeded 14°C 90% of the

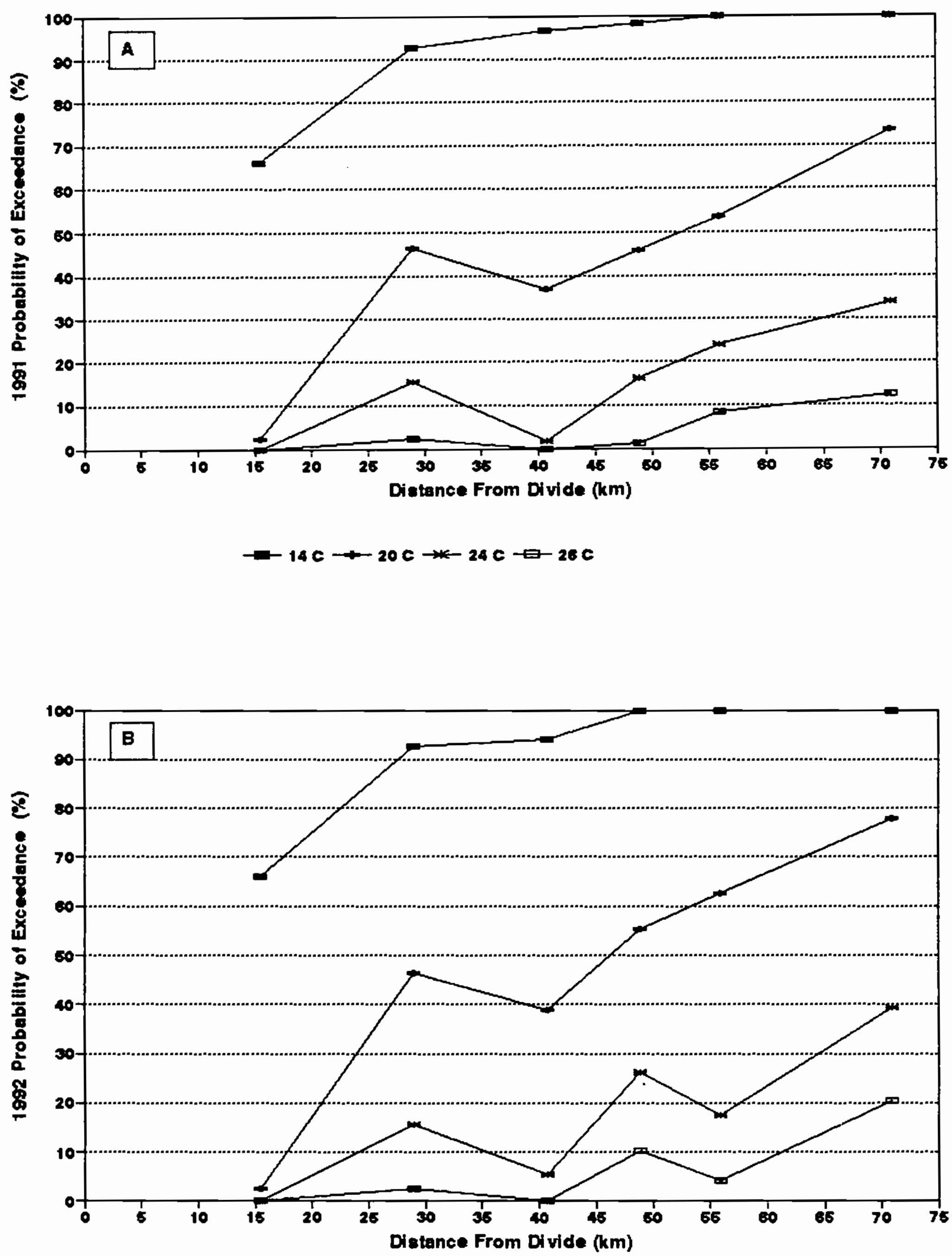


Figure 16. (A) 1991 and (B) 1992 probabilities of exceedance versus distance from the watershed divide for the Upper Grande Ronde River. Probabilities are based on average hourly stream temperatures during the seven-warmest consecutive days during each year.

time). The Upper Lethal Limit of 26°C, which represents extremely physiologically stressful conditions, was exceeded 10.5% and 20% of time below Site 3 during the seven warmest days of 1991 and 1992, respectively. The real significance of these extreme temperatures is uncertain and may be dependent upon the abundance of food required as a result of the higher metabolic rates, diurnal variations in temperature, and on the availability of cool water pockets (Bjornn and Reiser, 1991). Given the widespread reduction in large pools within the Grande Ronde since 1943 (McIntosh, 1993), however, the Grande Ronde River below Meadow Creek probably provides very poor habitat for fish during these warm periods.

Tributaries. The upper preferred stream temperature (14°C) was frequently exceeded in many of the tributaries (Figure 17). During August of 1991, July of 1992, and August of 1992 only 6 sites, namely 21, 22, 23, 24, 25 and 27, exceeded 14°C less than 50% of the time. While Site 32 (upper Limber Jim Creek) was not monitored during 1991, it too exceeded 14°C less than 50% of the time. In general, these seven streams represent small, headwater streams above 1300 m in elevation. In addition, four tributaries (Sites 2, 4, 12, and 15) exceeded 14°C more than 90% of the time in 1991 (and 85% of the time in July of 1992). In August of 1992, however, none of the tributaries exceeded 14°C more than 82% of the time. Chicken Creek, notably the only tributary in the basin which supports native bull trout, was the coolest running stream with temperatures exceeding 14°C less than 12% of the time during August of 1991 and July of 1992. Finally, Sites 21, 24, 25, and 27, all of which represent densely forested (shaded) reaches, were the only other sites which never exceeded 20°C (68°F) during August of 1991.

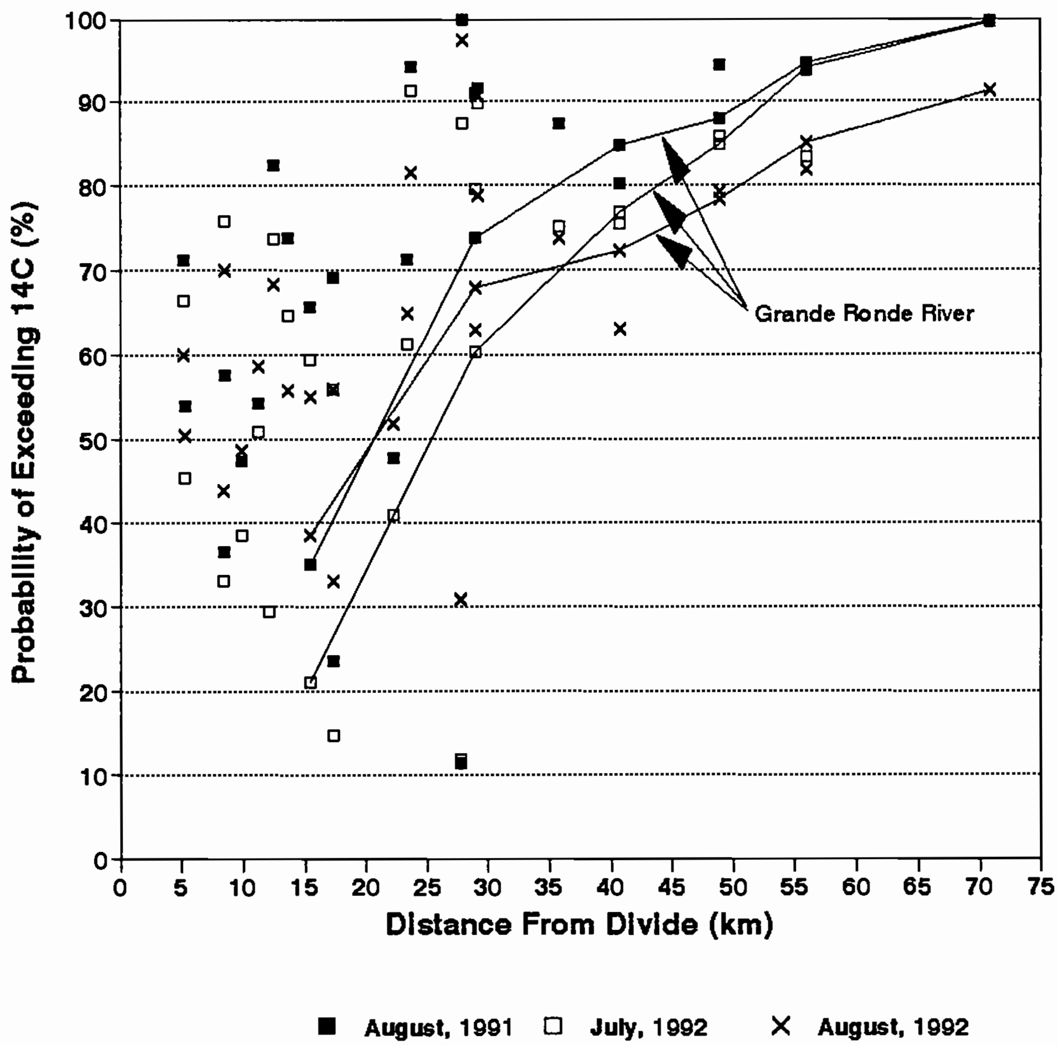


Figure 17. 1991 and 1992 probabilities of exceeding 14°C versus distance from the divide for all sites in the Upper Grande Ronde River Watershed. Probabilities based on average hourly stream temperatures for the month. Lines connect sites on the mainstem.

Context of 1991 and 1992 Stream Temperature Data

As this study occurred several years into a drought that began in 1985, the issue of how representative 1991 and 1992 stream temperatures are relative to the norm is particularly important. Using longterm flow records for the Grande Ronde at La Grande (1904-1992; 1982 to 1992 flows were predicted using flow data a Rondowa) and weather data at La Grande (1948-1993), an index was developed so as to assess the extremity of 1991 and 1992 data. The parameters used in the index include the median Julian day of the ten lowest annual daily flows (JD), the lowest 10-day average flow (LF), and average August air temperature (AugT). These specific parameters were chosen for the following reasons: 1) after the summer solstice there is a negative correlation between noon solar angle and Julian day, hence earlier Julian days correspond to increased inputs of direct solar radiation; 2) the magnitude of summer low flows directly affect the temperature increase which will occur with a given input of energy; and 3) given the typically late occurrence of low flows (September) and generally cool September air temperatures, the use of August air temperatures is a reasonable indicator of sunny, warm days which are usually associated with the occurrence of high stream temperatures.

The equation used to calculate each yearly index is:

$$\text{Elevated temperature index} = (((1-(JD/\text{Sum of }JD))*0.92) +((1-(LF/\text{Sum of }LF))*0.67) +((AugT/\text{Sum of }AugT)*0.41))$$

Each yearly julian day, low flow and air temperature value is "relativized" by the sum of values for that variable over the period of record (e.g., Julian day) so as to reduce the affect of outliers (McCune, 1993). To achieve an index in which large values correspond to a greater likelihood of elevated stream temperatures, the relativized Julian day and low flow values were subtracted from 1. Finally, each relativized value was also multiplied by a coefficient (the average for that variable divided by the average of all three average relativized variables) so as to give equal weight to each component.

As shown in Figure 18, an index as high as that observed in 1992 has only occurred twice since 1948, resulting in a 4.5% probability of exceedance. In comparison, the 1991 index has a 43.2% probability of exceedance. The index suggests, therefore, that 1992 would be more likely to experience high elevated stream temperatures relative to 1991. The trend in indexes also suggests that elevated stream temperatures have been less common since approximately 1970, synchronous with the trend in increasing low flows since 1948 (Figure 2a). However, using this index to speculate on future stream temperature regimes would be imprudent given that it does not include any parameters related to changes in stream cover or channel morphology.

<u>Comparison of 1991 vs. 1992 maximum stream temperatures.</u> The highest average of 7-consecutive daily maximum stream temperatures were generally higher in 1992 than 1991 (Figure 19). The conclusion suggested by the frequency analysis of elevated stream temperature indices (Figure 18), namely that elevated stream temperatures would be more likely in 1992 than 1991, is therefore at least weakly supported. Of the three sites with equal or slightly lower maximums in 1992, namely 7, 11 and 12, Site 7 is the most anomalous. As previously mentioned, Site 7 data was estimated based on Site 19 data and errors stemming from the predictive equation may account for the anomaly. With regard to Sites 11 and 12, however, one explanation for the lower 1992 temperatures may involve a lack of subsurface flow brought about by the relatively high degree of channel incision and very wide, shallow channels relative to other sites. Attributes such as incised channels and increased channel widths may lead to a lowering of the hydraulic potential of a

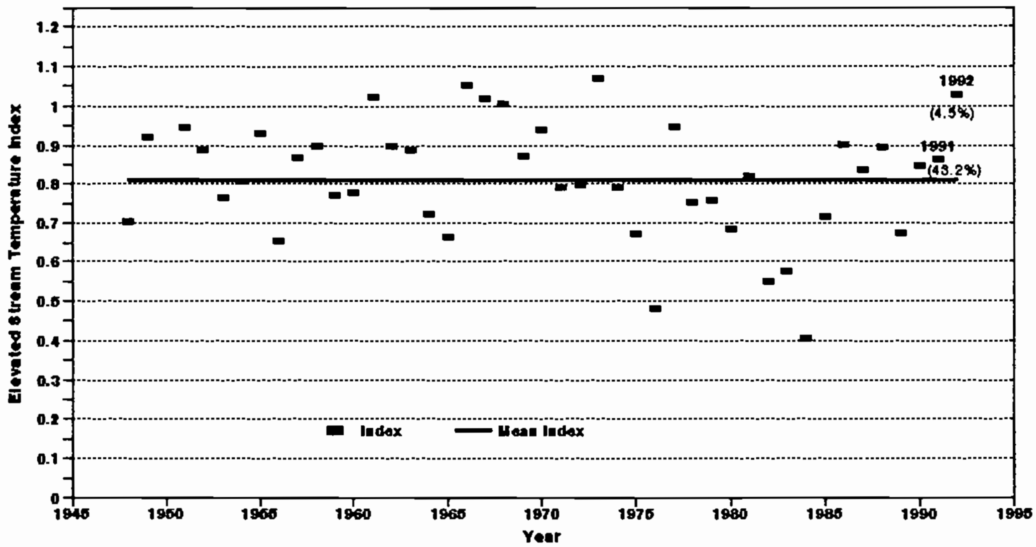


Figure 18. Index of elevated stream temperatures in the Upper Grande Ronde River Watershed for 1948 to 1992. Probabilities of exceeding the observed 1991 and 1992 indices are in parentheses.

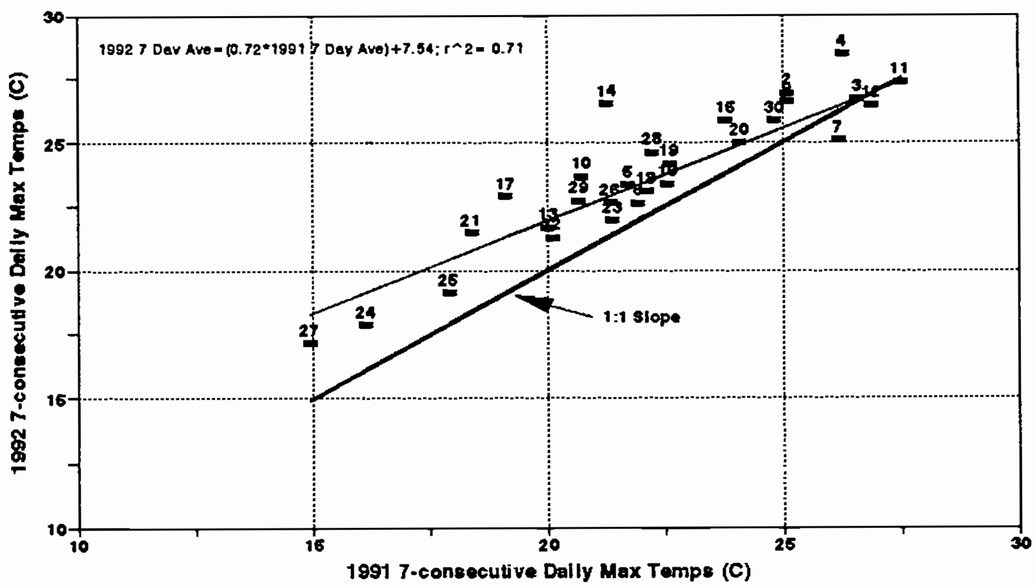


Figure 19. Comparison of 1991 versus 1992 highest average of seven-consecutive daily maximum stream temperatures in the Upper Grande Ronde River Watershed.

stream, resulting in decreased rates of exchange between the channel and its banks (Gebhardt et al., 1989; Elmore, 1992). A relative lack of storage of subsurface water, in turn, may have produced low flows at Sites 11 and 12 which had largely reached their minimums by 1991, resulting in comparably high stream temperatures during both years.

The two stations showing the greatest increase during 1992, Sites 4 and 14, may reflect a change in probe placement between the two years (even though a sincere effort was made to eliminate this possibility). In addition, sites with relatively high seven day maximum stream temperatures during 1991, namely 2, 3, 7, and 11, had very comparable values during 1992, possibly reflecting their close proximity to an upper stream temperature limit, above which evaporative heat loss greatly increases and helps negate any additional energy gains (Beschta et al., 1987).

Longitudinal Stream Temperatures

Theoretical work on stream temperatures suggests that within every basin there is a point or threshold distance at which neither groundwater inflow or riparian vegetation significantly influence water temperature and after which water temperatures are regulated primarily by air temperature (Sullivan and Adams, 1990). At the threshold distance, mean stream temperatures approximate mean air temperatures. Using weather data from Site 2, a relatively open site approximately two kilometers away from the lowest station on the Grande Ronde River, estimates of mean air temperatures for August of 1991 and 1992 are 17.7°C and 17.2°C, respectively. Estimates of mean air temperatures based on the weather station in La Grande, however, are 21.9°C and 21.1°C, for the two years. When using Site 2 data, mean August stream temperatures on the Grande Ronde equalled mean air temperatures at a distance of 30 to 40 km from the watershed divide during both years (Figure 20). However, below Site 19 (at a distance of 41 km from the divide) mean August stream temperatures continued to climb, possibly indicating that the stream is responding to mean air temperatures slightly higher than those observed at Site 2. When using data from the La Grande weather station, mean August stream temperatures within the first 70 km from divide never exceed the mean air temperature. Given that Sullivan and Adams (1990) have found threshold distances to be between 40 to 60 km from the divide in western Oregon and Washington basins, both scenarios are puzzling. However, one explanation may be found in the relatively wide, shallow channels and little stream cover that are common along much of the Upper Grande Ronde River.

Sullivan and Adams (1990) suggest that the threshold distance commonly occurs where average depths are between 0.6 and 1 m. Though an extensive survey of channel depths on the Grand Ronde was not performed, thalweg depths at points 56 and 71 km from the divide were 0.56 and 0.18 m, respectively, and support observations of persistent shallowness throughout the study area. Thus, the Grande Ronde River may not markedly increase in depth with distance from the divide, an assumption upon which the threshold distance is based, thereby making continued increases in mean stream temperatures possible up to and perhaps beyond 71 km from the divide.

Reach Survey Data

For undisturbed systems, characteristics such as wetted width, thalweg depth, and percent stream cover, although locally highly variable, tend to change in relatively systematic ways in a downstream direction, usually resulting in a gradual increase in mean daily stream temperatures. Therefore, when examining the relationships between stream temperature patterns and various reach

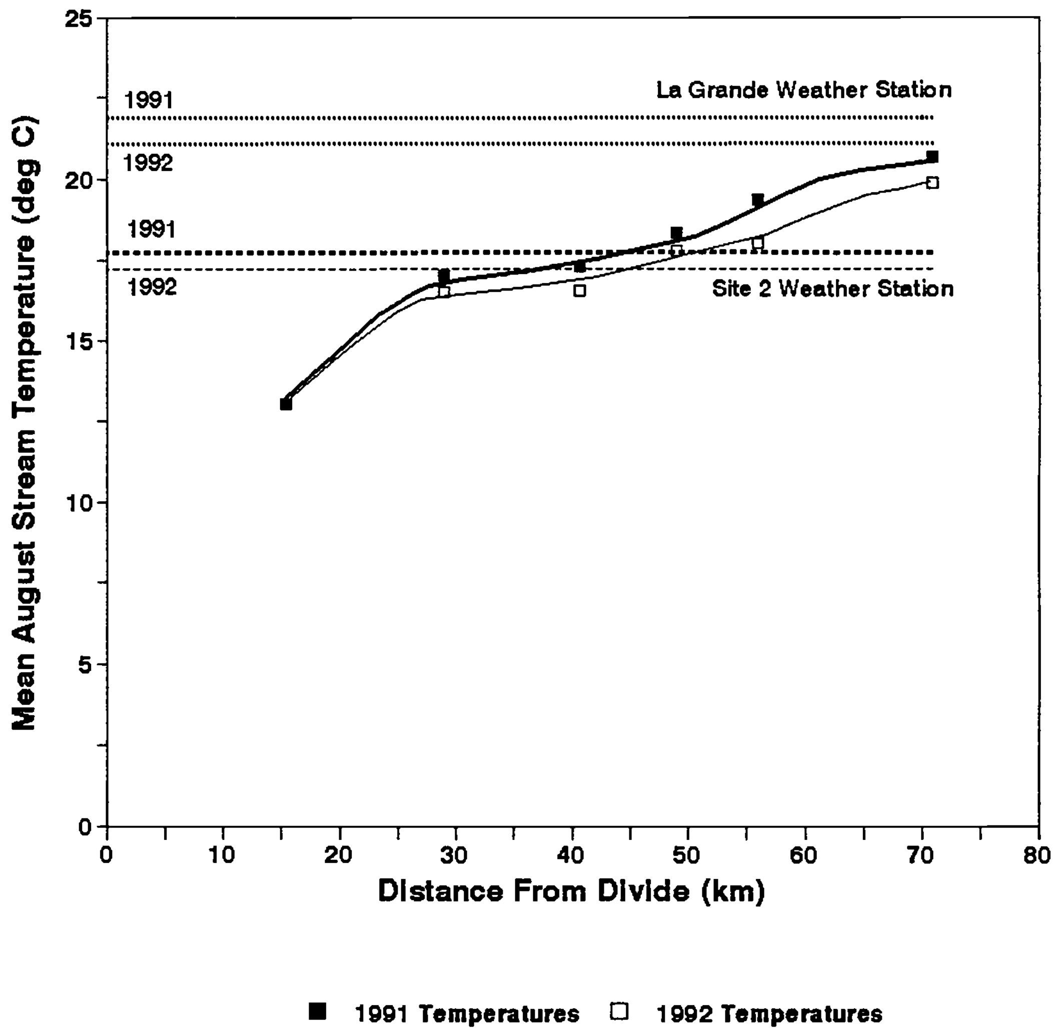


Figure 20. Mean August stream temperatures on the Grande Ronde River during 1991 and 1992 versus distance from the watershed divide. Dashed lines indicate mean August air temperatures based on Site 2 data; dotted lines indicate estimates based on La Grande weather station data.

characteristics, an attempt was made to only consider streams with comparable sizes and elevations. As shown in Figure 21, the 11 surveyed reaches were scattered throughout the basin and fall into roughly three broad categories, namely forest, mixed forest-meadow, and meadow.

Tree basal area. The surveyed reaches had basal areas ranging from 0 to 32 m^2/ha (Figure 22). Three of the reaches (24, 31, and 32) are rather densely forested, whereas Reaches 15, 16, and 11 are sparsely forested, and Reaches 12, 23, 26, 30, and 33 are open meadow sites. In addition, there is a paucity of trees within the first 5-m of the channel in all but the most densely forested reaches. Although Reach 15, and to a lesser extent 16, have many trees between 5 to 15 m from the channel edge, lesser densities occur within the nearest five meters. Wide channels, unstable streambanks, and little vegetative cover as a result of grazing, high water and ice flows have eliminated existing vegetation and prevented natural recolonization of the streambanks (Buckhouse et al., 1981).

Stream cover. The general arrangement of reaches based on tree basal area parallels that of stream cover (Figure 23a). The densely forested reaches, namely 24, 31, and 32, all have greater than 60% stream cover, signifying attenuation of a large proportion of incoming solar radiation. In contrast, meadow reaches (11, 12, 23, 26, 30, and 33) had less than 15% average stream cover and three of these reaches, namely 11, 12, and 33, had less than 5% cover over the stream. The two reaches with intermediate amounts of stream cover, 15 and 16, both represent mixed forest/meadow reaches. While average tree heights were perhaps 35 m, and thus a potentially important component of shade from a distance of 15 m, the relatively wide, shallow channels found at Reaches 15 and 16 served to diminish

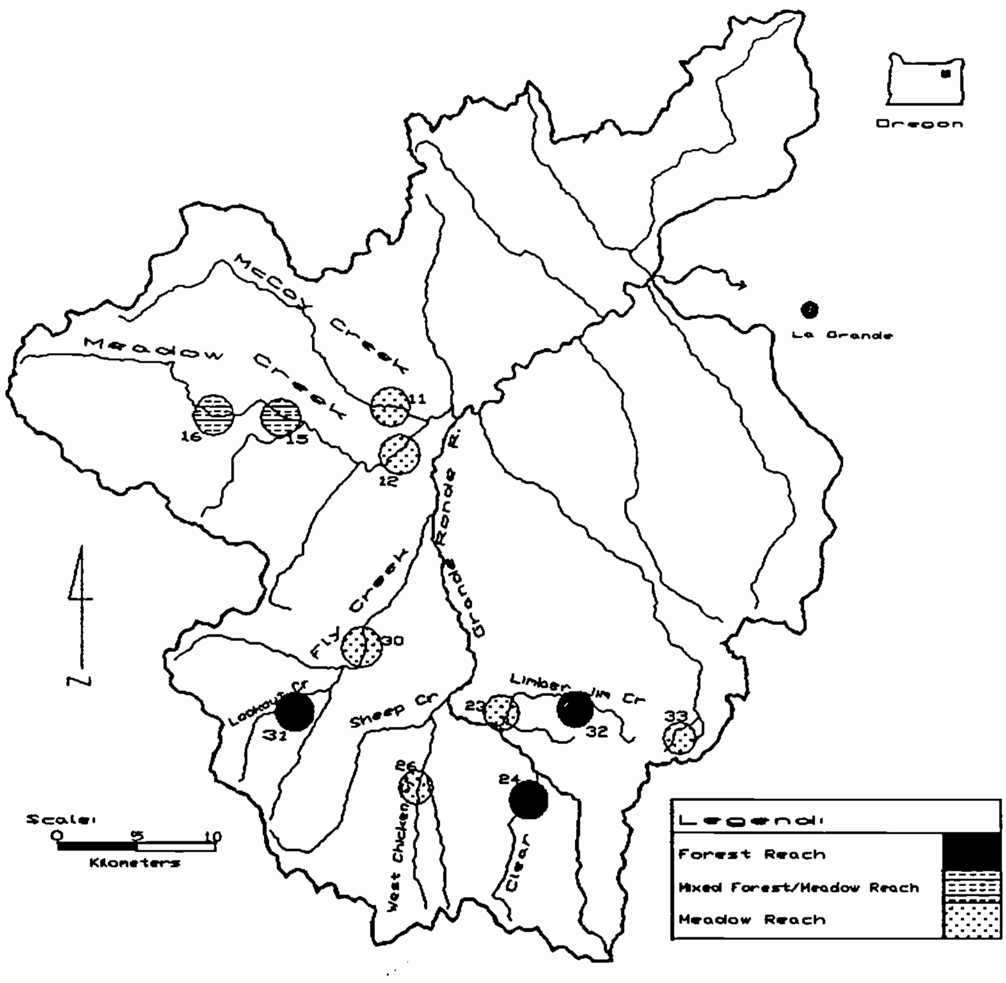


Figure 21. Reach locations and numbers in the Upper Grande Ronde River Watershed.

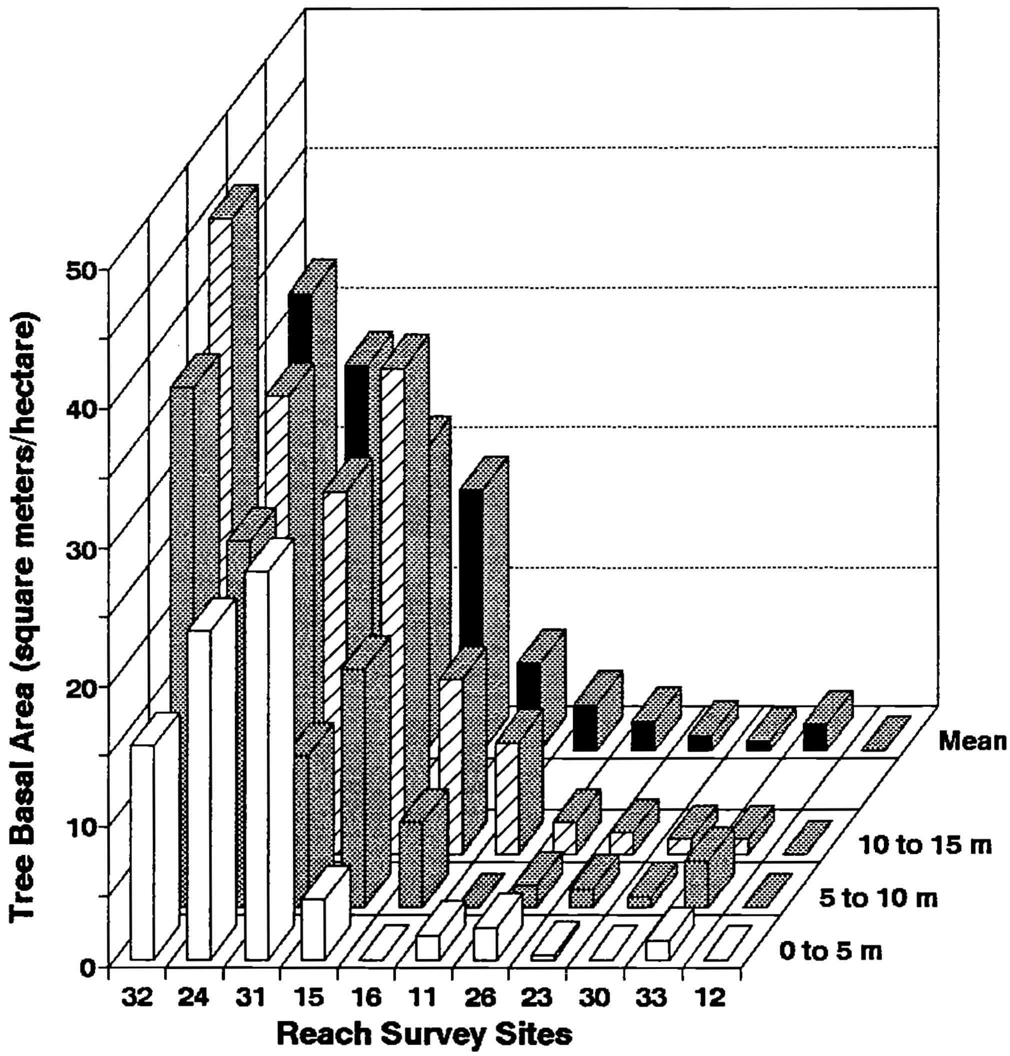
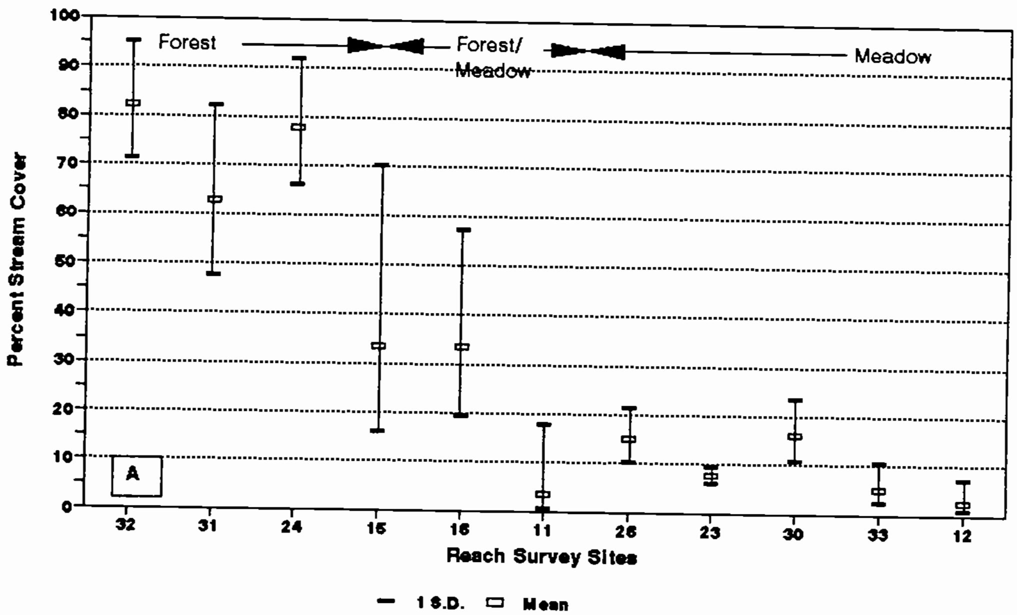


Figure 22. Tree basal area with respect to distance from the channel for stream reaches in the Upper Grande Ronde River Watershed.



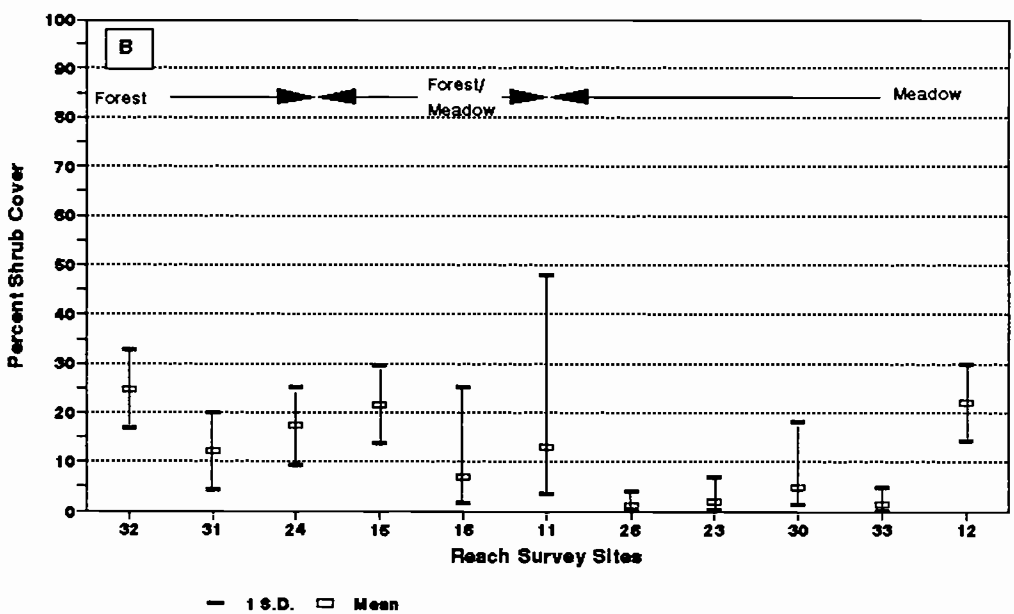


Figure 23. (A) Percent stream cover and (B) percent shrub cover for stream reaches in the Upper Grande Ronde River Watershed.

the capability of trees greater than 5 m from the channel edge for providing shade.

Shrub cover. Percent shrub cover within 15 m of the channel was also measured at each reach (Figure 23b). Average values were all under 25%, and with the exceptions of Reaches 11 and 12 which are located within 5- to 10-year old exclosures, the meadow and mixed meadow reaches had less than 10% shrub cover. By significantly reducing or eliminating grazing pressure on the shrubs, overall shrub cover increases (Kauffman and Krueger, 1984). Any improvements in shrub cover within the exclosures, however, has yet to produce much stream cover, possibly reflecting the severity of channel degradation, primarily indicated by very large width-to-depth ratios and unvegetated streambanks. The low conversion of shrub cover to stream cover indicates stream cover may not appreciably improve until tall shrubs can be established near the wetted channel edge. However, Elmore (1992) noted that drought conditions may promote the recolonization of shrubs on the channel edge. Observations in 1992 in surveyed reaches support this as shrubs, primarily coyote willow (Salix exiqua exiqua), seemed to be encroaching on the exposed channel edges.

The extent to which shrubs provide stream cover is a function of shrub height, their distance from the channel, and stream width. For all of the surveyed reaches, shrub cover was generally greater within the first five meters of the wetted channel (Figure 24a). The one exception is Reach 12 (lower Meadow Creek), in which high shrub cover further from the channel may reflect the recovery of willows facilitated by an exclosure. Infrequent disturbance of low-angle streambanks by high flows and ice flows, however, has probably led to the periodic removal of streambank vegetation, explaining the smaller percent cover closer to the channel for this reach. Of the existing vegetation within 10 m of the channel at Reach 12, over

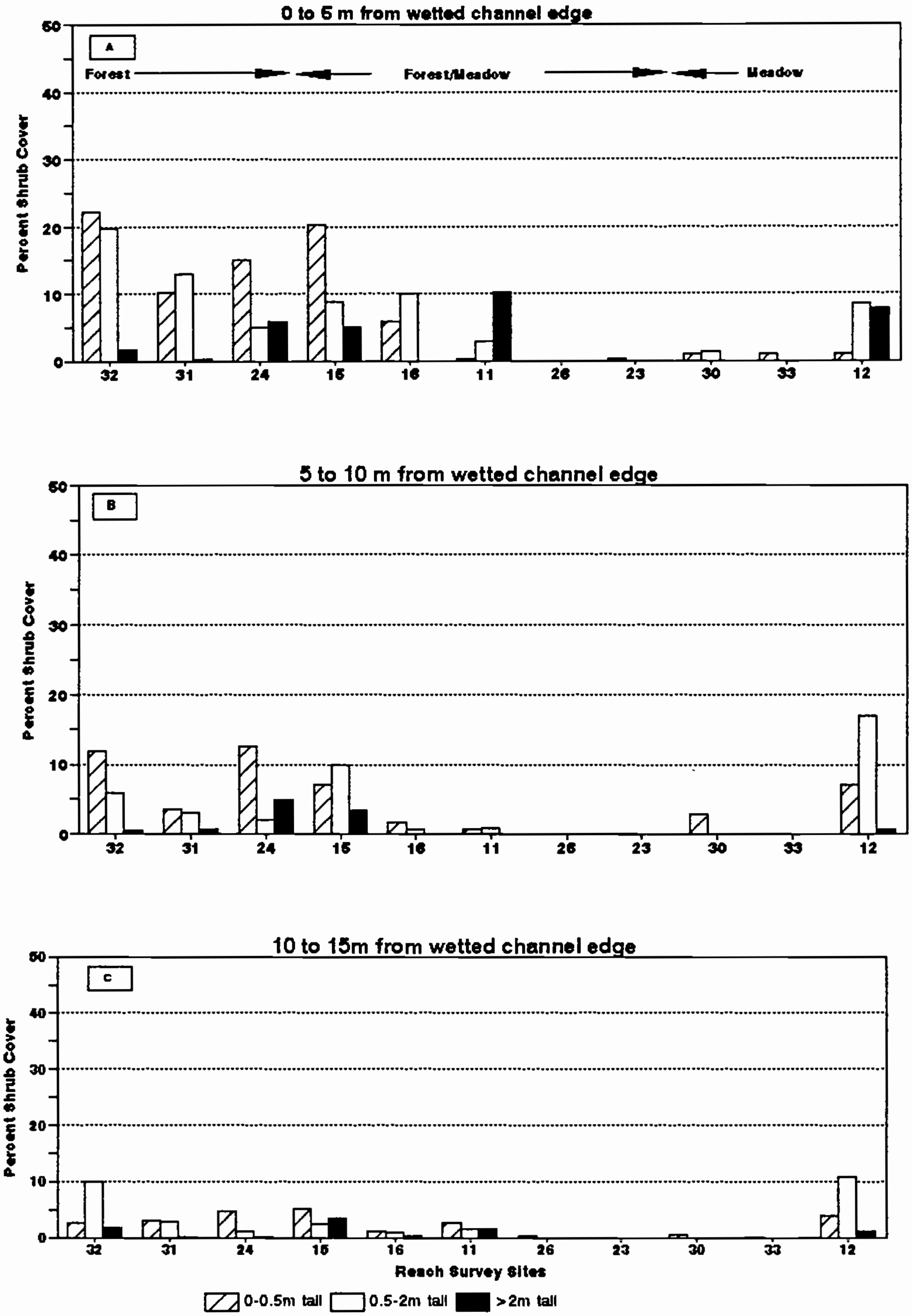


Figure 24. Percent shrub cover between (A) 0 to 5 m, (B) 5 to 10 m, and (C) 10 to 15 m from the wetted channel edge for stream reaches in the Upper Grande Ronde River Watershed. Percent cover is broken into three height classes: 0-0.5 m, 0.5-2 m, and >2 m tall.

half of the total shrub cover (22%) is less than 2 m tall. Given continued growth, however, this shrub cover may soon be an important component of stream cover. However, along open forest-meadow and meadow reaches where grazing exclosures are not installed (e.g., 23, 26, and 30) shrubs are almost totally absent within 15 m of the stream (Figure 24a-c).

Though no formal quantification of species richness was attempted, Figure 25 shows that the number of different shrub genera providing cover is generally small. Within the forested reaches where grazing and other activities have been minimal, five or more genera were found, with snowberry (Symphoricarpos albus), current (Ribes spp.) and alder (Alnus incana) accounting for much of the shrub cover. The forest-meadow reaches also contained five or more genera, though only snowberry on Meadow Creek (15) provided appreciable cover. However, snowberry seldom exceeded 0.5 m in height and consequently provided little stream cover. Within the meadow sites, McCoy and lower Meadow Creek contained more than five genera, while the rest were quite depauperate. The occurrence of Salix spp., a genus upon which ungulates graze heavily when available (Kauffman and Krueger, 1984), was conspicuously absent in the meadow reaches with the exception of both Fly Creek (30) and the exclosed section on lower Meadow Creek (12).

Stream Cover-Stream Temperature Relationships

Significant linear relationships[3] were found between percent stream cover (provided by riparian vegetation and topography during August) and two stream temperature characteristics (Figure 26). Percent stream cover explained 82% of the variability in average August diel fluctuations during 1992 ($p \leq 0.01$) and 69% of the variability in the highest average of seven-consecutive daily maximum stream temperatures ($p \leq 0.01$). In general, the strength of

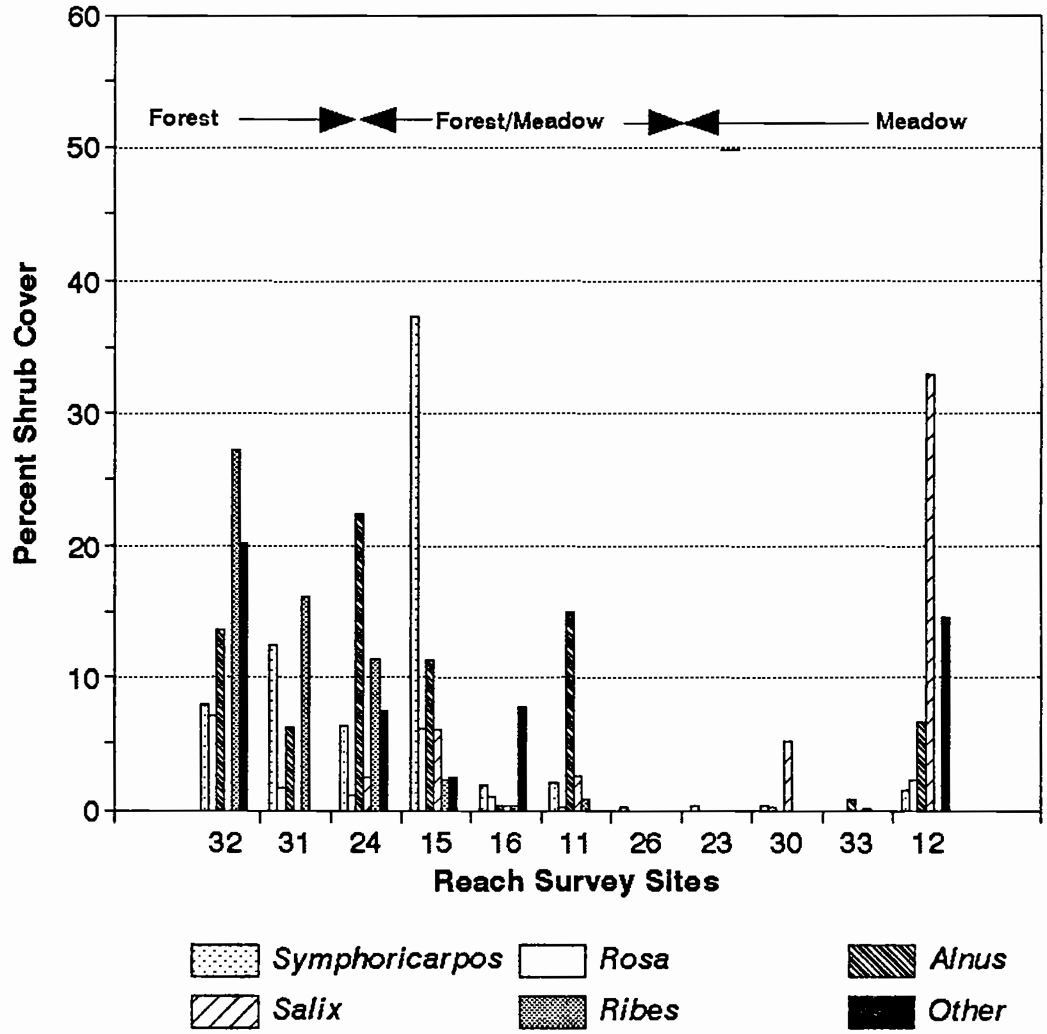


Figure 25. Percent shrub cover according to genus for stream reaches in the Upper Grande Ronde River Watershed. The genus "other" consists predominantly of Rubus, Cornus, Vaccinium, Ledum, and Amalanchier.

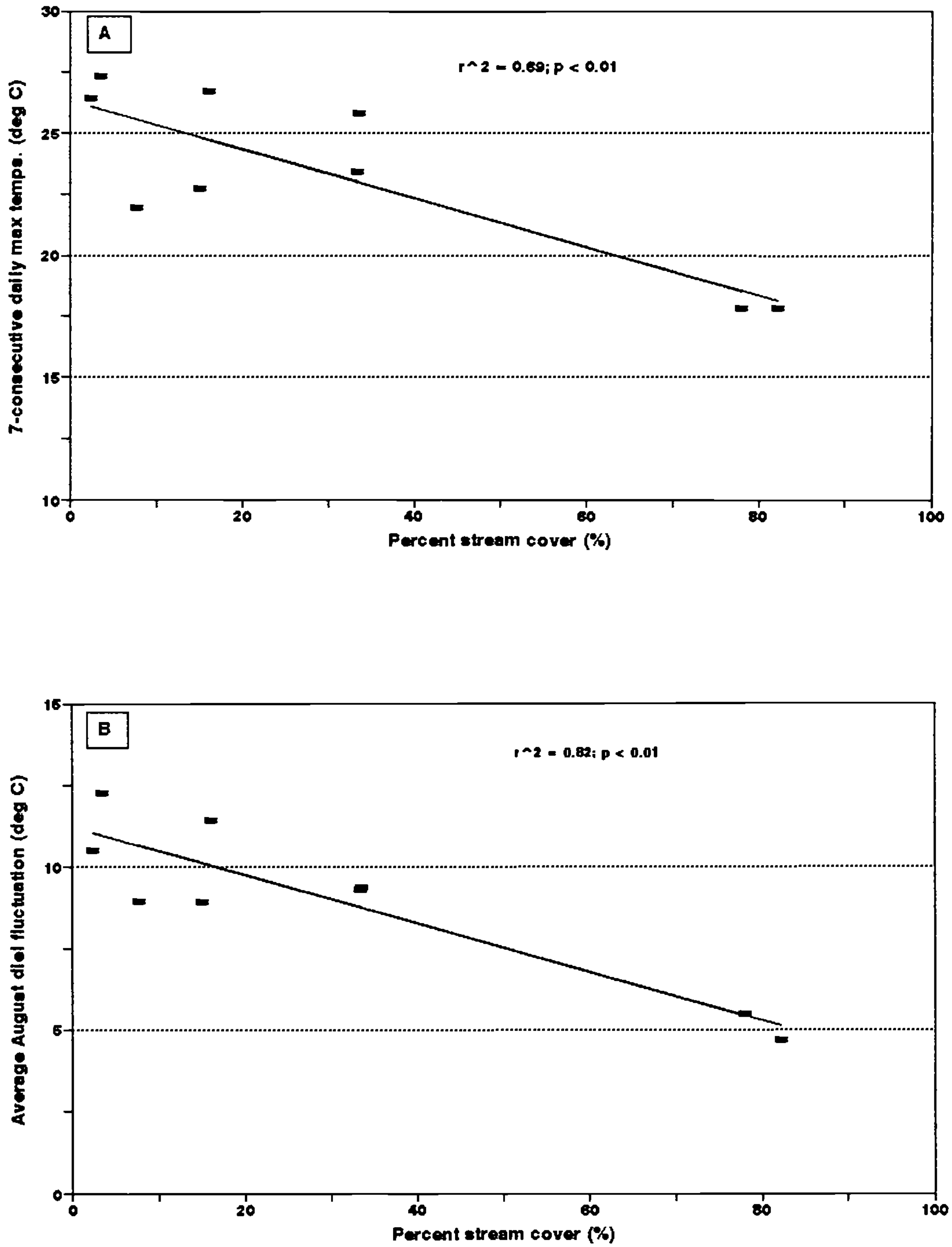


Figure 26. Linear regression of (A) average seven-consecutive daily maximum stream temperatures and (B) average August diel fluctuations in 1992 regressed on percent stream covers for nine stream reaches (Reaches 31 and 33 had no August stream temperature data).

these correlations, while not surprising, points to the importance of stream cover in limiting the amount of incoming solar radiation and thereby reducing the magnitude of daily temperature increases.

Channel Morphology of Surveyed Reaches

Inspection of Table 7 reveals the considerable variability in channel characteristics which occurred between surveyed reaches. Average wetted widths, for example, while generally less than 5 m, ranged from 1.8 to 9.0 m. In addition, average discharge entering each reach ranged between 2 and 195 l/s, though most were between 22 and 170 l/s. Percent undercut streambank, essentially that percentage of the streambank at which a root wad mass projects over the channel even during low flows, ranged from a high of 88% at site 33 to a low of 10% at middle Meadow Creek (Reach 15). In general, a paucity of large woody debris was observed within (Zones 1-2) and above (Zone 3) the bankfull width at most sites. In particular, W. Chicken, McCoy and lower Meadow Creek had 1.2, 1.2 and 0.4 m^3/100 m of wood, respectively, in Zones 1-3. At Reaches 16, 23 and 30, large woody debris was actively placed in the channel in conjunction with habitat alteration projects.

Channel Morphology-Stream Temperature Relationships

Components analysis of Brown's equation (1970) illuminates the potential importance of channel features such as wetted width, thalweg depth, flow velocity and discharge with regards to summer stream temperatures. However, very poor correlations were found in

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[3] Reaches 31 and 33 were excluded from this analysis. No August stream temperature data was collected at Reach 33. At Reach 31, however, a comparison of 1992 and 1993 stream temperatures indicate that the temperature probe was either buried, malfunctioning, or positioned in the channel such that it was not measuring temperatures in the actively mixed portion of the channel during 1992.

Table 7. Channel morphology data for surveyed stream reaches, Upper Grande Ronde River Watershed.

Reach parameter	Survey sites										
	32	31	24	15	16	11	26	23	30	33	12
Azimuth	215	15	320	120	120	100	0	197	354	32	94
Gradient	2	1	2	1.1	1	1	2	1	0.8	2.2	0.5
Thalweg (cm)	11	10	48	28	31	13	49	14	34	47	38
Wetted width (m)	3.5	2.2	4.3	2.3	6.6	5.8	2.0	3.9	4.9	1.8	9.0
Cross-sectional area (m^2)	0.39	0.23	0.52	0.66	0.83	0.79	0.24	0.54	0.57	0.31	1.96
Bankfull width (m)	5.5	6.3	11.1	15.7	5.2	16.4	4.9	8.1	10.4	3.2	22
Bankfull depth (m)	0.32	0.26	0.30	0.43	0.21	0.47	0.31	0.27	0.23	0.16	0.31
Average pool depth (cm)	35	30	48	26	37	33	33	44	38	40	72
Flow velocity (m/s)	0.24	0.1	0.25	0.09	0.2	0.11	0.08	0.29	0.04	0.01	0.09
Flow entering (l/s)	93	21	129	57	170	85	19	158	22	2	195
Percent stream in pools	15	36	16	15	37	26	38	25	29	59	36
Percent stream in riffles	61	39	59	79	39	39	42	27	53	11	36
Percent bedrock	6	0	13	4	20	12	1	0	10	1	3
Percent cobble	37	6	36	42	35	30	15	24	19	3	31
Percent gravel	44	63	35	48	39	45	40	53	64	47	60
Percent sand	13	32	15	5	6	13	44	23	7	49	6
Percent undercut bank	32	36	45	10	11	15	48	18	33	88	11
Large woody debris: Total (m^3/100m)	13.0	6.0	14.0	3.2	9.2	3.3	2.6	8.9	15.7	6.8	0.4
LWD: Zones 1-2	5.0	1.7	6.5	1.7	2.5	1.0	0.6	7.4	8.6	2.7	0.4
LWD: Zones 1-3	9.0	4.6	11.7	2.8	8.1	1.2	1.2	8.4	12	3.8	0.4
LWD: Zones 1-3 in fish structures	0	0	0	0	4.9	0	0	6.2	3.8	0	0

simple linear regression analysis of the average wetted widths corresponding to seven surveyed reaches against various stream temperature variables, listed in Table 8. Reaches 31 and 33 were again omitted from the analysis due to a lack of data while sites 24 and 32, having dense forest canopies and thus very high percent stream cover relative to the others, were omitted due to the confounding affect of cover on channel morphology-stream temperature relationships.

Average August diel fluctuations and the highest average of 7-consecutive daily maximum stream temperatures were also regressed against inflow (Q), flow velocity and bankfull depth. As shown in Table 8, inflow (flow entering the reach), measured in liters per second, correlates very poorly with the temperature parameters. Differences between sites related to stream cover, and thus the amount of incoming solar radiation to a stream, may account for this. Additional regressions, omitting Reaches 24 and 32 (where percent stream cover is greater than 50%), did not lead to improved models or greater correlations.

Flow velocity is significantly negatively correlated with average August diel fluctuations and the highest average of 7-consecutive maximum daily stream temperatures based on all nine sites. Sites, therefore, with fast moving water tended to have lower diurnal fluctuations and average maximum stream temperatures. In general, given comparable rates of incoming solar radiation and subsurface flow, reaches with high flow velocities will exhibit more moderate elevated stream temperatures (Brown, 1983). However, large differences in percent stream cover between sites suggest that rates of incoming solar radiation were not comparable. As the two forested reaches included in this regression (24 and 32) had relatively high flow velocities as well as percent stream cover

Table 8. Regression analysis summary of three stream temperature characteristics measured in 1992 for nine* stream reaches as related to five channel morphology characteristics, Upper Grande Ronde River Watershed.

		Regression analysis				
Dependent variable: stream temperature	Independent variable: channel morphology	n	Slope	r^2	Significance	Standard Error of Estimate (°C)
Avg. August diurnal fluctuation	Percent undercut bank	9	-0.082	0.24	0.18	2.33
	Flow entering (l/s)	9	-0.047	0.01	0.76	2.65
	Flow velocity (m/s)	9	-18.729	0.46	0.03	1.96
	Wetted width (m)	7	0.209	0.15	0.39	1.34
	Bankfull depth (m)	7	0.098	0.18	0.34	1.3
Average max. of 7 warmest (consec.) days	Percent undercut bank	9	-0.138	0.32	0.11	3.21
	Flow entering	9	-0.009	0.02	0.70	3.85
	Flow velocity	9	-31.364	0.61	0.01	2.43
	Wetted width	7	0.250	0.24	0.23	3.48
	Bankfull depth (m)	7	0.317	0.13	0.43	2.21
Average max. of 7 warmest day (not cons)	Percent undercut bank	9	-0.149	0.36	0.09	3.16
	Flow entering	9	-0.006	0.11	0.79	3.94
	Flow velocity	9	-30.950	0.57	0.02	2.58
	Wetted width	7	0.324	0.14	0.41	2.17
	Bankfull depth (m)	7	0.277	0.56	0.05	1.55

* Regressions where n = 7 reflect the omission of sites 24 and 32.

(Table 7), this combination may have worked in tandem to moderate maximum stream temperatures.

Finally, bankfull depth had a significant ($p \leq 0.05$) positive correlation when regressed on the highest average of 7-maximum daily stream temperatures (Table 8). This positive correlation can be better understood by considering the specific reaches in which large bankfull depths were observed. While the difference in bankfull depths between reaches were not large, Reaches 11 and 15 had bankfull depths about 15 cm above the average. Both of these creeks represent streams which have been significantly altered, Reach 11 by channelization and livestock grazing and Reach 15 by grazing (past and present), logging and splash dams. The association of large bankfull depths with reaches where intense human impacts have led to reductions in stream cover and dewatering of the floodplains (Platts, 1991), may account for the strength and direction of the correlation. It should be noted that the regression model was statistically significant ($p \leq 0.05$) only when Reaches 24 and 32 were omitted. Although neither of these reaches had unusually small nor large bankfull depths, both have significant stream cover (and perhaps subsurface flow inputs) and consequently very moderate maximum daily stream temperatures.

Ordination of Reach Survey Data

To identify the combination of features (related to channel form and riparian vegetation listed in Table 9) which account for the greatest amount of relative variability between reaches, ordination was used. Ordination, using Non-metric Multidimensional Scaling, was used to evaluate relationships between surveyed reaches and among reach characteristics. Fourteen channel morphology and riparian vegetation variables were used in the ordination of reach data. Three axes were used to explain 55%, 9% and 32% of the

Table 9. R-squared values of riparian vegetation and channel morphology variables for Non-metric Multidimensional Scaling ordination axes 1-3 for stream reaches in the Upper Grande Ronde River Watershed.

Variable	Axis 1	Axis 2	Axis 3
Percent stream cover	0.68	0.40	0.03
Percent shrub cover: 0 to 15 m from channel	0.79	0.10	0.36
Percent shrub cover: 0 to 5 m from channel	0.96	0.32	0.10
Percent shrub cover: 0.5 to 2 m tall	0.61	0.08	0.33
Wetted width	0.00	0.04	0.57
Thalweg	0.03	0.30	0.00
Width-to-depth ratio	0.00	0.00	0.59
Bankfull depth	0.01	0.02	0.81
Bankfull width	0.45	0.42	0.17
Bankfull area	0.02	0.02	0.81
Percent undercut bank	0.06	0.23	0.77
Average flow velocity	0.13	0.45	0.01
Q-ratio: inflow/outflow	0.19	0.41	0.44
Tree basal area	0.84	0.40	0.01

variability in the relative position of the original set of data points. A list of the input variables and their r-squared values for the first three axes is shown in Table 9.

Figure 27 shows the relationship of the 11 reaches with respect to axes 1 and 3. Of the 14 variables used in the ordination, eight were found to be strongly correlated, $r^2 > 0.59$, to the first and third axes. Axis 1, which explained 55% of the variability, was most strongly correlated with percent shrub cover between 0 and 5 m from the channel ($r^2 = 0.96$), tree basal area (0 to 15 m from channel) ($r^2 = 0.84$), mean percent shrub cover between 0 and 15 m from the channel ($r^2 = 0.79$), and percent stream cover ($r^2 = 0.68$). Bankfull depth, percent undercut bank, and the width to depth ratio all correlated strongly with the third axis ($r^2 = 0.77$, 0.81, and 0.59, respectively). Finally, reaches did not differ significantly with respect to the axis 2 scores, making its interpretation and use in correlations with stream temperature variables of little value.

The distribution of sites along axis 1 in Figure 27 appears to fall into roughly three different groups, reflecting differing levels of stream cover and thus direct interception of solar radiation. Forested Reaches 15, 24, 31, and 32 form a group, while the more open, meadow reaches (16, 23, 26, 30 and 33) seem to comprise a second group at the opposite end. Interestingly, Reach 12, and to a lesser extent 11, while located in the center of axis 1, are also open meadows. They differ from the other open sites, however, in that they currently are within fenced exclosures to prevent cattle grazing; as a consequence they have slightly higher percentages of shrub cover.

Considering the location of sites relative to axis 3, alone at one end is Reach 33, a small and exceptionally healthy meadow system with vegetated streambanks and a narrow, deep channel with over 50%

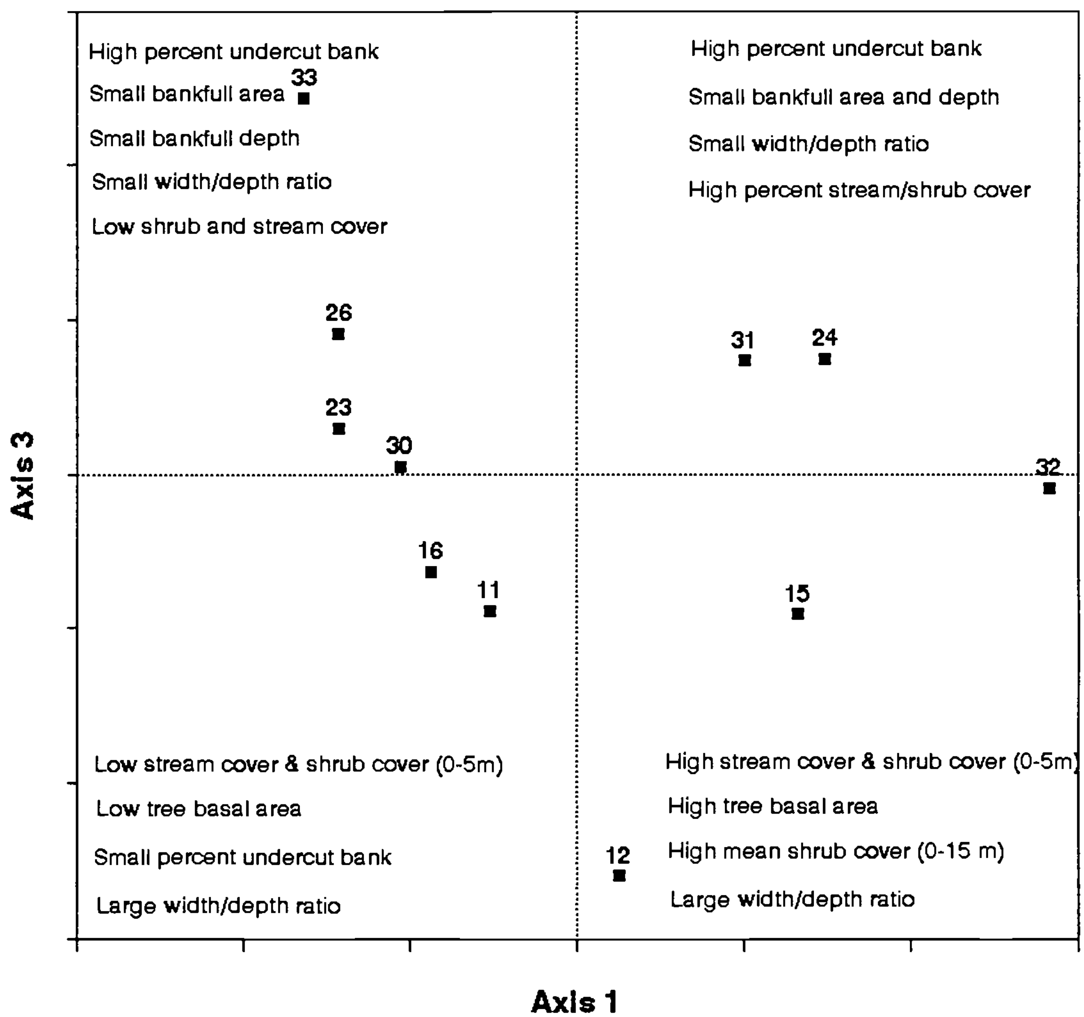


Figure 27. Ordination axes 1 and 3 for 11 stream reaches and 14 site characteristics in the Upper Grande Ronde River Watershed using non-metric multidimensional scaling.

undercut banks). On the opposite end is Reach 12, which represents the largest creek and one in which wide, shallow channels and exposed, low angle streambanks are common. In addition, the 3 reaches nearest Reach 12 in Figure 27, namely 11, 15 and 16, have also experienced the effects of intensive land use (Bohn and Buckhouse, 1985; McIntosh, 1992). Given this distribution, axis 3 appears to reflect relative levels of human influence stemming from splash dams (Reaches 12, 15 and 16), channelization (11), or livestock grazing (11, 12, 15, 16, 23, 26, 30) which have led to significant changes in riparian vegetation and channel banks.

Correlation of axis scores to stream temperature variables. Diel stream temperature fluctuations, which are largely determined by conditions which limit both solar radiation inputs during the day and nighttime radiational cooling, are strongly correlated with axis 1 ordination scores (listed in Appendix B). Simple linear regression analysis of Average August diel stream temperature fluctuations on axis 1 scores results in an r^2 of 0.48 and a p-value of 0.04 (n = 9) (Table 10). Given the strong correlation of axis 1 scores to shade parameters in the ordination, the regression reinforces the importance of shade on moderating stream temperatures within small, headwater streams.

Similarly, simple linear regression of axis 3 scores on the average daily maximum stream temperature (for July and August of 1992) and the average of the seven daily minimum stream temperatures associated with the highest average of seven consecutive maximum values were significant ($p \leq 0.05$), with r^2 of 0.54 and 0.51, respectively (Figure 28 and Table 10). The strong negative correlations between the temperature variables and axis 3 scores suggest that sites with higher percent undercut banks, smaller bankfull depths and areas, and smaller width-to-depth ratios have lower maximum stream temperatures and higher average seven day

Table 10. Regression analysis summary of selected stream temperature variables measured in 1992 for nine stream reaches regressed on axis 1 and 3 ordination scores, Upper Grande Ronde River Watershed.

		Regression analysis				
Dependent variable: Ordination axis score	Independent variable: Stream temperature	n	Slope	r^2	Significance	Standard Error of Estimate (°C)
Axis 1 scores	Average August diel fluctuation	9	-2.30	0.48	0.04	1.93
	Average max. of 7 warmest (consec) days	9	-2.47	0.26	0.16	3.35
	Julian day of maximum	9	6.55	0.25	0.17	9.15
	Average of daily maximum	9	-2.16	0.22	0.20	3.24
Axis 3 scores	Average August diel fluctuation	9	-2.08	0.20	0.23	2.40
	Average max. of 7 warmest (consec) days	9	-3.99	0.34	0.10	3.16
	Average max. of 7 warmest (not consec) days	9	-4.28	0.38	0.08	3.11
	Average July and August	9	-3.07	0.54	0.02	1.61
	Average min. of 7 warmest (consec) days	9	-1.80	0.51	0.03	1.00
	Julian day of maximum	9	5.58	0.09	0.43	10.08
	Average of daily maximums	9	-4.18	0.42	0.06	2.80

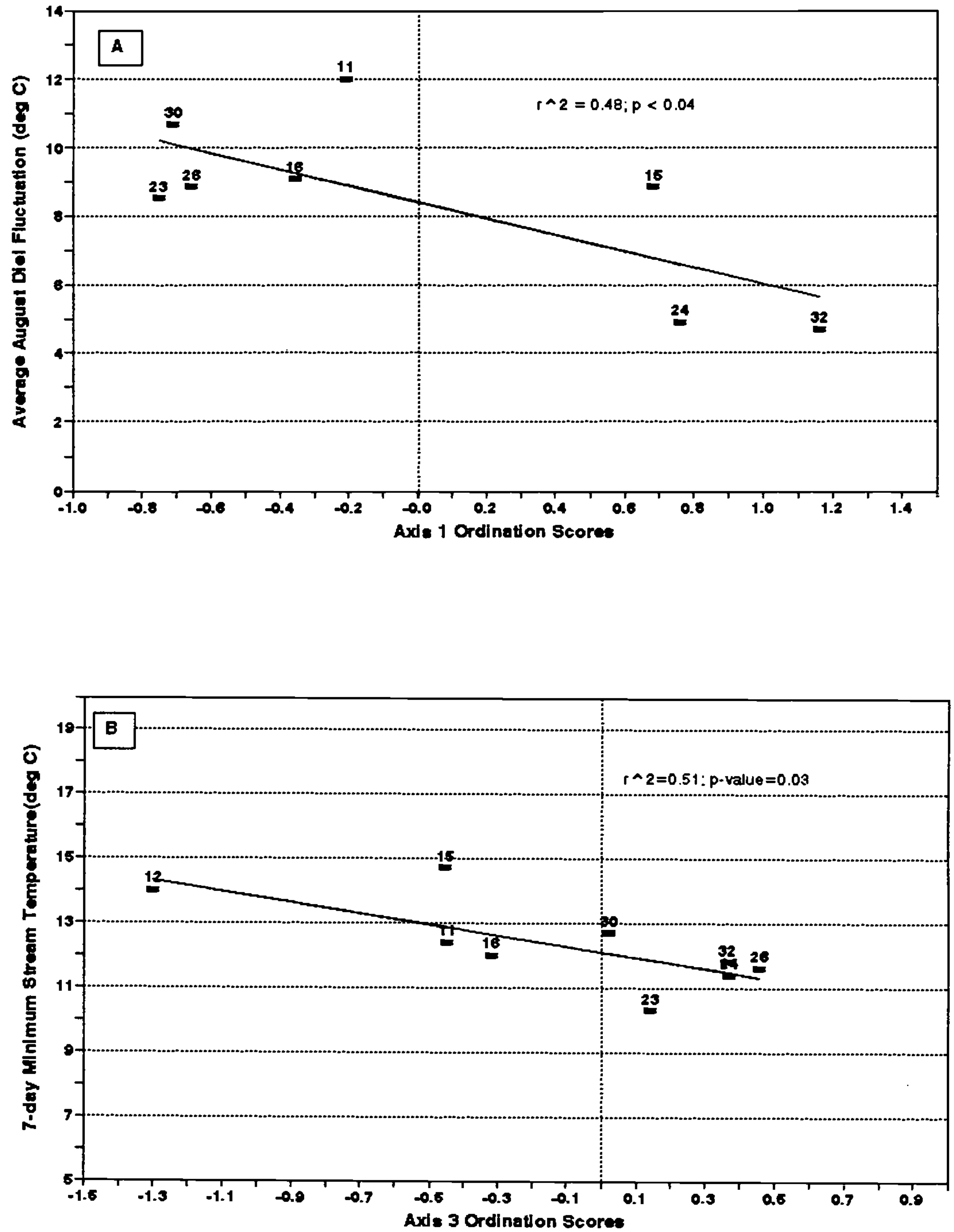


Figure 28. Linear regression of (A) axis 1 and (B) axis 3 non-metric multidimensional scaling ordination scores regressed on 1992 stream temperature variables corresponding to nine stream reaches (no temperature data available for Reaches 31 and 33) in the Upper Grande Ronde River Watershed.

minimums. These findings support the idea that morphologically complex channels serve an important role in buffering streams from extremes in thermal heating.

Evaluation of TEMP-86

TEMP-86, a stream temperature prediction model developed in 1984 (Beschta and Weatherred, 1984) and revised in 1986 for use with desktop personal computers, predicts stream temperatures through relatively short reaches (less than 1 km). The model is driven by an extensive array of reach characteristics that include stream, shade, and climatic factors (Appendix C). The precision and accuracy of TEMP-86 was evaluated using hourly input and output temperatures. Stream temperature recorders were placed for up to 48 hours at the upstream and downstream ends of the intensively surveyed reaches shown in Figure 21. Model accuracy was evaluated using hourly stream temperatures and the WSTAT (defined on page 39). Accuracy measures how close the prediction is to the true value and systematic errors or bias will result in large values. Precision, a measure of the total number of degrees which predicted temperatures differed from the observed temperatures, was evaluated to determine relative confidence in the results. Daily maximum and minimum or average hourly stream temperatures can be used to run TEMP-86.

A sensitivity analysis of TEMP-86, performed by the Timber/Fish/Wildlife (TFW) work group in Washington based on maximum and minimum daily stream temperatures suggests that differences in observed stream temperatures result in large errors in predicted downstream temperatures (Sullivan et al., 1990). However, the model's sensitivity with regard to all other parameters was generally quite small. In contrast to the TFW evaluation, however, this study used hourly stream temperatures. As a result, the extent to which changes in environmental variables affect changes in predicted stream temperatures is unclear. Given the rather fine scale at which most of the inputs variables were measured within the reach surveys, however, poor model performance stemming from inaccurately measuring reach characteristics is unlikely.

The accuracy of individual reaches, represented by the WSTAT in Figure 29, illustrates that with two exceptions TEMP-86 was a good predictor of average hourly stream temperatures. Reaches 11 and 31, McCoy and Lookout Creeks respectively, both had large consistent deviations from observed stream temperatures, though in opposite directions. At McCoy Creek, TEMP-86 consistently over-predicted downstream temperatures by 4.76°C, whereas on Lookout Creek it under-predicted observed temperatures by an average of 3.45°C.

Predicted downstream temperatures at McCoy Creek (Reach 11) were consistently much higher than those observed. Given the location of the reach relative to the 1964 channelization project, however, this error likely stems from undetected contributions of subsurface flow. The upper 75 meters of the reach flow along the southern valley wall and has a sparsely vegetated riparian zone consisting primarily of alder and pine. Immediately below this, however, channelization following the 1964 flood has resulted in a highly constrained reach with little vegetative cover. Given the streams exposure to incoming solar radiation, therefore, predicted increases in stream temperature seemed reasonable. The actual (observed) decrease through the reach, however, may reflect inputs of subsurface flow caused by differences in piezometric head created by the channelization. Water that is in the floodplain at the top of the reach may be drawn back into the channel due to the decrease in water level brought about by channelization. The lack of a difference in surface flow which was observed between the top and

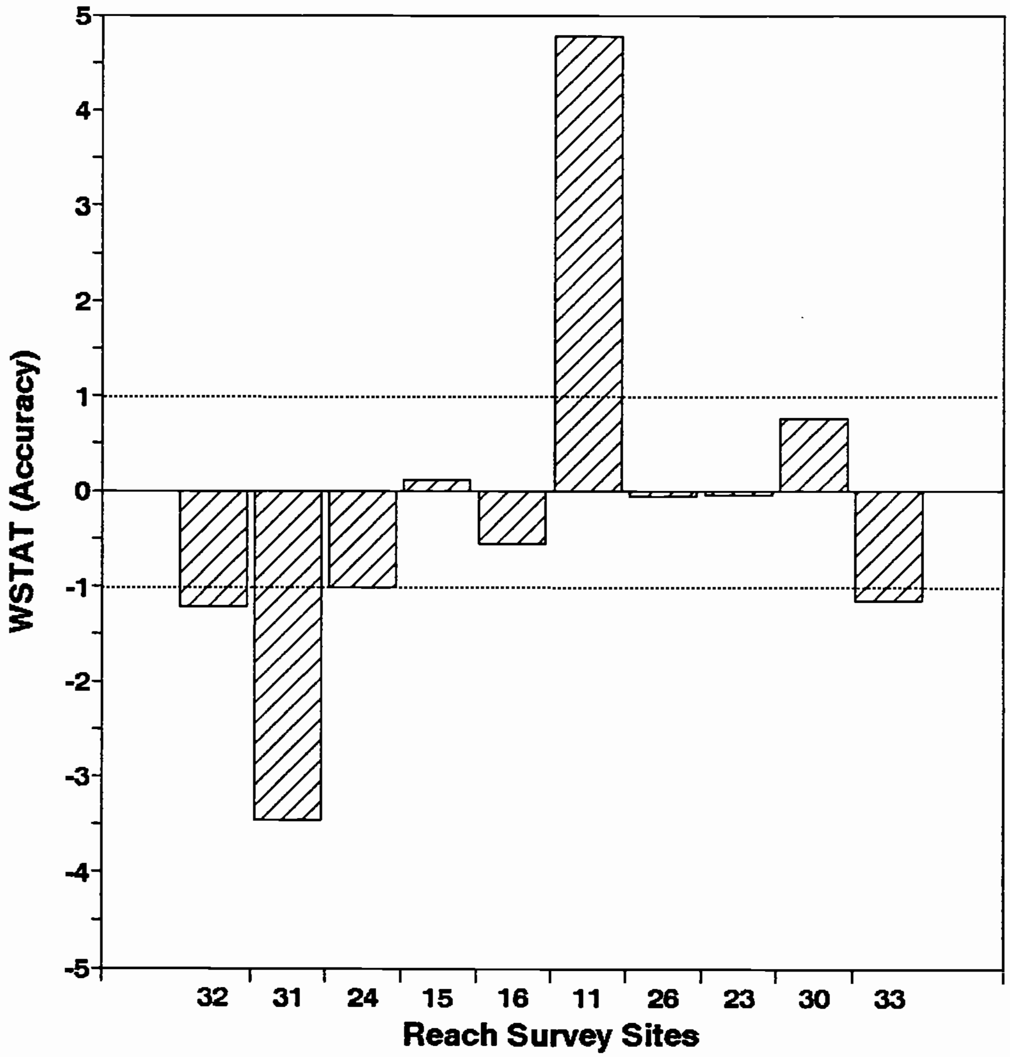


Figure 29. Accuracy (WSTAT) of TEMP-86 in predicting hourly stream temperatures on ten stream reaches in the Upper Grande Ronde River Watershed.

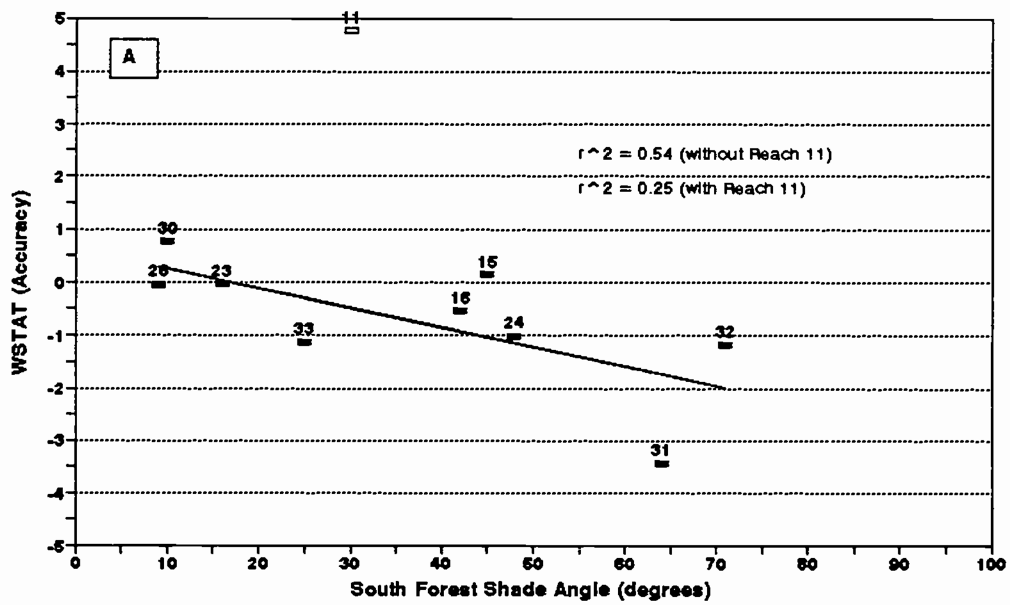
bottom of the reach may reflect the inherent inaccuracy of flow measurements using instantaneous values (±10%), the loss of flow within the lower section of the reach, or a combination of both. However, this reach serves as an example of the importance of subsurface flow as a moderator of stream temperatures. It should also be noted that while stream temperatures appeared to decrease through the upper 250-m of this channelized reach, a comparison of annual maximum stream temperatures between the top and the bottom of the channelized section (a distance of over one kilometer) indicate a reach through which an increase of 3°C occurred in 1992. Given this, the suggestion that channelization may promote consistently cooler downstream temperatures during warm summer conditions probably only applies to the upper-most portion of this channelized reach.

TEMP-86's lack of accuracy associated with Lookout Creek, and to a smaller degree with the other forested reaches, is less of a surprise given the complexity of the reach and the inherent error associated with measuring such a heterogeneous system. Shade provided by the canopy, though frequently greater than 70%, was patchy and unevenly distributed throughout the reach. The pervasiveness of subsurface flow is also an important issue which was not adequately addressed given the limited resources. While stream cover was estimated every 10 m within each reach, the magnitude and spacial variability of subsurface inputs reflect perhaps the most significant unknown. Consistent overestimations of forest and topographic shade angles or an inability of TEMP-86 to adequately simulate canopies of varying densities and configurations may be responsible for the low WSTAT's for all three of the forested reaches.

Unfortunately, the determination of model precision with respect to each site was not possible given the short length of time for which both upstream and downstream temperatures could be monitored. The precision of TEMP-86 based on an average of all sites, however, was 1.31°C. This, it turns out, is relatively close to the value of 1°C which the TFW work group (Sullivan et al., 1990) determined for streams located primarily in western Washington. The average WSTAT's were also quite comparable; the TFW value of 0.0°C was only slightly smaller than the value of -0.18°C found in this analysis.

Bias in TEMP-86. Systematic errors in the models predicted hourly temperatures were evaluated by looking for trends in the WSTAT. A simple linear regression of the WSTAT against the South Forest Shade Angle, an input variable in TEMP-86, shows a negative correlation (r^2 = 0.54 without Reach 11)(Figure 30a). Reaches with South Forest Shade Angles greater than 45° have a slightly smaller WSTAT than sites with lower shade angles. As this shade angle is used in estimating the amount of solar radiation which enters the stream (Beschta and Weatherred, 1984), the model seems to be underpredicting stream temperature changes in reaches with good cover in the southerly direction. Consistently overestimating shade angles would reduce the amount of energy available for input into the stream, thereby reducing the magnitude of predicted temperature increases. The problem of accurately quantifying this variable also greatly increases along densely vegetated and heterogeneous streams (Reaches 24, 31, and 32). A second possible source of error may stem from the equations used in TEMP-86 to route direct and diffuse beam radiation through canopies.

Bias stemming from reach differences in stream cover is also indicated by the correlation between tree basal area and the WSTAT (Figure 30b). Though tree basal area is not an input variable in TEMP-86, the same slight negative correlation exists. As is shown in Figure 30b, the correlation is slightly higher when Reach 11 is



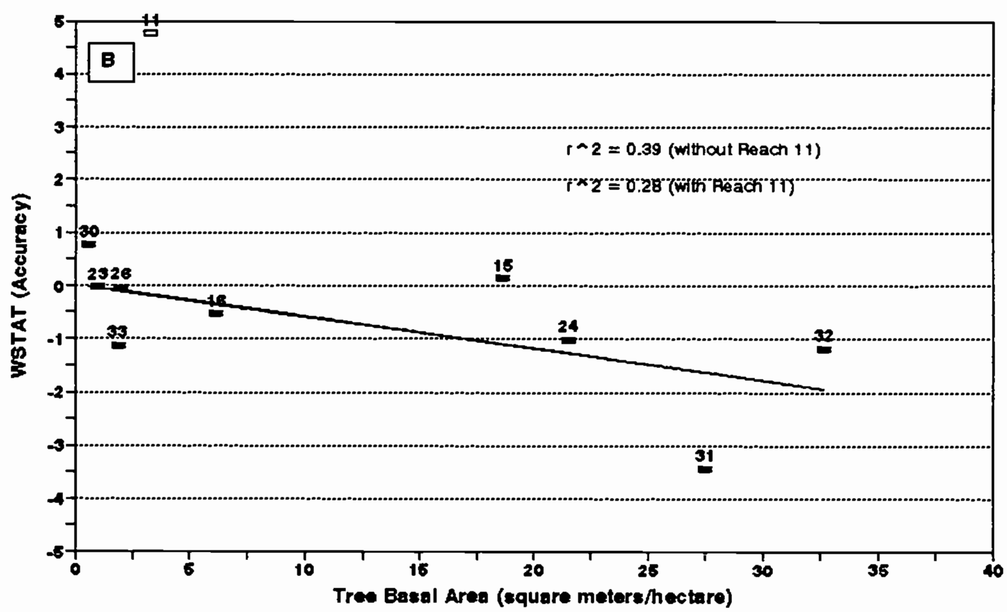


Figure 30. Linear regression of the WSTAT (accuracy) for TEMP-86 hourly stream temperature predictions for ten stream reaches regressed on (A) average south forest shade angle and (B) mean tree basal area, Upper Grande Ronde River Watershed.

excluded (r^2 = 0.39 versus 0.28). Exclusion of this reach site from the analysis seems justified in this instance given the location of the reach relative to post-1964 channelization practices. If, as mentioned previously, speculation about the effect of channelization on current subsurface inputs is correct, the magnitude of subsurface flow inputs within this reach might be anomalous and thus warrant its exclusion.

TEMP-86 as a management tool. Having established that TEMP-86 is, in most cases, an accurate stream temperature prediction model, evaluating the effects of various management strategies on stream temperatures becomes feasible. Reach 30 (Fly Creek), being a relatively degraded meadow system with large width-to-depth ratios and low stream cover, was chosen as representative of a reach for which such an evaluation might be useful. Combinations of two variables likely to be addressed and altered by stream restoration projects, namely percent stream cover and wetted width, were manipulated in the analysis. Seventeen modeling runs were undertaken using the present wetted width value of 4.9 m, as well as 10%, 25% and 50% reductions from the original wetted width, and percent stream covers of 0%, 10%, 25% and 50% (the current stream cover is 13%).

As is shown on the surface plot in Figure 31, TEMP-86 predicts a maximum daily stream temperature of about 29°C below the 250-m long reach under present conditions. In general, the plot indicates that lower maximum daily stream temperatures are predicted following the establishment of 50% stream cover than by a 50% reduction in wetted width. If 50% stream cover was somehow achieved with no concurrent change in wetted width, a maximum daily stream temperature of 27.7°C is predicted. Conversely, if stream cover remained at 13% while wetted widths were reduced by 50% (to 2.4 m), a slightly higher maximum daily temperature of 28.1°C would be

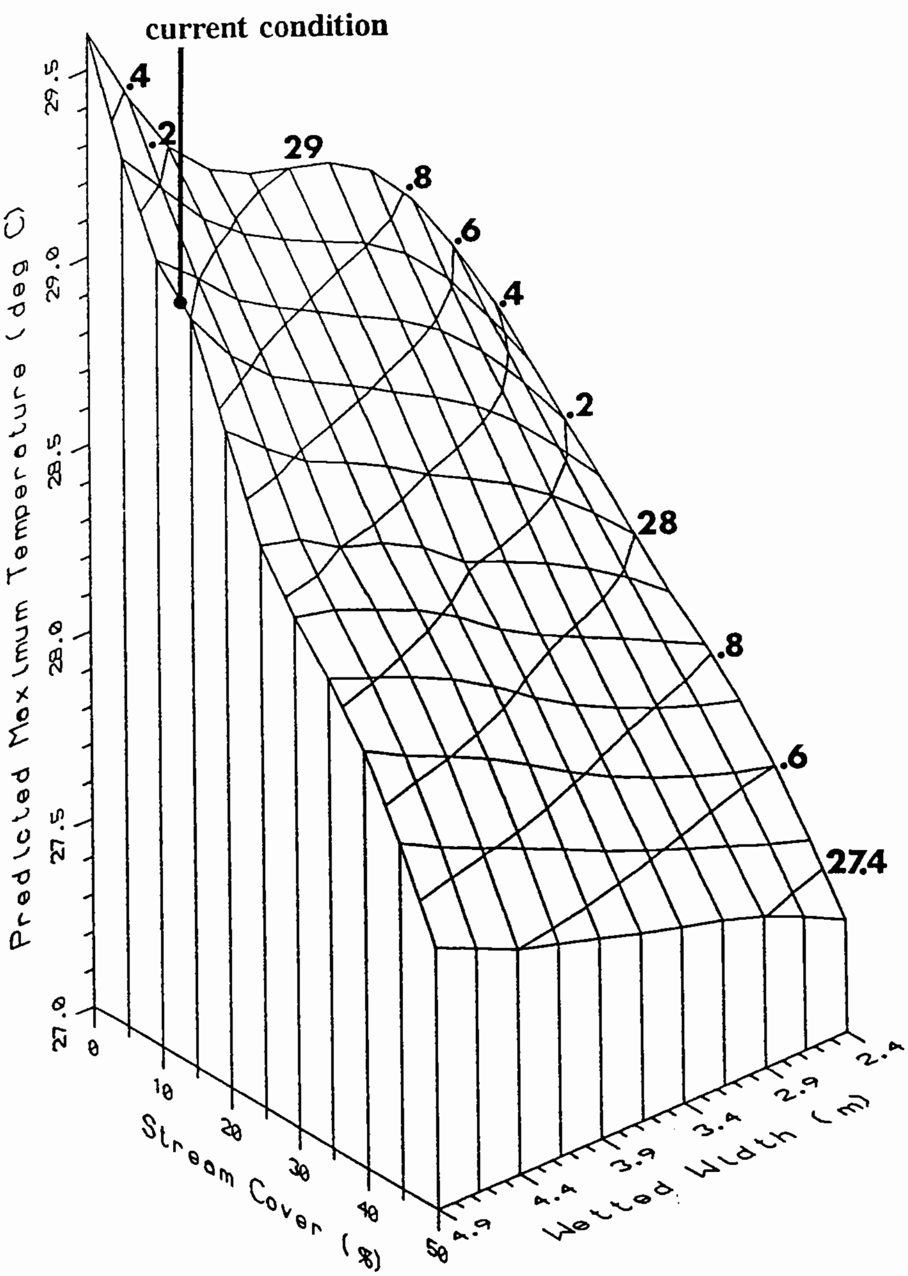


Figure 31. Response surface of TEMP-86 predicted maximum daily stream temperatures for Fly Creek as a function of 0, 10, 25, and 50% changes in wetted width and 0, 10, 25, and 50% stream covers.

predicted. However, in a recovering riparian system, significant increases in stream cover would likely facilitate decreases in wetted width (Elmore and Beschta, 1987) and simultaneous changes in both characteristics would incur even greater reductions in daily maximum stream temperatures than isolated changes to either. Of course not all sites have the same capacity for vegetation recovery and the degree to which vegetation controls or affects changes in channel shape depends at least in part on it's ability to improve inherent (site specific) substrate stability (Gebhardt et al., 1989).

SUMMARY AND CONCLUSIONS

Stream Temperatures

During the summers of 1991 and 1992, stream temperatures above 14°C were common in the Upper Grande Ronde River. Seven-day maximum stream temperatures at the upper-most site (Site 25) on the UGR River, 15 km from the watershed divide, were 17.9°C and 19.1°C during the summers of 1991 and 1992, respectively. Continuing 14 km downstream to Site 20 below Vey Meadow, seven-day maximum stream temperatures increased more than 6°C during 1991 and 1992, whereas between Sites 20 and 19, a distance of 12 km, maximum temperatures decreased about 1.5°C. However, below Site 19 seven-day maximum stream temperatures once again increased with distance downstream to Site 3, 71 km from the divide, where values of 26.6°C and 26.7°C were observed during 1991 and 1992, respectively.

General changes in maximum stream temperatures along the Upper Grande Ronde River reflect both local reach characteristics and large-scale changes in valley width. The most dramatic rise in maximum temperatures, a 0.45°C/km rate of increase based on seven-day averages, occurred where the river flows through Vey Meadow, an unconstrained reach with little stream cover and very wide, shallow channels. Immediately below Vey Meadow (between 29 and 41 km from the divide), the Grande Ronde River flows through a very narrow, steep-sided valley. Maximum stream temperatures decreased in this reach at rates of 0.11 and 0.06°C/km during 1991 and 1992, respectively, in response to reductions in solar radiation inputs from topographic and vegetative shade. Maximum temperatures below Site 19 (41 km from the divide) rose at a rate of 0.1°C/km, reflecting small concurrent increases in wetted width and decreases in stream cover, both of which led to increases in inputs of solar radiation. In contrast to the reach level changes in maximum temperatures, minimum stream temperatures associated with the annual maximums exhibited a gradual increase throughout the monitored section of the Upper Grande Ronde River (Figure 8a).

Large differences in diel fluctuations were also observed in the Upper Grande Ronde River between 15 and 71 km from the divide (Figure 11). Between Site 25 and 20, seven-day average diel fluctuations of 7°C and 8°C (in 1991 and 1992, respectively) increased about 4°C, while through the constrained reach immediately downstream of Site 20 average diel fluctuations decreased by 2.5°C. Between Sites 9 and 3, however, diel fluctuations actually decreased to an average of about 8.5°C, reflecting greater thermal inertia stemming from deeper channels and larger volumes of water.

Forested, headwater tributaries had the lowest seven-day maximum stream temperatures as well as the lowest seven-day (and average August) diel fluctuations in the UGRR Watershed. Seven-consecutive daily maximum stream temperatures on Chicken Creek (27), Limber Jim Creek (21), South Fork Limber Jim Creek (22), Clear Creek (24) and Little Fly Creek (29) were at or below 21.4°C and 22.7°C during 1991 and 1992, respectively. In contrast, values exceeding 25°C were common at sites below open reaches (namely 30, 12 and 11). Seven-day diel fluctuations at the forested sites were generally less than 7°C, roughly 3°C lower than fluctuations common to open meadow systems such as Fly Creek (30), Sheep Creek (28), McCoy Creek (11) and lower Meadow Creek (12).

From a physical habitat perspective, the Grande Ronde River was apparently a physiologically stressful environment for salmonids during late summer. For juvenile chinook salmon, the "upper preferred stream temperature" of 14°C was exceeded more than 60% of the time at all sites below Vey Meadow during July of 1991 and July and August of 1992. At Site 3, the lowest site on the Grande Ronde River, stream temperatures never fell below 14°C during July of 1991 or 1992. It should be noted that while 14°C was commonly exceeded in the mainstem for month-long periods, temperatures greater than 24°C occurred less than 30% of the time during the warmest week of each summer. Many tributary streams also exceeded 14°C for more than half of the time during these same three months. The exceptions to this were several moderate to densely forested, north-facing tributaries (21, 24, 25 and 27) which exceeded 14°C less than 50% of the time in July of 1991 and in July and August of 1992. In general, however, the absence of persistent, high stream temperatures appears to be unique to only these few forested tributaries with north-facing aspects.

Climatic conditions varied markedly between 1991 and 1992. July and August air temperatures in 1991 were 1.3°C and 0.9°C above those observed in 1992 (at La Grande). However, baseflows in 1992 were significantly lower during June, July, and August than those of 1991. While the warmer 1991 air temperatures seem to correspond to generally warmer mean monthly stream temperatures, annual and seven-day maximum stream temperatures do not. In all but two sites (both of which went dry in mid-August of both years), maximum temperatures were about 2°C warmer in 1992, a trend which probably reflects lower flows in the watershed. Smaller volumes of water in the streams during 1992 also parallel consistently higher diel fluctuations that year.

In attempting to evaluate how anomalous 1991 and 1992 maximum stream temperatures might be relative to the norm, an index was developed using Julian day of low flow, magnitude of low flow and mean August air temperature. Yearly indices from 1946 to present (Figure 18) suggest that 1991 and 1992 were slightly and extremely conducive, respectively, to elevated stream temperatures. Additionally, yearly indices suggest a decreasing trend since 1948. The primary reason for this decreasing trend is largely due to the concurrent increase in low flows (Figure 2a). Given the slight decreasing trend in precipitation (0.08 cm per year) (Figure 4) in the watershed since 1900, however, the 0.003 m^3/s per year increase in baseflows since 1904 seems puzzling. One explanation is that widespread defoliation in the watershed due to insect damage, timber harvesting and livestock grazing has reduced water loss from evapotranspiration, resulting in longer storage of water in hillslopes and streambanks and thus greater delivery of water during late summer periods.

Reach Surveys

Stream cover provided by shrubs, and to a lesser extent by trees and topography, was less than 15% in reaches associated with open, unconstrained valleys. Shrub cover within the nearest 15-m of the channel, regardless of height or genus, is also largely absent with the exception of two reaches. Lower Meadow Creek (12) and McCoy Creek (11), reaches around which livestock exclosures have been established, were the only two reaches with average shrub covers above 10%. In addition, Reach 12 is the only "meadow" or "mixed forest/meadow" reach where greater than 0.5-m tall shrubs comprised greater than 10% of the cover. Forested reaches (24, 31, and 32) had mean stream covers above 60% in addition to mean shrub covers between 10% and 25%.

A strong correlation between percent stream cover and average August diel stream temperature fluctuations (r^2 = 0.82) as well as the highest average of seven-consecutive maximum daily stream temperatures (r^2 = 0.69) suggest the importance of stream cover in moderating stream temperatures during warm summer days. By reducing the amount of incoming solar radiation in small headwater streams, streams exhibit much more moderate maximum temperatures and hence, lower diel fluctuations as well (Beschta et al., 1987). Where reaches had stream covers above 70%, low diel fluctuations (less than 7°C) and annual maximum stream temperatures (less than 19°C) were observed during both years.

In light of the generally depauperate conditions of the riparian vegetation within the eight "meadow" and "mixed forest/meadow" reaches, and the strong correlation between stream cover and elevated stream temperatures, the likelihood for more moderate stream temperatures (within these reaches) in the future seems low unless restoration of vegetation occurs. Because stream cover is relatively low throughout the UGRR Watershed (UGRRTWG, 1992), it would appear that elevated summer stream temperatures could be reduced by activities which promote the establishment, growth, and succession of riparian vegetation.

Several channel morphology characteristics were also significantly correlated with stream temperatures. Significant negative correlations between average flow velocity and seven-day maximum stream temperatures (r^2 = 0.61) and average August diel fluctuations (r^2 = 0.46) were observed. While smaller changes in stream temperature would be expected on reaches with higher flow velocities (Brown, 1969), the association of high flow velocities to high percent stream covers (in this study) may account for some of this correlation. In addition, percent undercut bank, namely the root wad mass which projects over the water even during low flows, was weakly negatively correlated with seven-day maximum stream temperatures (r^2 = 0.32) and average August diel stream temperature fluctuation (r^2 = 0.24). While the regression models were not significant (p =0.11 and 0.18, respectively), they reinforce the importance of intact streambanks in providing shade and moderating maximum stream temperatures.

TEMP-86

TEMP-86, a stream temperature prediction model, is a generally accurate predictor of hourly stream temperatures through short 250-m long reaches. Accuracy, represented by the WSTAT (see methods section), ranged from a high of 4.76°C at Reach 11 to a low of -3.45°C at Reach 31, with an average of -0.18°C based on 11 reaches. Consistent over-predictions of downstream temperatures at Reach 11 (lower McCoy Creek) suggest significant inputs of subsurface flow. While these inputs were not observed, the consistently much cooler downstream temperatures within a reach with very little stream cover suggests that cooling mechanisms other than convection and evaporation are involved.

Greater levels of inaccuracy with TEMP-86 predictions seemed to be associated with more densely forested streams. A negative correlation between the WSTAT and South Forest Shade Angles (r^2 = 0.28) may indicate consistent overestimates of this angle. The greater heterogeneity of riparian canopy cover found in the forested reaches may serve to magnify the error inherent in quantifying this variable (needed for input). This error, in turn, may reflect overestimates in the amount of solar radiation intercepted and thus the magnitude of predicted temperature increases (Beschta and Weatherred, 1984). Error associated with the routing of direct and diffuse beam radiation through canopies is another possible explanation for the bias apparent in TEMP-86 predictions.

Following model evaluation, TEMP-86 was used to consider potential effects of a stream restoration project, in terms of changes in wetted width and percent stream cover, on maximum daily stream temperature during warm summer days. Using present conditions at Reach 30 on Fly Creek (currently with 13% stream cover and an average wetted width of 4.9 m), 16 different restoration scenarios involving combinations of 0, 10, 25 and 50% reductions in the present wetted width and 0, 10, 25 and 50% percent stream covers were considered. In general, model simulations suggest that a 50% reduction in wetted width would result in a 0.4°C higher maximum daily stream temperature when compared to maximum temperatures following a 50% increase in stream cover. If the goal of a restoration effort is to keep maximum daily temperatures below 28°C (during warm summer conditions) through this 250-m long reach, TEMP-86 predicts that scenarios ranging from a 37% stream cover (reflecting a 24% increase from current conditions) to a 50% decrease in wetted widths (to 2.4 m) would be sufficient to achieve this. In the real world, however, restoration of streamside vegetation would likely produce, over time, concurrent changes in both variables. However, increases in stream cover tend to proceed at a faster pace than wetted width reductions (Elmore and Beschta, 1987).

Management Implications

Potentially physiologically stressful thermal conditions for anadromous fish were common throughout the UGRR Watershed during the summers of 1991 and 1992. These high temperatures, in combination with relatively low numbers of pools (McIntosh, 1992), indicate that the watersheds' ability to support viable populations of chinook salmon may be in jeopardy. While the likelihood for elevated stream temperatures could decrease if the current trend of increasing baseflows continues, channel alteration (primarily widening) and removal of riparian vegetation may have functioned to offset the benefits to stream temperatures from increased baseflows. Results of this study indicate that the restoration of streamside vegetation (where significant recovery is likely) and associated changes in riparian characteristics over time (increased shading of streams, decreased channel widths, greater interaction with hyporheic flows, and others) could help ameliorate the high temperatures that currently occur throughout much of the Upper Grande Ronde River Watershed.

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APPENDICES

APPENDIX A: Unit Conversion Factors

Table 11. Unit conversion factors.

mi	= 0.62137 * km
in	= 0.3937 * cm
mi^2	= 0.38610 * km^2
ft^3	= 35.315 * m^3
acre	= 2.4711 * hectare
ft/s	= 3.2808 * m/s
cfs	= 35.315 * m^3/s = 0.035315 * l/s
°F	= (1.8 * °C) + 32
°F/mi	= 2.90 * °C/km
ly/min	= 0.001433 * W/m^2

APPENDIX B: Ordination Procedures and Scores

The following introduction and brief discussion of Nonmetric Multidimensional Scaling was taken from the PC-ORD users manual used in the analysis (McCune, 1993).

A. <u>Introduction.</u>

Non-metric Multidimensional Scaling (NMS) is an ordination method that is well suited to data that is well suited to data that are nonnormal or are on arbitrary, discontinuous, or otherwise questionable scales. For this reason, NMS should probably be used in ecology more often than it is. This method can be used both as an ordination technique and as a method for assessing the dimensionality of a data set (plot minimum stress against k, the number of dimensions in the ordination space.

An advantage of NMS is that, being based on ranked distances, it tends to linearize the relation between environmental distance and sociological distance (Beals, 1984), relieving the "zero-truncation" problem, a problem which plagues all ordinations of heterogenous data sets. Possible disadvantages include difficulties in detecting discontinuities and failing to find the best solution (minimum stress) because of intervening local minima. Although MS has performed well with simulated gradients, it has received very little use and testing with field data.

NMS is an interactive search for a ranking and placement of n entities of k dimensions (axes) that minimizes the stress of the k-dimensional configuration. The calculations are based on an n x n distance matrix calculated from the n x p-dimensional main matrix in the work file, where n is the number of rows and p is the number of columns in the main matrix. "Stress" is a measure of departure from monotonicity in the relationship between the dissimilarity (distance) in the original p-dimensional space and distance in the reduced k-dimensional ordination space.

Program NMS in PC-ORD is largely based on Mather's program NMMDS (Mather, 1976; includes listing of source code)> The central computational algorithm (steepest descent minimization to find minimum stress) in NMMDS is based on Kruskal (1964).

B. <u>Preparation of data.</u>

One data set is required (the work file in standard PC-ORD format) and another ordination is optional (ordination scores form another ordination, to be used as a starting point). The secondary matrix, if present in the work file, is not used.

To speed up the calculations and avoid local minima, it is recommended that you supply a starting configuration rather than request a random starting configuration. Follow these steps to use a starting configuration:

1. Run ordination on your data set.
2. After returning to the DOS prompt and PC-ORD menu, save the ordination scores by renaming GRAPH.FIL to a name of your choice, eg.:

   RENAME GRAPH.FIL SCORES.OUT

Table 12. Nonmetric Multidimensional Scaling ordination scores.

Reach	Axis 1	Axis 2	Axis 3
11	-0.258	0.174	-0.447
12	0.130	0.412	-1.30
15	0.664	-0.227	-0.455
16	-0.438	-0.207	-0.318
23	-0.711	-0.323	0.144
24	0.746	0.040	0.369
26	-0.714	0.154	0.455
30	-0.528	0.224	0.024
31	0.506	-0.386	0.363
32	1.418	-0.523	-0.049
33	-.816	0.662	1.212

APPENDIX C: TEMP-86 Input Parameters

The following is a list of inputs parameters required to run TEMP-86:

<u>Stream data</u>

- Hourly stream temperatures (°C)
- Azimuth of stream section (°)
- Gradient of stream section (%)
- Length of stream section (m)
- Width of stream section (excluding boulders and pools) (m)
- Average depth (m)
- Average flow velocity in stream section (m/s)
- Average flow entering stream section (l/s)
- Percent of stream section taken up by pools (%)
- Average pool depth (m)
- Percent of stream channel where depth is < 0.2 m and average bed material diameter > 0.24 m

<u>Shade data</u>

- Topographic shade angles (°):
  - southeast
  - south
  - southwest
  - left side
  - right side
- Forest shade angles (°C):
  - southeast
  - south
  - southwest
  - left side•
  - right side
- Percent canopy cover (%):
  - left side
  - right side
- Height of buffer (m):
  - left side
  - right side
- Width of buffer (m):
  - left side
  - right side
- Percent brush cover over stream (%)

<u>Site data</u>

- Simulation date (month, day, year)
- In daylight savings time (Y/N)
- Latitude of stream site
- Longitude of stream site
- Elevation of stream site (m)
- Mid-day relative humidity (%)
- Rate of groundwater seepage for stream section (l/s)
- Hourly air temperatures (°C)

• Left/Right side = side of channel while facing downstream (true left/right)

Table 13. TEMP-86 simulation runs for Fly Creek:

Run	Wetted width (m)	Percent stream cover	Predicted maximum stream temp. (°C)	Predicted change in maximum temp. through reach
1	4.9	0	29.6	2.5
2	4.9	10	29.1	2.0
3	4.9	13	29.0	1.9
4	4.9	25	28.5	1.4
5	4.9	50	27.7	0.6
6	4.4	0	29.2	2.1
7	4.4	10	28.9	1.8
8	4.4	25	28.4	1.3
9	4.4	50	27.6	0.5
10	3.6	0	29.0	1.9
11	3.6	10	28.7	1.6
12	3.6	25	28.2	1.1
13	3.6	50	27.5	0.4
14	2.4	0	28.4	1.3
15	2.4	10	28.2	1.1
16	2.4	25	27.9	0.8
17	2.4	50	27.3	0.2

APPENDIX D: Discharge Measurements for Temperature Monitoring Sites

Table 14. Upper Grande Ronde River Watershed discharge summary.

Site #	Location	Date	Discharg m^3/s	Date	Discharge m^3/s	Date	Discharg m^3/s	Date	Discharg m^3/s
1	Pelican Ck	08/02/91	0.003	10/01/91	dry	07/11/92	0.012	09/04/92	dry
2	5 Points Ck above Pelican Ck	08/02/91	0.108	10/01/91	0.025	07/11/92	0.061	09/04/92	0.020
3	Grande Ronde above 5 Points Ck	07/31/91	2.163	09/25/91	0.897	07/13/92	2.251	09/04/92	0.623
4	Rock Creek	07/31/91	0.043	09/25/91	0.005	07/13/92	0.085	09/04/92	0.005
5	Spring Creek	07/31/91	0.034	09/25/91	0.006	07/11/92	0.016	09/04/92	0.003
6	Jordan Creek	07/31/91	0.006	09/25/91	dry	07/13/92	0.067	09/04/92	dry
7	Grande Ronde @ Red Bridge Park	07/31/91	1.896	10/01/91	0.726	07/11/92	1.863	09/04/92	0.623
8	Beaver Creek	07/31/91	0.163	09/25/91	0.070	07/11/92	0.508	09/04/92	0.150
9	Grande Ronde below Meadow Ck	08/01/91	1.414	09/25/91	0.647	07/11/92	0.991	09/06/92	0.648
10	Dark Canyon Creek	08/01/91	0.019	09/25/91	0.005	07/11/92	0.017	09/06/92	0.010
11	McCoy Creek	08/01/91	0.043	09/30/91	0.020	07/24/92	0.036	09/03/92	0.027
12	Meadow Creek near McIntyre Rd.	08/01/91	0.151	09/30/91	0.097	07/18/92	0.055	09/04/92	0.045
13	Burnt Corrall Creek	08/01/91	0.021	09/30/91	0.009	07/13/92	0.015	09/03/92	0.022
14	Bear Creek	08/01/91	0.014	10/02/91	0.002	07/13/92	0.007	09/03/92	0.002
15	Meadow Ck @ old weather stn.	08/01/91	0.097	10/02/91	0.062	07/18/92	0.060	09/03/92	0.042
16	Meadow Ck above smolt trap	not done	---	10/02/91	0.051	07/20/92	0.049	09/03/92	0.035
17	Beaver Pond at Starkey store	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
18	Fly Ck. above Grande Ronde	08/02/91	0.147	09/27/91	0.055	07/15/92	0.052	09/05/92	0.051
19	Grande Ronde above Fly Creek	08/02/91	1.164	09/27/91	0.454	07/15/92	0.906	09/05/92	0.672
20	Grande Ronde below vey meadows	08/02/91	1.098	09/27/91	0.440	07/14/92	1.048	09/05/92	0.573
21	Limber Jim ck above S. Fork	08/01/91	0.112	09/27/91	0.053	07/14/92	0.107	09/01/92	0.043
22	S. Fork Limber Jim Creek	08/01/91	0.0056	09/27/91	0.0004	07/14/92	0.007	09/01/92	0.0003
23	Limber Jim below N & S Forks	08/01/91	0.106	09/27/91	0.059	07/10/92	0.159	09/01/92	0.042
24	Clear Creek	08/02/91	0.130	09/26/91	0.063	07/10/92	0.255	09/02/92	0.038
25	Grande Ronde above Clear Ck	08/02/91	0.604	09/26/91	0.256	07/10/92	0.645	09/02/92	0.226
26	West Chicken Creek	08/02/91	0.030	10/01/91	0.015	07/15/92	0.018	09/02/92	0.009
27	Chicken Ck above W. Chicken Ck	08/02/91	0.084	10/01/91	0.042	07/15/92	0.066	09/02/92	0.026
28	Sheep Creek	08/02/91	0.134	10/01/91	0.071	07/15/92	0.080	09/02/92	0.044
29	Fly Creek above vey meadow	08/02/91	0.043	10/01/91	0.020	07/15/92	0.031	09/02/92	0.016
30	Fly Creek below vey meadow	08/01/91	0.130	09/30/91	0.041	07/15/92	0.039	09/02/92	0.026
31	Lookout Creek above road 5160	---		---		07/21/92	0.018	09/04/92	0.012
32	Upper Limber Jim Creek	---		---		07/14/92	0.091	09/01/92	0.038
33	Beaver Meadow (near road 43)	---		---		07/19/92	0.005	09/02/92	0.003