OREGON DEPARTMENT OF FORESTRY

COOPERATIVE STREAM TEMPERATURE MONITORING: PROJECT COMPLETION REPORT FOR 1994-1995.

Prepared by: E. George Robison, John Runyon, and Chip Andrus

Prepared for: Oregon Department of Environmental Quality
For DEQ Contract 003-95

September 30, 1999

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The authors and the Department of Forestry would like to thank all the landowners who cooperated on this project. Lone Rock Timber allowed access to their land and provided future harvesting plans for the Brush Creek basin. Weyerhaeuser Corporation provided access for measurements to be taken for one of the seven extensive sites, while International Paper gave permission at three. In addition, we would like thank Starker Forests and Hull Oaks for permission to deploy temperature probes at the remaining three sites.

Ruth Willis deserves special mention because she did an exemplary job of working with the temperature probes and in taking corresponding shade, stream morphology, and streamflow measurements. Along with this she also organized the data into an easy to use format. Without her hard work, the data obtained would have been scarcer and of less quality. Mike Newton, who supervised much of this data collection, also deserves mention. He has been a tireless inspiration and embodies the cooperative spirit that existed between the Department and the College of Forestry on this project.

ABSTRACT

In the summer of 1994 the Oregon Department of Forestry, in cooperation with Oregon State University's College of Forestry, conducted water temperature monitoring on a range of streams in the Coast Range and Interior georegions. The objectives were: 1) to characterize the variability in temperature patterns throughout a forested basin in mostly closed canopy conditions; 2) to collect pre-harvest water temperature data for a streamside alder conversion unit; 3) to examine water temperature patterns and downstream heating and cooling trends for small nonfish-bearing streams flowing out of clearcuts without tree retention; and 4) to use the water temperature data to field-check Oregon's proposed method for characterizing water temperature.

Continuous water temperature thermographs were installed in the streams to record temperatures every 48 minutes during the summer months. Intensive monitoring was conducted on Brush Creek, a tributary to the Umpqua, a 13,000-acre watershed with significant populations of coho salmon, steelhead and cutthroat trout. Twenty-two thermographs were placed in Brush Creek's headwaters, main stem and major tributaries. Thermographs were also placed at seven other sites where streams were flowing through clearcut units. For most clearcut sites thermographs were installed just below the unit and at about 500 and 1200 feet downstream.

The summer of 1994 was drier and warmer than normal, with low stream flows and sustained high air temperatures. Maximum air temperatures occurred during the last week in July. Water temperature data were summarized using the seven-day-moving-mean of the maximum temperatures. This moving mean is Oregon's proposed method for summarizing water temperatures.

For all of the sites, the maximum water temperature period corresponded to the July period of the warmest sustained air temperatures. There was considerable variability in water temperature patterns observed in the Brush Creek basin, with cool temperatures in the headwater reaches and significant warming above 70^0 F in the lower portion of the watershed. Significant warming occurred below a small clearcut with no streamside tree retention followed by rapid cooling as the stream flowed through a shaded reach. There was also significant heating within a large beaver pond complex. Small tributaries entering the main channel contributed significant cold water refuges.

In general, maximum water temperatures for streams flowing out of the clearcut units were below 60^0 F. Two clearcut unit streams had maximum water temperatures greater than 60^0 F. For most of the clearcut units, there was significant cooling below the unit as the streams re-entered the forest canopy. This finding is consistent with previous temperature monitoring on small headwater streams.

The general conclusions from this water temperature monitoring effort for the Coast Range and Interior georegions are : 1) natural influences on water flow and stream channels, such as beaver ponds, increased maximum water temperatures as much as 10 degrees; 2) even under closed forest canopy conditions without streamside harvest, maximum stream temperatures increased to levels high enough to affect fish distributions; 3) in areas within three miles of the drainage divide, water temperatures cooled downstream of canopy openings caused by harvest and beaver complexes; and 4) cold water tributary

streams can provide a significant warm water refuge for salmonids.

1. INTRODUCTION

Stream heating, which is largely controlled by the amount of solar radiation reaching the water's surface, is influenced by the amount of shade provided by riparian vegetation (Brown, 1991). The Oregon Department of Forestry (ODF) administers streamside harvest practice rules designed, through tree and understory vegetation retention standards, to minimize water temperature increases. The Department of Forestry's forest practices monitoring program, in cooperation with Oregon State University's College of Forestry, is conducting an intensive study of forest stream temperature patterns and the impacts of stream-side forest harvest on stream heating.

The purpose for the monitoring was to address a critical water quality question identified outlined in the *Forest Practices Monitoring Strategic Plan:*

Are best management practices resulting in unacceptable temperature increases at the site and watershed levels?

The monitoring was also designed to answer a question related to beneficial uses:

Under what conditions does water warmed in headwater channels in harvested areas affect beneficial uses, and are there any affects on downstream fish-bearing streams?

In the summer of 1994, the department assessed forest stream temperatures throughout Oregon's Coast Range. Stream temperatures were monitored in two different settings: a watershed dominated by forest land uses; and seven small streams flowing out of clearcuts. The watershed monitoring was conducted in Brush Creek, a tributary to the Umpqua, a large forested basin with mostly closed canopy conditions with some recent streamside harvests. Brush Creek, a watershed of about 20 square miles, supports significant populations of coho salmon, steelhead trout, and cutthroat trout. The clearcut units monitored contained small headwater streams that do not contain fish. Under current forest practice rules these small streams do not, under most situations, require tree retention buffers.

1.1 Previous Department of Forestry water temperature monitoring

This study is designed to build upon ODF water temperature data collected in the summer of 1993 (Andrus, 1993). That previous monitoring effort was undertaken to determine how rapidly water that is warmed within a clearcut cools off once the stream enters a downstream forested (closed canopy) reach. The monitoring was conducted in channels that flow through six clearcut units. Thermographs were installed at the clearcut boundary and 300, 600, and 1200 feet downstream in shaded reaches.

The summer of 1993 was unusually wet and cool (see results section), which probably resulted in water temperatures that were cooler than would be expected during a normal summer. Maximun stream temperatures were recorded during the first week in August. The streams flowing through clearcuts had temperatures 1^0 to 5^0 F greater than would be expected under forested conditions. The maximum temperatures for the gauges below the clearcut units ranged from about 57^0 F to 65^0 F. Water temperatures decreased with increasing distance from the clearcut boundary at four of the six sites. At sites where cooling of water occurred below the clearcut, the cooling rate was greatest in the first 600 feet downstream.

2. FOREST PRACTICES RULE BACKGROUND

The 1994 water protection rules minimize change in water temperature through shade provided by the retention of riparian vegetation. These vegetation retention standards are determined by the ODF stream classification system. Stream classifications vary by stream size, based on mean annual flow, and beneficial uses. The beneficial uses for water recognized under the Oregon Forest Practices Act (FPA) are fish presence or if the stream is a domestic water supply.

2.1 Oregon's water temperature standard

The State of Oregon's water quality standard for temperature is undergoing review and possible revision. The current standard is designed to minimize increases in water temperatures. In streams with salmonids water temperatures must be maintained at or below 58^0 F. If the temperature is 56^0 F or less, a 2^0 F increase is permissible. At stream temperatures of 58^0 F or more, no measurable increases are allowed. In non-salmonid streams, no increase above 64^0 F is allowed.

2.2 Water temperature protection for streams with fish or domestic use

Streams with domestic uses or fish presence (Type D and F streams respectively) require the retention of streamside trees and other vegetation to maintain shade The vegetation retention standards, for all sizes (small, medium, and large) of D and F streams require the retention of all trees within 20 feet of the high water mark. Exceptions to this rule do allow for some removal of streamside vegetation to accommodate yarding corridors or stream crossings. In addition, removal of some vegetation along limited sections of streams is also permitted where hardwood stands are harvested with the intention of regenerating conifers. These rules assume that the trees retained in the 20-foot area near the stream, combined with other trees to be retained in the riparian management area, will minimize water temperature impacts, resulting in compliance with the water quality standards.

2.3 Water temperature protection for streams with no fish or domestic use

Streams without fish or domestic water supply use (Type N streams) have variable shade protection standards. Large and medium streams, with mean annual flows greater than two cubic feet per second (CFS), have some tree retention requirements that will effectively provide shade. Small headwater streams with mean annual flows less than two CFS and no domestic or fish use (Type N streams) do not require that merchantable trees be retained in streamside harvest areas. Exceptions to this requirement exist for specific geographic regions where temperature is a greater concern for these small streams. In these cases, determined by basin size, understory vegetation and unmerchantable conifers (conifers less than 6 inches DBH) must be retained 10 feet each side of the high water mark (Table 1). In addition to these requirements, landowners are encouraged to voluntarily leave wildlife leave trees along nonfish-bearing channels to protect water temperatures and amphibians that require a cool and moist riparian environment.

2.4 Water temperature protection for hardwood conversion units along fish use streams

Alternative harvest regulations can apply to streamside stands that are currently dominated by hardwoods or brush. For sites that are capable of growing conifers, some removal of the streamside competing hardwoods and brush is allowed. The intent of this alternative harvest prescription is to provide enough vegetation for adequate shade to minimize water temperature impacts. Temperature protection for the stream is based upon the assumption that water heating impacts are minimized by alternating segments of harvest near the stream (conversion blocks) with adjacent segments where more vegetation is retained (retention blocks). For the conversion blocks, hardwoods and conifers are retained within 10 feet of the stream's high water level (within 20 feet for trees leaning towards the channel). In the retention blocks larger areas of conifers and hardwoods are to be retained (Figure 1).

Table 1. Understory and unmerchantable conifers to be retained along perennial small streams without fish or domestic uses (Type N).

GEOGRAPHIC REGION	***WHERE REQUIRED***
Coast Range and Western Cascades	None required
South Coast	Perennial channels where the upstream drainage area is greater than 160 acres
Interior	Perennial channels where the upstream drainage area is greater than 330 acres
Siskiyou	Perennial channels where the upstream drainage area is greater than 580 acres
Eastern Cascades and Blue Mountains	All perennial channels

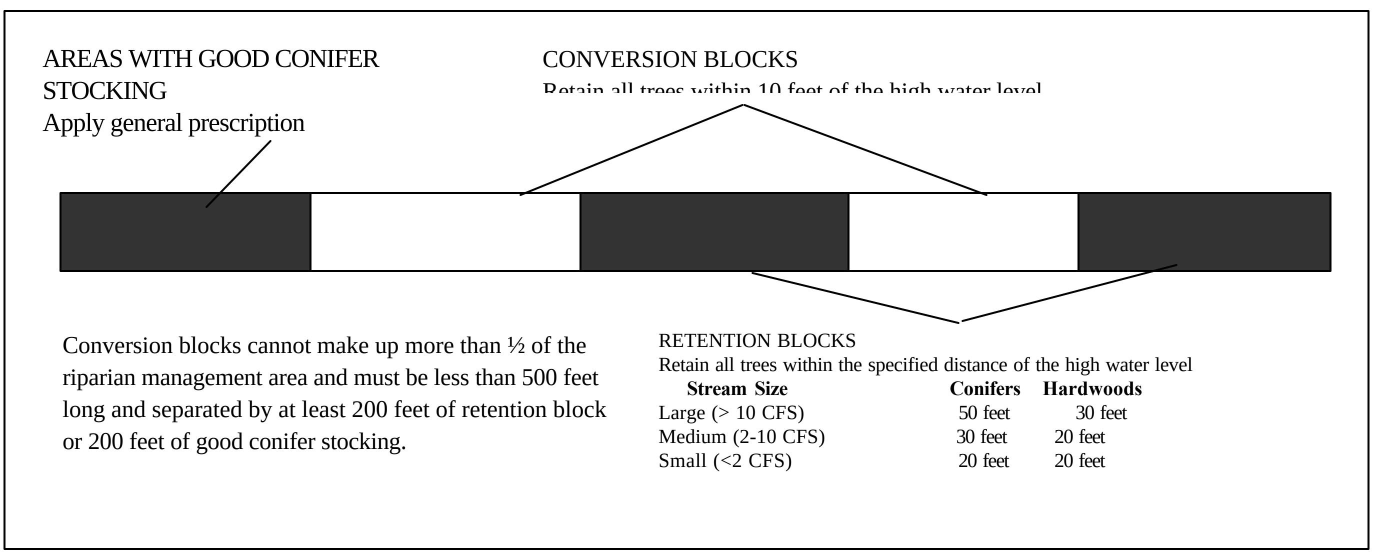


Figure 1. Diagram of the vegetation retention requirements for hardwood conversion stands.

3. MONITORING OBJECTIVES

The monitoring was designed to address the following objectives:

1) To characterize the variability in temperature patterns throughout a large forested basin in mostly closed canopy conditions.
2) To collect pre-harvest water temperature data for a streamside alder conversion unit.
3) To examine water temperature patterns and downstream heating and cooling trends for small nonfish-bearing streams flowing out of clearcuts without tree retention.
4) To use the water temperature data to field-check Oregon's proposed method for summarizing water temperature.

4. STUDY DESIGN

Maximum stream temperatures are recorded in July or August when incoming solar radiation and air temperature levels are high and stream flows are low. The 1994 water temperature sites were selected during the late spring, and all thermographs were in the streams by mid-July with data collection continuing through mid-September.

4.1 Monitoring site selection

The monitoring focused on water temperature data collection from the western Oregon geographic regions. Seven clearcut sites and one basin (Brush Creek) were selected for monitoring in the Coast Range and Interior georegions (Figure 2). Due to logistical considerations and a limited number of thermographs, no sites were selected in the Western Cascade, South Coast or Siskiyou georegions.

Brush Creek Basin

Brush Creek basin was selected for comprehensive water temperature monitoring. The basin provided an excellent case study for water temperature assessments because:

1) The basin is representative of Coast Range geographic region, characterized by low elevations (180 to 2456 feet); consistent sandstone geology; and precipitation patterns dominated by rainfall, mostly falling in the winter months.

2) Brush Creek, a tributary to the Umpqua, is an important coho salmon spawning and rearing stream.

3) The basin's second-growth forest (about 40 years old) is just now being re-entered for harvest, including some streamside alder conversions, which offers the opportunity to collect pre-harvest baseline data.

4) An effective watershed partnership is in place. This partnership -- involving the basin's primary landowners, Lone Rock Timber and the USDI Bureau of Land Management, and the cooperation of the Oregon departments of Forestry, Fish and Wildlife, and Environmental Quality, and Oregon State University -- provided a cooperative foundation for monitoring across the different landownerships.

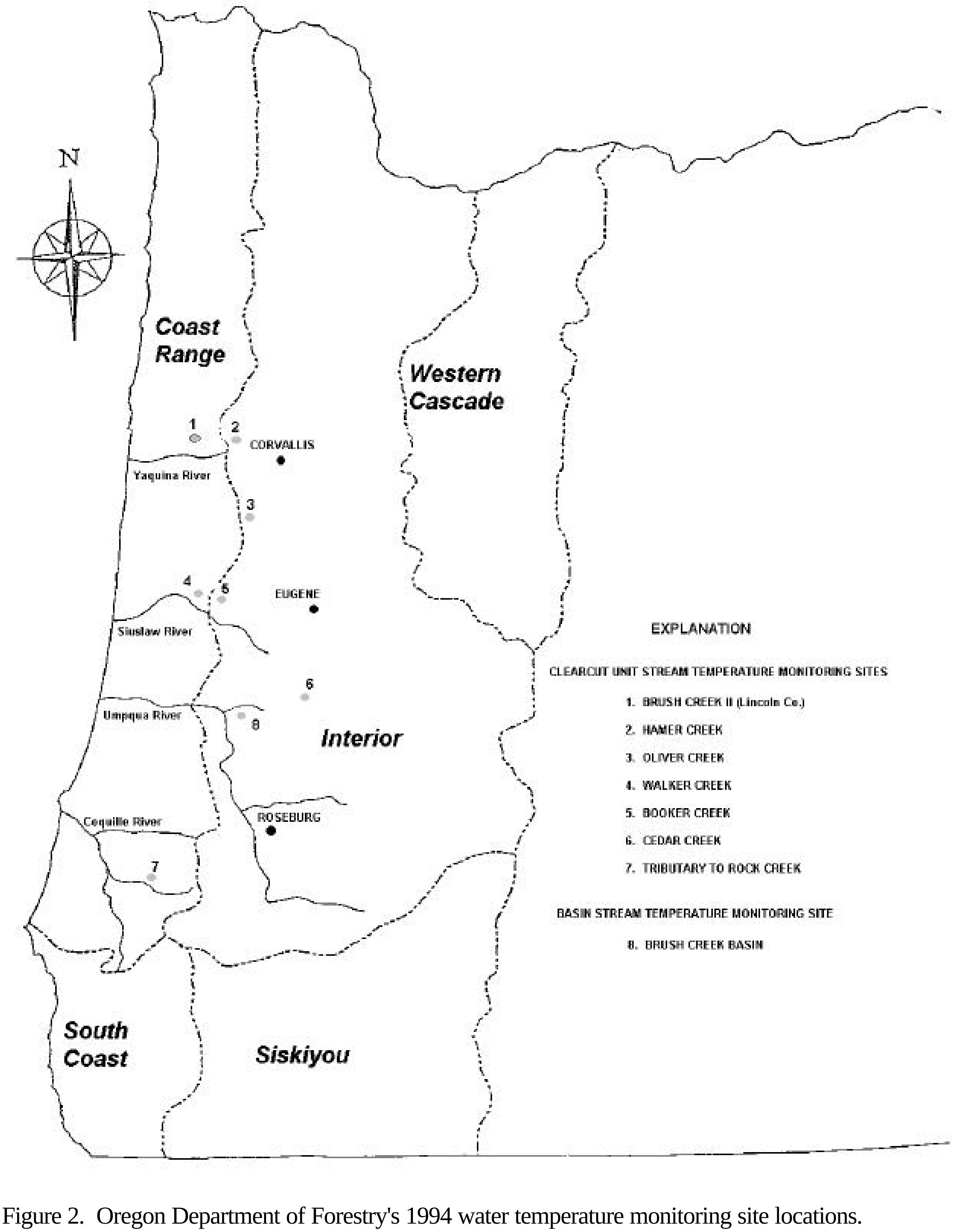


Figure 2. Oregon Department of Forestry's 1994 water temperature monitoring site locations.

Clearcut units

After extensive review of harvest notifications and site visits, seven clearcut units were selected for water temperature monitoring. Candidate monitoring sites were evaluated on several criteria:

1) Harvested less than six years ago;
2) The reach downstream of the clearcut is primarily closed canopy forest (hardwood or conifer) for a distance of at least 1500 feet downstream;
3) The stream begins or flows through the harvest unit with consistent surface flow downstream; and
4) No vegetation retention along the stream within the clearcut unit.

In addition to these criteria, several streams with more complex situations (beaver ponds and tributaries) were also selected to illustrate the range of variability in site conditions.

4.2 Air and water temperature monitoring design

Continuous recordings of water temperature were obtained at 48 minute intervals with recording thermographs (Hobo-Temp®, Onset Computer Co., Pocasset, MA). These thermographs are accurate to within 0.5^0 F. Temperature data were downloaded at approximately two-week intervals onto a field data logger (Corvallis Mirotechnology, Corvallis, OR). Calibration of the thermographs was done by immersion in an ice water bath and checking for consistent readings between units. In some cases the thermograph measurements were checked against hand-held thermometer measurements in the field.

Air temperatures were measured with a thermograph (in a housing to prevent direct solar heating) suspended two to three feet over the channel. This design provided a measurement of air temperatures in the riparian area and channel (microclimate), but not a measurement of the basin's air temperature above the forest canopy (macroclimate). In some cases, missing data were estimated using a regression relationship developed from nearby meteorological stations.

Brush Creek basin

Twenty-two water and two air thermographs were installed in Brush Creek basin (Figure 3). Thermograph locations included the entire basin, ranging from the headwaters to the end to the basin. Thermographs were placed above (No. 12) and below (No. 11, 10, 9) a small clearcut with 175 feet of streamside area without tree retention. Thermographs were also placed within (No. 8) and directly below (No. 7) a large beaver complex. In order to collect pre-harvest water temperature data for an alder conversion unit, thermographs were placed above, within, and below the unit, including a small tributary (Figure 4). Harvest on the alder conversion unit was completed before the summer of 1995 to allow followup monitoring during the summer of 1995. All thermographs were in place by the first week in July.

Clearcut units

For most of the clearcut units, thermographs were placed in the stream just below the unit and at about 500 and 1200 feet downstream (Figure 5). Thermographs were also installed in any significant tributary streams. Air temperature thermographs were installed over the channel in the clearcut and in the downstream shaded portion of the stream. Table 2 includes a description of the sites and thermograph locations.

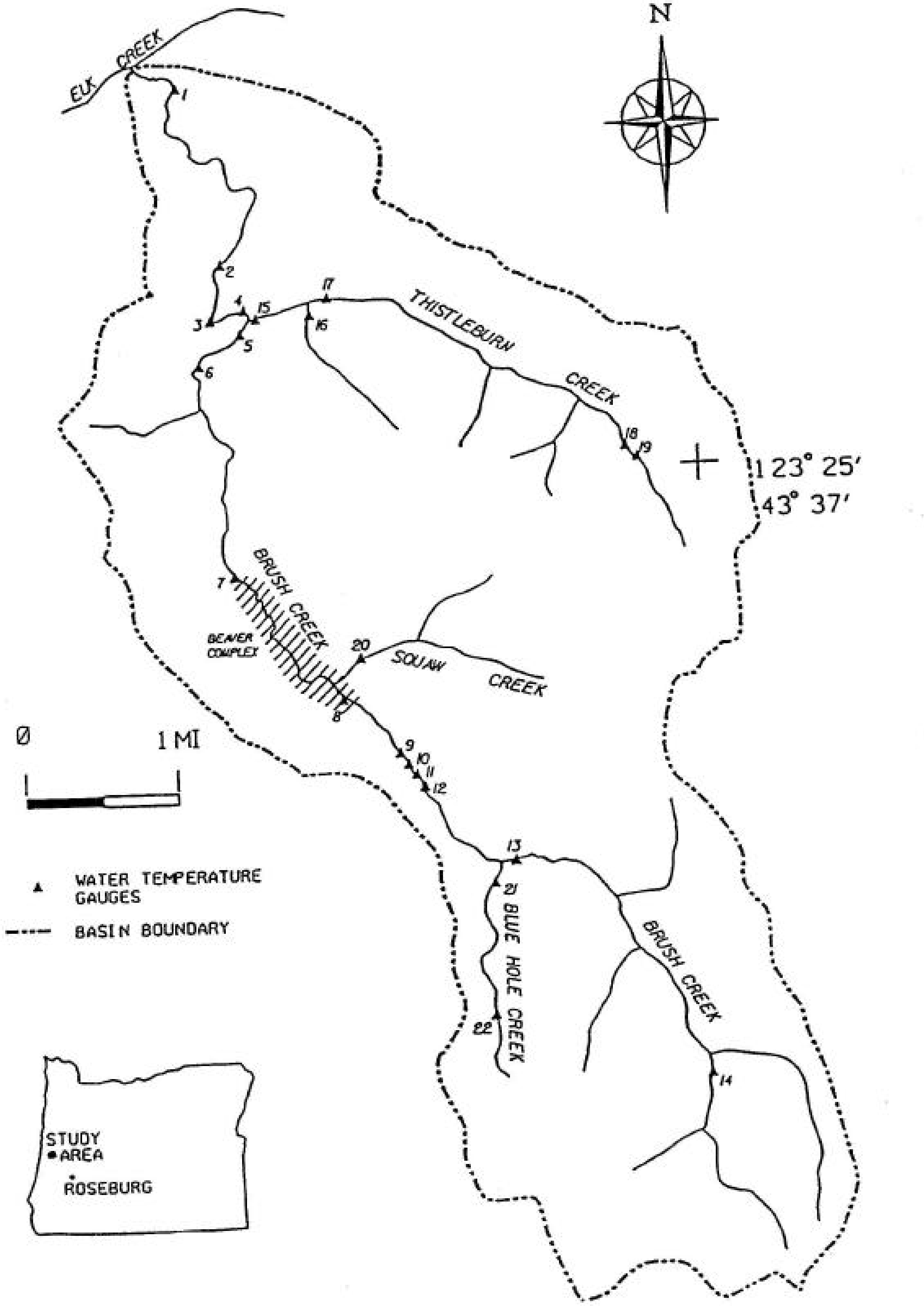


Figure 3. Air and water temperature thermograph locations in Brush Creek basin.

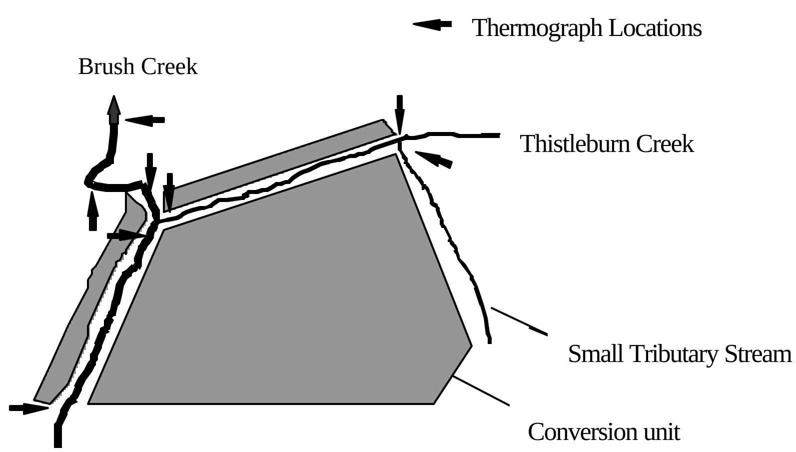


Figure 4. Thermograph locations on the Brush Creek alder conversion unit.

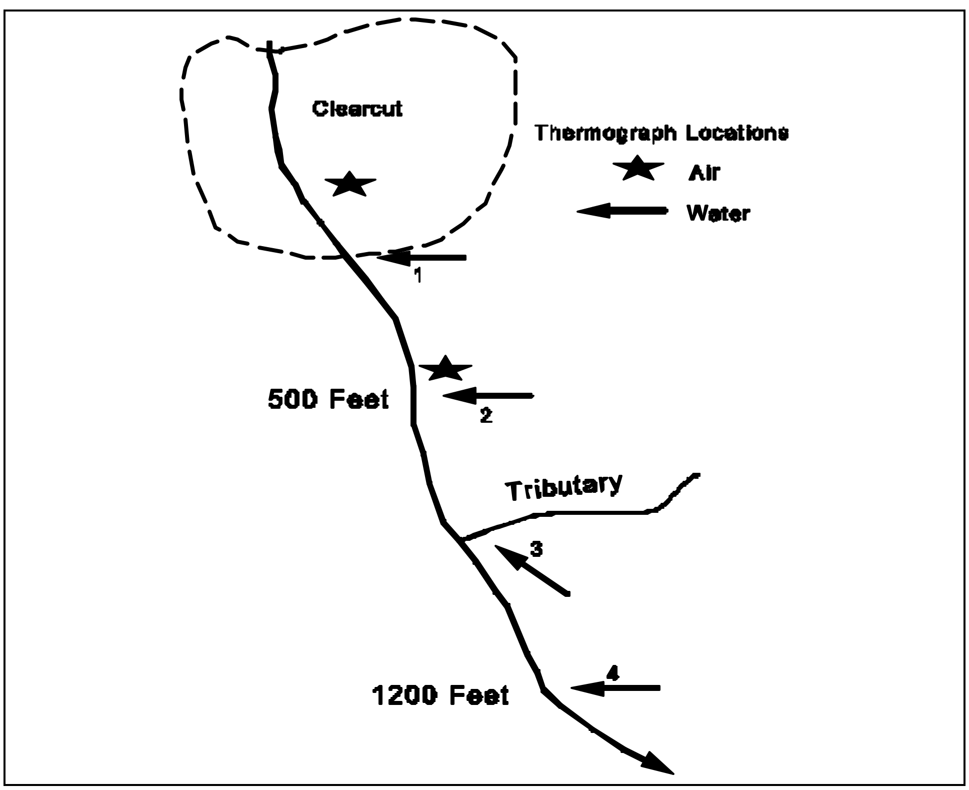


Figure 5. Temperature monitoring design for the clearcut units.

Table 2. Clearcut unit descriptions and thermograph locations.

ODF Geographic Region	Stream Name	Location	Comments
Interior	***Booker***	T17S, R7W, Sec. 16	1-yr.-old clearcut; unit was subject to a moderately hot broadcast burn; downstream area 40-yr.-old forest of dense hardwoods and conifers. 3 water thermographs: (1) Base of clearcut; (2) 500 ft.; (3) 1200 ft..
	Cedar	T22S, R4W, Sec. 1&2	2-yr.-old clearcut; downstream area 50-yr.-old forest of dense conifers. 3 water thermographs: (1) Base of clearcut; (2) 500 ft.; (3) 1500 ft..
	Hamer	T10S, R8W, Sec. 26	2-yr.-old clearcut with dense regrowth; downstream area 30-yr.-old forest of dense hardwoods and brush. 3 water thermographs: (1) Base of clearcut; (2) 500 ft.; (3) 1200 ft..
	Oliver	T13S, R6W, Sec. 30&31	1-yr.-old clearcut; downstream area 50-yr.-old forest of dense hardwoods and conifers. One tributary stream, draining a closed canopy area, contributes flow. 5 water thermographs: (1) Base of clearcut; (2) tributary; (3) 500 ft.; (4) 1100 ft.; (5) top of clearcut.
Coast Range	***Brush 2***	T10S, R8W, Sec. 22&27	5-yr.-old clearcut; beaver complex at base of clearcut; downstream area 30-yr-old forest of dense hardwoods. Two streams drain clearcut. Two tributary streams, both draining closed canopy areas, contribute flow. 9 water thermographs: (1) Base of clearcut; (2) base of clearcut; (3) below beaver complex; (4) 320 ft. (from beaver complex); (5) 800 ft.; (6) 1225 ft.; (7) tributary; (8) tributary; (9) 3200 ft..
	Tributary to Rock Creek	T30S, R10W, Sec. 2&3	14-mo.-old clearcut; downstream area 50-yr-old forest of dense hardwoods and conifers. 3 water thermographs: (1) Base of clearcut; (2) 500 ft.; (3) 1200 ft..
	Walker	T17S, R8W Sec. 36	3-yr.-old clearcut; downstream area 50-yr.-old forest of dense conifers and hardwoods. Two tributary streams, both flowing out of adjacent clearcuts, contribute flow. 5 water thermographs: (1) Base of clearcut; (2) tributary; (3) tributary; (4) 550 ft.; (5) 1250 ft..

4.3 Site Characterizations

Stream flow

For each site, stream flow was measured near the beginning and end of the monitoring period. Small weirs were constructed in the stream to confine the flow into a small channel. The discharge (cubic feet per second, CFS) was measured by capturing the water in bucket and recording the fill time with a stop watch. Several measurements were taken and then averaged.

Flow measurements were taken a range of sites throughout Brush Creek basin; for the clearcut units flow measurements were taken below the clearcuts, at a site downstream, and in any tributaries.

Width and depth

Riffle depth and low flow wetted width was measured with a rod and hip chain, and reported as an average of several measurements.

Gradient

The gradient (in percent) was measured for each stream segment above the thermographs with a clinometer. The reported number is an average of several measurements.

Substrate

For all of the monitoring sites the substrate was estimated visually for each habitat unit (pools, riffles and cascades) and recorded as the percent in each of four categories: 1) fines; 2) gravel; 3) cobbles; and 4) bedrock.

Canopy closure

Canopy closure (percent) was measured with a spherical densiometer upstream of each water temperature gauge. The reported number is the average of several measurements. In the clearcuts, canopy closure over the stream from understory vegetation and logging slash was estimated visually.

Distance from the divide and upstream area

Distance from the divide (in feet) and upstream drainage area (in acres) was determined for each thermograph location from USGS topographic maps.

Elevation

The elevation at each water thermograph was estimated using USGS topographic maps.

Fish use determinations

Summer fish use was determined for each of the clearcut units. The units were summer surveyed for the upper extent of salmonid use, by either electrofishing techniques or visually according to the ODF protocol (Oregon Department of Forestry, 1995), and noted on the USGS topographic map.

4.4 Data Analysis

The water temperature data were summarized using the average of daily maximum temperatures for seven consecutive days. The reported values are for the seven-day period of warmest temperatures for the entire data record. The seven-day average daily maximum temperature is an indicator measure intended to represent prolonged exposure by aquatic life to high temperatures. This moving mean method of summarizing temperature data is Oregon's proposed method for summarizing water temperatures.

5. RESULTS/DISCUSSION

5.1 Brush Creek Basin

The summer of 1994 was warmer and drier than average, with low stream flows and sustained high air temperatures. To quantitatively examine how dry 1994 was in comparison to other years, two nearby stream gages were used: Calapooya Creek near Oakland (#14320700 USGS) and the S. Fork Coquille River at Powers (#14325000 USGS). To evaluate 1994 in terms of temperature, the long term records for Roseburg were used. In terms of stream flow, 1994 was one of the driest years in recent history. Calapooya Creek gage had its third driest seven day average low flow in 30 years of record. On the S. Fk. Coquille, the gage had its fourth driest seven day average low flow in 76 years of record. However, the summer of 1992 was drier at both gages in terms of minimum average seven-day low flows:

Year	Calapooya Creek Gage 7-Day Average Lowflow	S. Fk. Coquille Gage 7-Day Average Lowflow	Roseburg 7-Day Avg. Max. Temp.
1992	0.3 cfs	11.9 cfs	98.1 ^{o}F.
1993	12 cfs	24.3 cfs	93.6 ^{o}F.
1994	0.4 cfs	12.0 cfs	96.1 ^{o}F.
Median	5.5 cfs	19.7 cfs	93.5 ^{o}F.

Note that 1993 being a relatively wet year tends to make 1994 look even drier by comparison. In contrast, 1994 was warmer than average, but only a mediocre 19th out of 64 years for seven-day high temperatures for records at Roseburg. For air temperatures, 1994 was more moderate than 1992, but much warmer than 1993. The warmest water temperatures for the Brush Creek basin were recorded during the seven days of July 17 - 23, which corresponded to the highest air temperatures in the area. Stream flows, corresponding to 1994's extreme drought conditions, were less than 0.5 CFS at the downstream end of the basin (Table 3).

Table 3. Summary of Brush Creek basin average water temperatures and other characteristics.

Stream	Thermo-graph #	7-Day Ave. Max. Water Temp. (°F)[5]	Flow (cfs) (date)	Distance to Divide (feet)	Upstream Area (acres)	Low Flow Width (feet)	Canopy Closure (percent)
	1	71.8 (73.3)	0.28 (7/26)	60,073	13,365	16	71
	2	70.1(74.5)	n.d.	50,908	12,319	n.d.	n.d.
	3	68.4(70.6)	n.d.	48,313	12,197	7	87
	4	69.1(72.1)	n.d.	47,786	12,183	4	67
	5	67.8	0.095 (8/01)	47,305	9,172	11	87
	6	69.3(71.8)	0.093 (8/01)	44,885	8,881	12	62
	7[1]	70.1(71.5)	n.d.	36,493	7,517	13	71
	8[2]	73.1(74.8)	n.d.	29,731	4,911	10	88
	9	69.1(71.8)	n.d.	26,670	4,607	10	89
	10	70.3(72.7)	0.240 (7/29)	26,258	4,578	11	90
	11[3]	75.4*	n.d.	25,836	4,530	14	60
	12	68.5(70.9)	n.d.	25,555	4,482	11	76
	13	66.7(68.8)	0.190 (7/29)	21,198	4,209	14	90
Brush	14	59.3(60.1)	0.064 (8/01)	9,770	1,200	5	95
	15	68.2(70.0)	0.056 (8/01)	23,376	3,002	8	88
	16[4]	58.7(63.2)	n.d.	6,954	357	3	98
	17	68.9(74.8)	n.d.	21,487	2,579	6	83
Thistleburn	18	59.7(60.4)	n.d.	8,811	876	n.d.	n.d.
	19	59.4(60.4)	0.026 (7/29)	8,376	710	3	96
Squaw	20	65.9(67.9)	0.012 (7/26)	12,126	1,775	4	95
	21	63.6(65.6)	n.d.	12,562	894	4	91
Blue Hole	22	53.3(55.9)	0.034 (8/01)	5,329	413	3	91

1 Temperature gauge below large beaver complex.
2 Temperature gauge within beaver pond.
3 Temperature gauge below 175 ft. long streamside clearcut with no riparian tree retention.
4 Small tributary stream to Thistleburn Creek.
5 Data in parenthesis in this column are the absolute maximum water temperatures for the period of record.
* Data were missing from this gauge for the period corresponding to highest water temperatures. The value cited is an estimate based on a regression relationship developed from the record of a downstream gauge. Field checks validated the water temperature difference between the upper and lower portions of the clearcut.

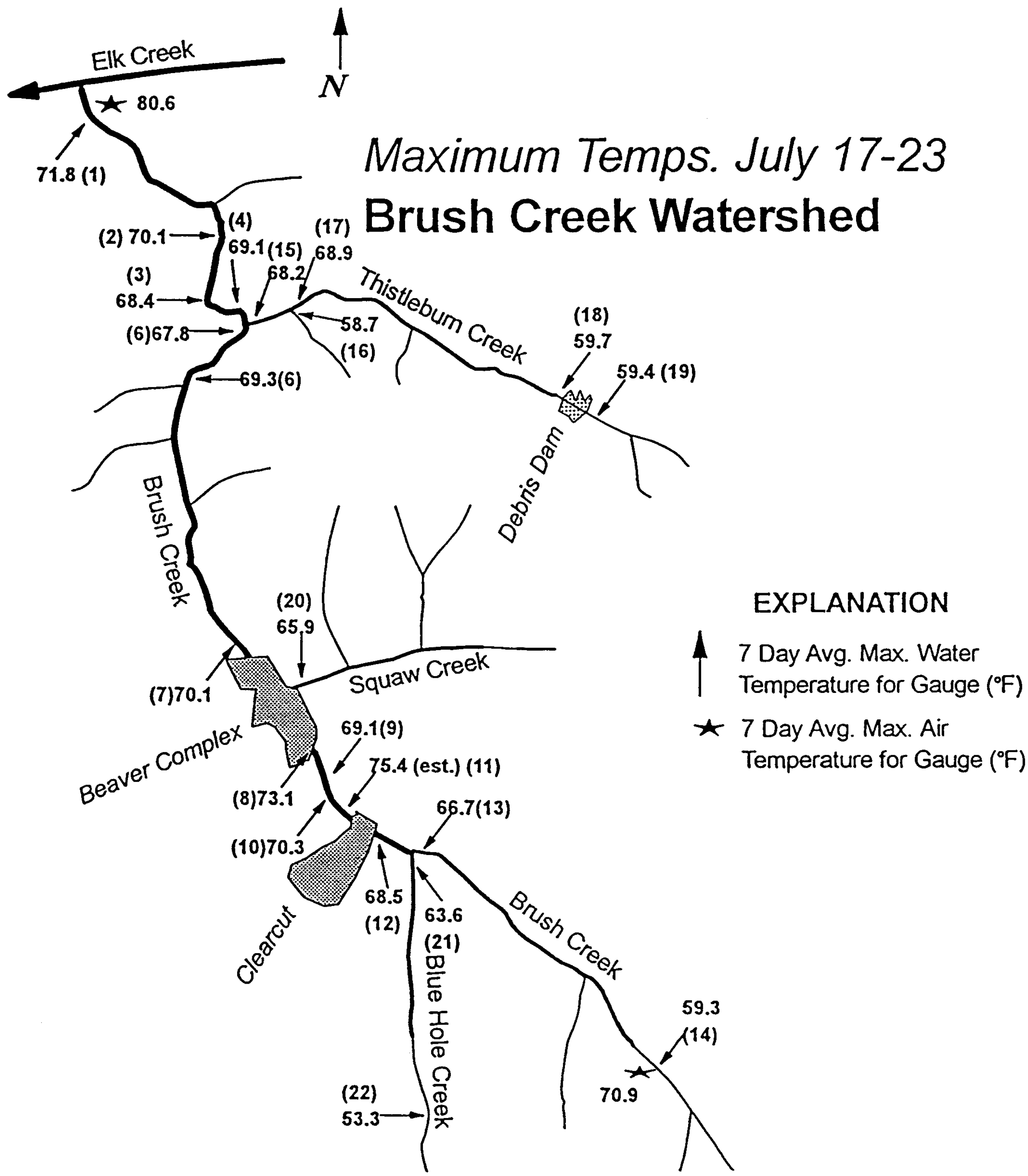


Figure 6. Water temperatures for gages in the Brush Creek basin for the week of July 17-23.

There was considerable variability in the water temperature patterns observed in the Brush Creek basin (Table 3, Figure 6). In the uppermost portions of the basin near the drainage divide temperatures were low ranging from 53 to 59 degrees Fahrenheit (^{o}F). These temperatures versus distance from divide conformed to a curvilinear relationship (Figure 7). This type of relationship was found for past studies of basins in Washington State (Sullivan et al. 1987 p. 88-89; see also Theurer et al. 1985). This relationship has also been shown for the upper John Day basin in Oregon (Robison unpubl.). Two points that deviated from this relationship were immediately downstream of a clearcut (Figures 7 and 8) and within a beaver pond in a beaver pond complex. In both cases the temperature recovered rapidly downstream (Figures 6-8). For the clearcut the temperature rose from 68.5 ^{o} F just above the clearcut to 75.4 ^{o} F 175 feet downstream (a temperature rise of 6.9 ^{o} F). Within 834 feet downstream, however, the temperature then recovered to 69.1 ^{o} F or within 0.6 ^{o} F of the reading upstream.

The rise in temperature in the clearcut can be easily explained by the increased exposure to light in that reach. Visual inspection of the clearcut reach showed almost no overhead cover as trees were cut right to the bank of the stream (no systematic measurements were taken for that reach in 1994). Most models of heat balance in streams list solar radiation hitting the stream with subsequent heat absorption as the major driver in causing stream temperature increases (Sullivan et al. 1990 and Brown, 1991). Heating due to solar radiation hitting the stream is well documented in Oregon (Levno and Rothacher, 1967 and 1969; Brown, 1969, and Moring 1975). While 6.9 ^{o} F is a dramatic rise in temperature, increases as great as 14 ^{o} F have been recorded for clearcuts along small wide and shallow streams in which the side brush has been cleared or burned (Adams and Stack, 1989). A strong indicator that solar radiation is the major contributor to heating is the seven-day average daily minimum temperatures for July 17-23 doesn't vary much through and below the clearcut, while the maximums do (Figure 8).

The rapid decrease in temperature downstream from the clearcut unit in Brush Creek is similar to findings by Andrus (1993). Three mechanisms have been proposed for the recovery. One mechanism is groundwater exchange and mixing (Sullivan et al. 1990 and many others). Groundwater is usually much cooler than corresponding surface water during the warmest part of the day in the summer. This is because groundwater flows through interstitial gravel and sediments that have temperatures below the daily average in a warm period. Under this mechanism the rate of recovery would be proportional to the amount of shading (no further heat input) and the amount of groundwater exchange and input. The type of geomorphology for the stream under this scenario would then be important. Streams that have large, well-connected terraces would have better temperature recovery than streams that are constrained and flowing over bedrock with little groundwater input or exchange. The second mechanism that has been postulated for recovery is conducive and convective heat losses to air in the riparian area (Andrus, 1993). This scenario is unlikely to cool water temperatures significantly because air temperatures at peak heating, even under riparian forests, are often comparable or even higher than the heated water temperatures (see air vs. water temperature readings under forest cover for clearcut unit data in Appendix A). For instance, tributary to Rock Creek has a forested air temperature of 72 ^{o} F while the water temperature is 67 ^{o} F, and yet the water cools 3.9 ^{o} F per 1000 feet under riparian cover. The higher air temperatures would then prevent a gradient for heat loss using convective or conducive heat transfer. Most models of heat balance also list water to air heat transfer as a minor mechanism because the transfer mechanism is not very efficient (Sullivan et al. 1990). Another possible mechanism would be latent heat losses as water evaporates. The contribution of this factor in cooling needs some careful research to determine how great a factor it would be for heat loss. The latent heat of vaporization is 540 calories per gram of water evaporated. If a significant amount of water evaporated under forested conditions, this would represent a significant heat loss. However, under riparian forest canopies, the air temperatures are lower (lower temperature means less water holding capacity for the air), humidity is often high and wind speeds are low, so a gradient from high to low humidity is probably not great, which would slow the evaporation rate.

The second highest temperature recorded in the Brush Creek basin was for the thermograph located in a beaver pond within a beaver complex (Figure 6). According to Oregon Department of Fish and Wildlife (ODFW) habitat surveys, the immediate area near the ponds had greater canopy opening due to the open water. The beaver dams also widened the stream and slowed water velocity. It is interesting to note that water just downstream of the beaver complex is 3^{o} F lower than that of the reading taken in the upstream pond. Perhaps pond water leached into groundwater and was cooled by flowing and losing heat underground and then re-entered the channel downstream.

A debris flow and debris dam on Thistleburn Creek appears to have little impact on heat loading (Figure 6). The lack of effect may be due to the stream still being extremely small (three feet wetted width, Table 3) and under heavy canopy cover, regardless of the debris flow effects.

In the area of the alder conversion unit (pre-harvest), the maximum water temperatures were in the 67^{o} to 69^{0} F range. The small tributary stream which entered Thistleburn Creek in the alder conversion unit was quite cool, with an average maximum temperature of 58.7^{0} F. Coho salmon juveniles were observed holding in this small stream. Although no systematic survey was completed, no juvenile coho were observed in the pre-harvest conversion unit area of Thistleburn and Brush Creek during the warm period.

The very low end reach of Brush Creek from just below the mouth of Thistleburn Creek to the outlet of Brush Creek heated nearly 3^{o} F (Figure 6). It also appears as a departure from the cuvilinear relationship given in Figure 7 (notice the upward tilt to the line). One possible reason for this departure is that ODFW habitat surveys (ODFW, 1992) found that this reach had only 56% canopy closure. Values for upstream reaches varied from 80-100 percent canopy closure.

In total, there were three departures from the curvilinear relationship for water temperature gages shown in Figure 7. These departures were for a clearcut, a beaver pond, and a reach with low canopy closure. In the first two cases, the stream recovered from the departure back to the curvilinear relationship. This recovery suggests that heat balance is in an equilibrium under closed canopy conditions (Theurer et al., 1985). When canopy cover is decreased, stream temperature goes out of this equilibrium. When

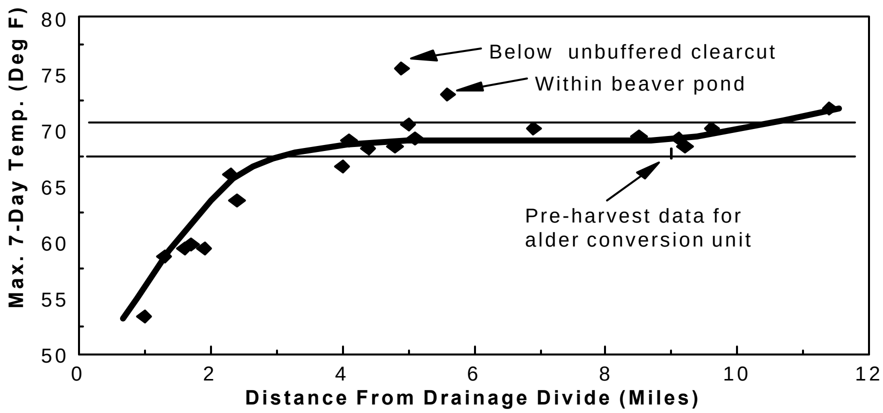


Figure 7. The relationship between the distance from the drainage divide and seven day average maximum water temperatures.

cover is restored downstream, the stream water temperature

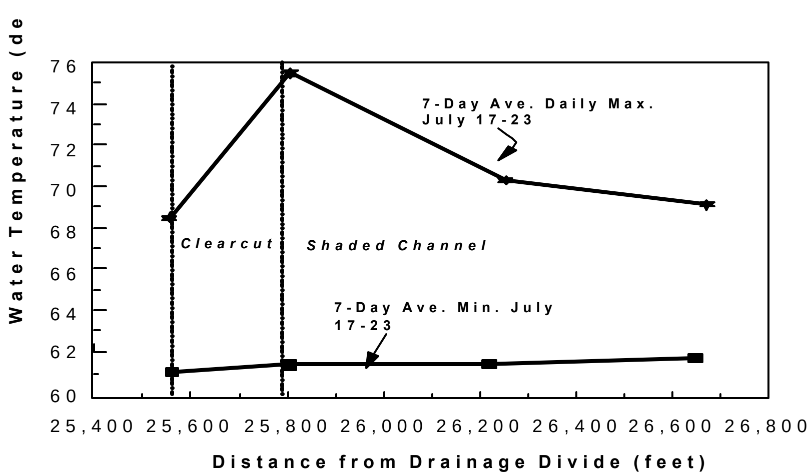


Figure 8. Stream heating and cooling trends for the Brush Creek clearcut unit without any tree retention for 175 feet.

tends to recover towards equilibrium. This equilibrium is a function of stream flow, width, depth, canopy closure, valley morphology, and groundwater exchange. For forested mountain streams, all the above factors (except for canopy closure) are, at least sometimes, related to distance from divide (Sullivan et al., 1990). This is probably the reason the curves conform so well to a curvilinear relationship with distance from divide as Sullivan et al. (1990) suggested. Absolute maximum temperatures for Brush Creek generally have a strong correspondence with the seven-day average daily maximum stream water temperatures ranging from 0.7 ^{o} F difference to a 4.3 ^{o} F difference (Table 3).

5.2 Extensive clearcut stream temperature monitoring sites

The elevations for the clearcut units ranged from 480 to 1340 feet. Basin sizes ranged from 77 to 450 acres. Most late summer flows were less than 0.2 CFS (Table 4). Fish use patterns were variable (Table 4). Three units had no summer fish use observations downstream of the clearcut. Summer fish use was observed in one unit (Brush 2, Lincoln Co.). Three units, where the streams were high gradient within the clearcut, had summer fish use observations immediately below the unit where the stream gradient was less. If looking at fish use during the spring months, it is quite possible that fish use would be found in clearcut reaches in four of the seven sites, with the others having barriers and no fish. Because of this fish use, under the new water classification and water protection rules, these treatments would not be done in at least part of the Brush 2 reach, and possibly not in four of seven of these reaches. The rules would require a 20-foot no-touch-zone in fish bearing streams, along with a 50 foot wide riparian management area (ODF, 1994).

All but two of the clearcut units had temperatures less than 60 ^{o} F where the streams flow out of the unit (Table 5). Two units, Cedar and Tributary to Rock Creek, heated to 62.2 ^{o} F and 64.4 ^{o} F, respectively. These temperatures are compatible with fish rearing, except for those from Cedar and Trib. to Rock Creek. For instance, coho salmon prefer juvenile rearing temperatures in the 53 to 58 ^{o} F range (Beschta, et al., 1987). Temperatures in all but one stream, tributary to Rock Creek, were lower than the 64 ^{o} F temperature criteria proposed in new Oregon Department of Environmental Quality temperature rule ammendments (DEQ, Draft). Brush Creek 2 (Lincoln Co.) had a temperature increase downstream of the clearcut due to beaver ponds from 58.3 ^{o} F to 67.2 ^{o} F (Table 5). The increased heating over that of the clearcut reach was probably due to water slowing and stream surface area increases within the beaver pond. Out of all the clearcut sites, only the tributary to Rock Creek had temperatures approaching what was leaving the beaver ponds.

It appears that the warmest streams generally experienced greater cooling (Figure 9A). There was a significant relationship between cooling and temperature in streams flowing out of clearcuts (R^2=0.83). Brush Creek 2 experienced the greatest cooling and also had the greatest temperature downstream from the beaver ponds. Like the results from the Brush Creek basin, distance from divide was highly related to stream water temperature (Figure 9B, R^2=0.54). This relationship improved greatly with the removal of Hamer Creek and Oliver Creek (R^2=0.81). Hamer Creek is unique in that it is a very narrow watershed, and distance from divide is not as related to stream flow and watershed area as it is for the other watersheds. Oliver Creek has basalt geology and has a groundwater component to the flow that makes it an outlier.

The two streams with the least streamflow had greater temperatures than the other five streams (Figure 9C). Stream gradient in the clearcut seems to be related to lowering the temperature of streamflow downstream from the clearcut (Figure 9D). Temperatures downstream of the four lower gradient streams were variable. For three streams with slopes greater than 18%, all temperatures were below 59 ^{o} F.

The tributary of Rock Creek had the greatest stream temperature downstream of the clearcut. This elevated temperature may be the result of several factors combined. The tributary of Rock Creek is widest of the seven sites (six feet, Table 4) even though it has the second lowest flow. This results in a stream with high surface area and very shallow depth. In addition, it has moderate gradient and moderate canopy closure. All of these factors would encourage maximal solar heating. However, except for Brush Creek 2, it also has the greatest temperature recovery downstream.

Table 4. Clearcut unit stream characteristics.

Stream	**Summer Fish Use Below Clearcut**	**Flow, cfs (date)**	**Stream Gradient Upstream of Clearcut Therm. (percent)**	**Low Flow Wetted Width (ft.)**	**Upstream Area (acres)**	**ClearcutCanopy Closure (percent)**
Booker	Yes	0.096 (8/09)	23	2	92	21
Cedar	No	0.027 (8/10)	8	3.5	153	50
Hamer	No	0.110 (8/04)	18	4	77	80
Oliver	Yes	0.484** (8/11)	32	4	203	37
Brush 2	Yes*	0.114 (8/04)	3	2	57	36
Trib. to Rock	No	0.078 (8/15)	10	6	450	50
Walker	Yes	0.110 (8/08)	10	3.5	89	24

* Fish use was observed within the clearcut

** Flow measurement taken above the clearcut.

Canopy closure for these clearcut sites varied from 21 to 80% for the seven sites. Recovery of shade occurs approximately five years after timber harvest (Summers, 1982; and Morman, 1993). As shown for Brush Creek in the previous section, removal of shade along small streams can result in large increases in maximum tempertures (Brown 1969; and Andrus 1993). This heating is expected in these small shallow streams since small streams respond rapidly to changes in heat energy exchange. However, small streams are expected to have high groundwater inflow rates. The morphology of the stream and corresponding riparian area characteristics will affect groundwater exchange dyamics, which will in turn affect the recovery rate. As shown above, the greater the increase in water temperature in the clearcut reach, the larger the increase in cooling for the downstream shaded reaches.

Table 8. Average maximum water temperatures and trends for the clearcut units.

Stream	7-Day Ave. Maximum Water Temp. At base of Clearcut (° F)[1]	7-Day Ave. Maximum Water Temp. at Third Gauge Below Clearcut (° F)[2]	Cooling Rate Below Clearcut (° F/1000 feet)
***Booke*r**	56.8 (57.8)	55.2 (57.6)	1.6
Cedar	62.2 (63.5)	59.7(est.)[4]	1.7
Hamer	55.5 (56.2)	55.1 (56.4)	Not Significant
Oliver	58.1 (59.3)	57.5 (58.7)	0.5
Brush 2	58.3[3]	61.1[5] (62.4)	5.0
Trib. to Rock	64.4 (66.2)	62.5[6] (63.8)	3.9
Walker	55.6 (59.3)	57.5 (58.7)	Warming (1.5/1000 ft.)

1-2 Values in parentheses for these columns are for the absolute maximum temperature for the period of record.

3 Two streams draining the clearcut were monitored. The temperature cited is for gauge no. 1; the water temperature average for the gauge monitoring the other tributary from the clearcut (No. 2) for the corresponding period was 57.1 °F. There was significant heating in the beaver pond at the base of the clearcut. The temperature below the beaver ponds is gage no. 3 which had a corresponding temperature of 67.2 °F.

4 Data were missing from this gauge for the period corresponding to the highest water temperatures. This value is an estimate developed from a regression relationship developed from the record of this gauge and gauge no. 2.

5 The temperature cited is for gauge no. 6, located 1225 feet below beaver complex before flow contributions from tributary streams. The cooling rate is based on the change from the beaver pond (gauge no. 3) to this gauge.

6 The entire data record for the lower sensor (1200 ft.) was missing. The temperature cited is for gauge no. 2, 500 feet below the clearcut.

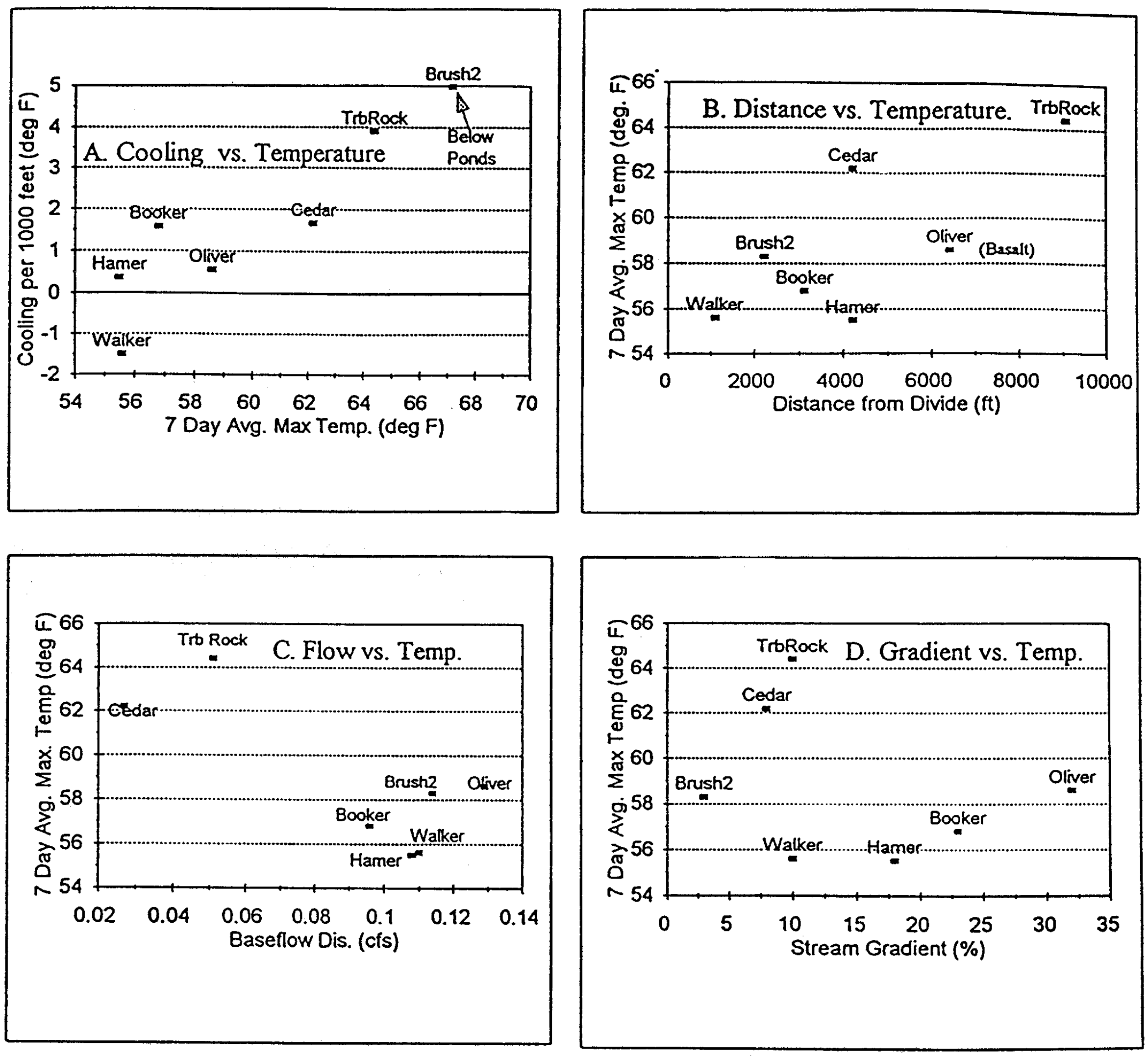


Figure 9. Relationships between water temperature in streams downstream from clearcuts and A. cooling downstream, B. distance from divide, C. baseflow streamflow, and D. stream gradient.

5.3 Air / Stream water temperature relationships

Oftentimes, there is a strong corresponding relationship between air and water temperatures (Figure 10A for open canopy site). These relationships can often be in both time (Figure 10A) and space (Figure 10B). Time relationships are between an air and a stream water gage at a given site for a number of different time periods. Space relationships are for a similar time period and sets of air and stream temperature gages dispersed over a given area. For Brush Creek, air and water temperatures were tightly coupled for the open canopy site (R^2=0.78 for water seven day average daily maximum vs. air seven-day average minimum, Figure 10A). Using seven-day minimum air temperature, values had the greatest correspondence with seven-day maximum water temperatures. This correspondence was higher than anything that could be found between one day, one day offset, or other seven-day temperature values. However, this relationship was not replicated for air and stream water gages under canopy cover. Since this relationship is only for open canopy, it could be that seven-day air temperatures are nothing more than an index for intense sunny weather, which would increase solar heating of stream water.

As for spatial relationships, there is little or no linear relationship between air and water temperatures for the seven extensive sites. While air temperature can be a surrogate for elevation and tendency to be cloudy, many other factors like distance from divide, stream slope, and canopy closure, can obscure this relationship for such a small extensive data set.

6. CONCLUSIONS/RECOMMENDATIONS

6.1 Conclusions

In the introduction, the purpose of this monitoring project was boiled down to two key questions:

Are best management practices resulting in unacceptable temperature increases at the site and watershed levels?

Under what conditions does water warmed in headwater channels in harvested areas affect beneficial uses, and are there any affects on downstream fish-bearing streams?

Results from the extensive clearcut monitoring sites indicate that timber harvesting to the bank of very small streams led to temperatures immediately downstream of above 60 ^{o} F in only two of seven instances. Only one of the seven instances had resulting temperatures above DEQ's proposed temperature standard of 64 ^{o} F, even under the extemely warm and dry conditions experienced during the summer of 1994. In both instances, the streams recovered quickly with one stream recovering at a rate of 3.9 ^{o} F per 1000 feet of stream, and the other recovering at 1.7 ^{o} F per 1000 feet of stream. At 500 to 1200 feet downstream of the clearcut, all of the seven streams were at temperatures below the 64 ^{o} F temperature standard. From these results, it can be

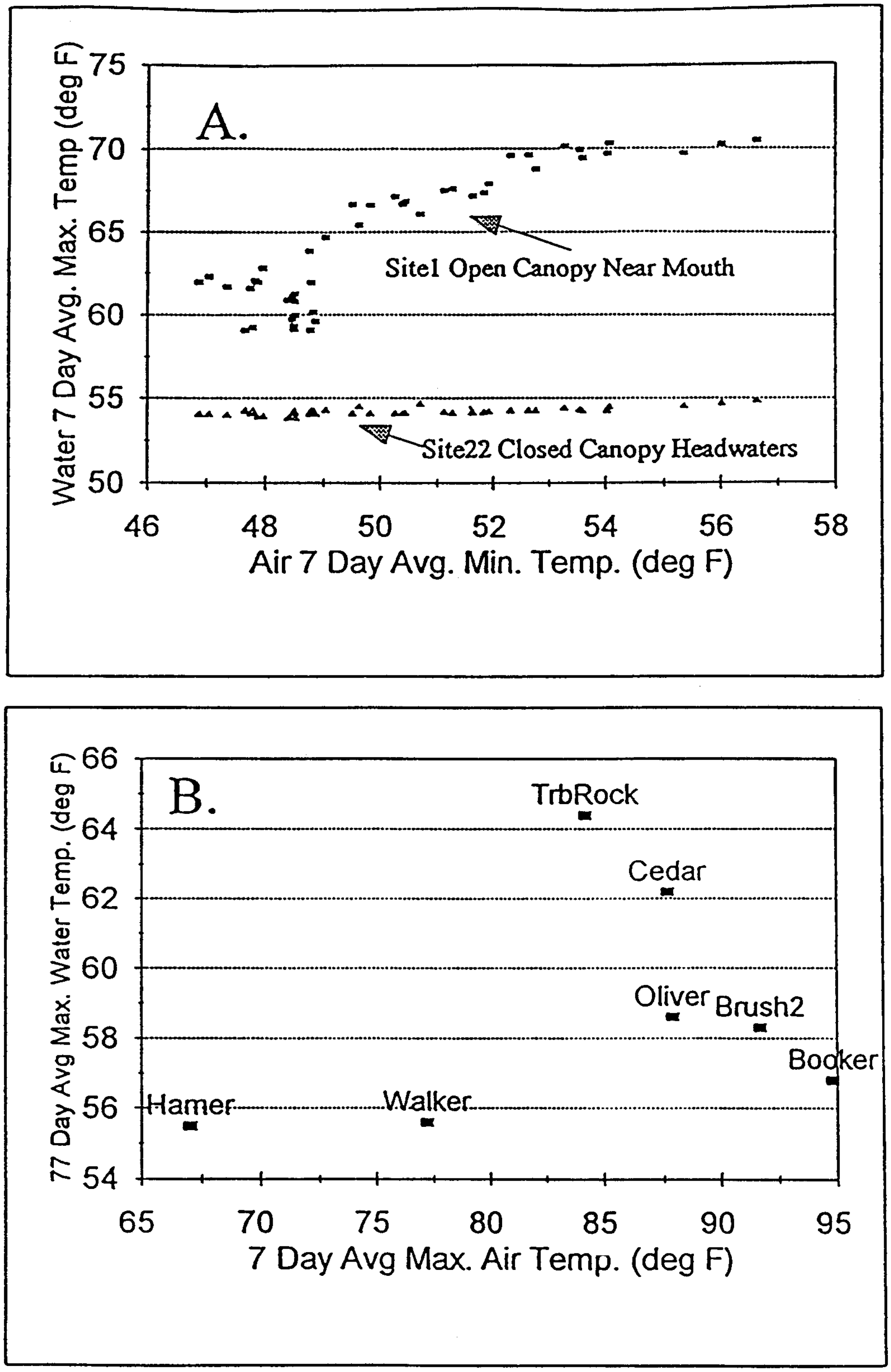


Figure 10. Air versus stream water temperatures for different seven-day time periods at Brush Creek and for seven different sites for the highest temperature values for the summer of 1994.

concluded that clearcutting trees up to the bank for very small streams with no fish (small type N designation, ODF, 1995) generally does not result in unacceptable temperature increases, at least for coastal streams in sandstone geology. At watershed level, it is unlikely that temperature problems will occur from this practice, as increases in temperature are mitigated in the downstream reach for small streams near the basin divide. Likewise, temperature increases, if any, from these clearcuts should be mitigated in the downstream fishbearing reach provided there is adequate canopy closure there. A key point is that this extensive monitoring effort was confined to evaluating the best management practice of clearcutting the riparian area for small type N streams in the Coastal and Interior georegions. Even though the results indicate little or no temperature water quality degradation for these regions, some monitoring (as resources permit) should be carried out in other regions, especially the South Coast, Siskiyou, Eastern Cascade, and Blue Mountain georegions.

Another important conclusion is that natural factors can cause increases in stream water temperature. For instance, the beaver ponds in Brush Creek 2 resulted in a temperature rise of 8.9 degrees beyond the temperature of water downstream of the clearcut for the warmest period of the year. Temperatures within a stream system with riparian areas mostly unharvested for decades (i.e. Brush Creek basin) with 80 to 100% canopy closure are highly variable and often above DEQ current 64 ^{o} F standard. It appears the curvilinear relationship indicated by Theurer et al. (1985) and others applies to the Brush Creek basin as well. It also appears that changes in stream shading with subsequent temperature increases are mitigated in the downstream reach, provided there is adequate cover. This argues against the concept of a cumulative watershed effect for temperature as impacts are (at least for the streams studied here) quickly mitigated within several hundred feet in the downstream reach, resulting in little or no additive effect.

6.2 Recommendations

1. Based on these results, no changes in the rules concerning stream temperature are warranted for small type N streams, but further monitoring is encouraged. Clearcutting small type N streams in the Coastal and Interior georegions in sandstone geology does not generally result in un-acceptable temperature increases. Moreover, any water heating is generally mitigated in the downstream reach, as long as there is canopy closure. However, extrapolation of this finding to other georegions should be done only after careful consideration and additional monitoring especially for the South Coast, Siskiyou, Eastern Cascade and Blue Mountain georegions.

2. In the future, basin-wide monitoring efforts should be encouraged to understand temperature dynamics throughout a watershed. A curilinear relationship between distance from divide and maximum water temperatures (Figure 7) exists for both Washington and Oregon streams on both the east and west sides of the Cascades. It is possible that future temperature standards could be expressed as curves, rather than single temperature standards.

3. When interpreting limited temperature data from the outlet of basins, care should be taken in making claims about cause and effects, especially cumulative watershed effects. The results from Brush Creek

basin cast doubt on the utility and relevance of a single series of temporal measurements taken at the outlet of a basin and its relationship to land management up the basin.
4. Because water temperatures are extremely variable in space and time, even under closed canopy conditions, most compliance should be geared around best management practices that are carefully monitored, rather than around absolute temperature readings.

5. In site specific plans, clearcutting a portion of a fish bearing stream's riparian area to the bank should be a last resort, and done only to mitigate other losses that may occur from other effects. While clearcutting to the bank of a fish bearing stream is not a best management practice or a prescription within ODF forest practice rules, the results from the Brush Creek basin clearcut area confirm that temperature increases, though local, are severe and can push streams to temperatures that can induce direct mortality of fish and other aquatic organisms.

6. Although not covered in this research, thresholds for diminshing shade need to be established. Current rates allow some reduction in shade for hardwood conversions. The baseline data taken in the Brush Creek basin for this study will allow future monitoring of shade reduction and resulting effects.

7. REFERENCES

Adams, P.W. and W.R. Stack. 1989. Streamwater quality after logging in southwestern Oregon. Project Completion report (PNW 87-400) to the USDA Forest Service, Pacific Northwest Research Station. Portland Oregon.

Andrus, C.W. 1993. Issue #2: How rapidly does water that is warmed within a clearcut cool off once the stream enters a downstream reach?........ Oregon Department of Forestry Issue paper dated August 25, 1995. 2600 State Street, Salem Oregon, 97310. 6 p. + Tables and Figures.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: Fisheries and forestry interactions. p. 191-232. In: E.O Salo and T.W. Cundy (eds). Streamside management: Forestry and fisheries interactions. Inst. For. Resources. University of Washington.

Brown, G.W. 1969. Predicting temperatures of small streams. Water Resour. Res. 5(1): 68-75.

Brown, G.W. 1991. Forestry and water quality. 2nd. Ed. Oregon State University Book Stores, Inc. Corvallis, Oregon, 973331.

Department of Environmental Quality (DEQ). DRAFT. Proposed Amendments to OAR 340-41-[Basin] (2) (b); OAR 340-41-685(2)(0). DEQ, Standards and Assessment Section, 811 Sixth Ave. Portland Oregon, 97204.

Levno, A. and J. Rothacher. 1967. Increases in maximum stream temperatures after logging old-growth Douglas-fir watersheds. Research Note PNW-65, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

Levno, A. and J. Rothacher. 1969. Increase in maximum stream temperatures after slash burning in a small experimental watershed. Research Note PNW-110, USDA Forest Service, Pacific Northwest Forest and Range Exp. Station. 7 p.

Moring, J.R. 1975. The Alsea watershed study: effects of logging on the aquatic resources of three small headwater streams of the Alsea River, Oregon. Part II - Changes in environmental conditions. Fishery Research Report 9, Oregon Department of Fish and Wildlife, Corvallis, 39 p.

Oregon Department of Fish and Wildlife (ODFW). 1992. Fish habitat survey for Brush Creek (part of greater survey for the Elk Creek basin tributary to Umpqua River). ODFW, Research Station, Corvallis, Oregon.

Morman, D. 1993. Riparian rules effectiveness study. Oregon Department of Forestry, Forest Practices Program, 2600 State Street, Salem, Oregon, 97331. 198 p.

Oregon Department of Forestry (ODF) and ODFW. 1995. Surveying forest streams for fish use. ODF, Forest Practices Section. 2600 State Street, Salem, Oregon, 97310. 30 p.

Robison, E.G. Unpubl. Unpublished manuscript concerning temperature patterns in John Day Basin. Has a curvilinear graph like that seen for Brush Creek.

Sullivan, K., S.H. Duncan, P.A. Bisson, J.T. Heffner, J.W. Ward, R.E. Bilby, and J.L. Nielsen. 1987. A summary report of the Deschutes basin: sediment, flow, temperature, and fish habitat. Weyerhaeuser Corp. Research and Development, Research Report Paper No. 044-5002/87/1. 129 p.

Sullivan, K., J. Tooly, K. Doughty, J.E. Caldwell, and P. Knudsen. 1990. Evaluation of prediction models and characterization of stream temperature regimes in Washington. Timber Fish and Wildlife Rep. No. TFW-WQ3-90-006. Washington Dept. Natural Resour., Olympia, Washington. 224 p.

Summers, R.P. 1982. Trends in riparian vegetation regrowth following timber harvesting in western Oregon watersheds. A thesis submitted to Oregon State University, Corvallis, Oregon.

Theurer, F.D., I Lines, and T. Nelson. 1985. Interaction between riparian vegetation, water temperature, and salmonid habitat in the Tucannon River. Water Resour. Bull. 21(1):53-64.

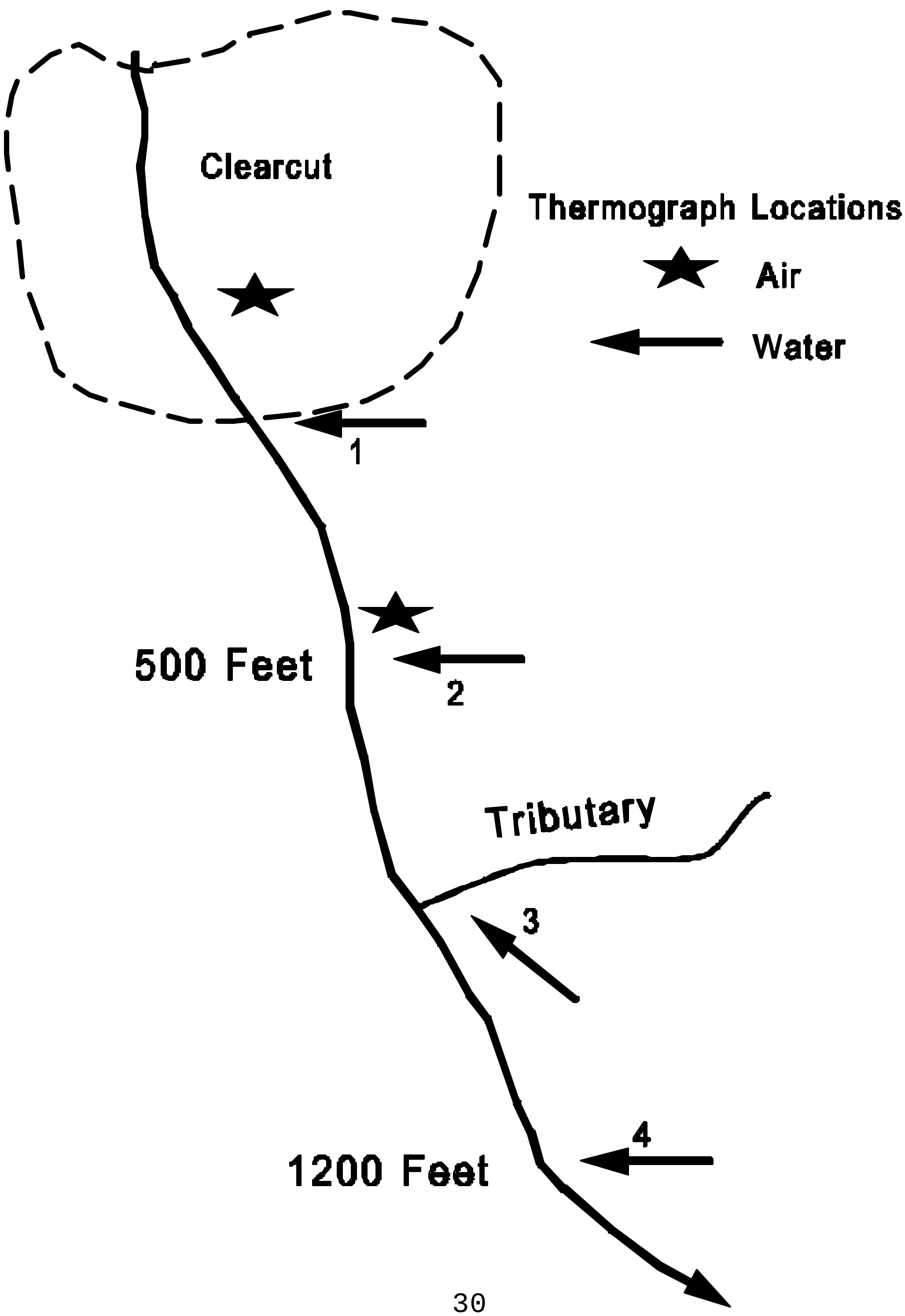
APPENDIX A

Clearcut Unit Site Maps

Appendix A Page 26A

1994 Water Temperature Monitoring

General Study Design

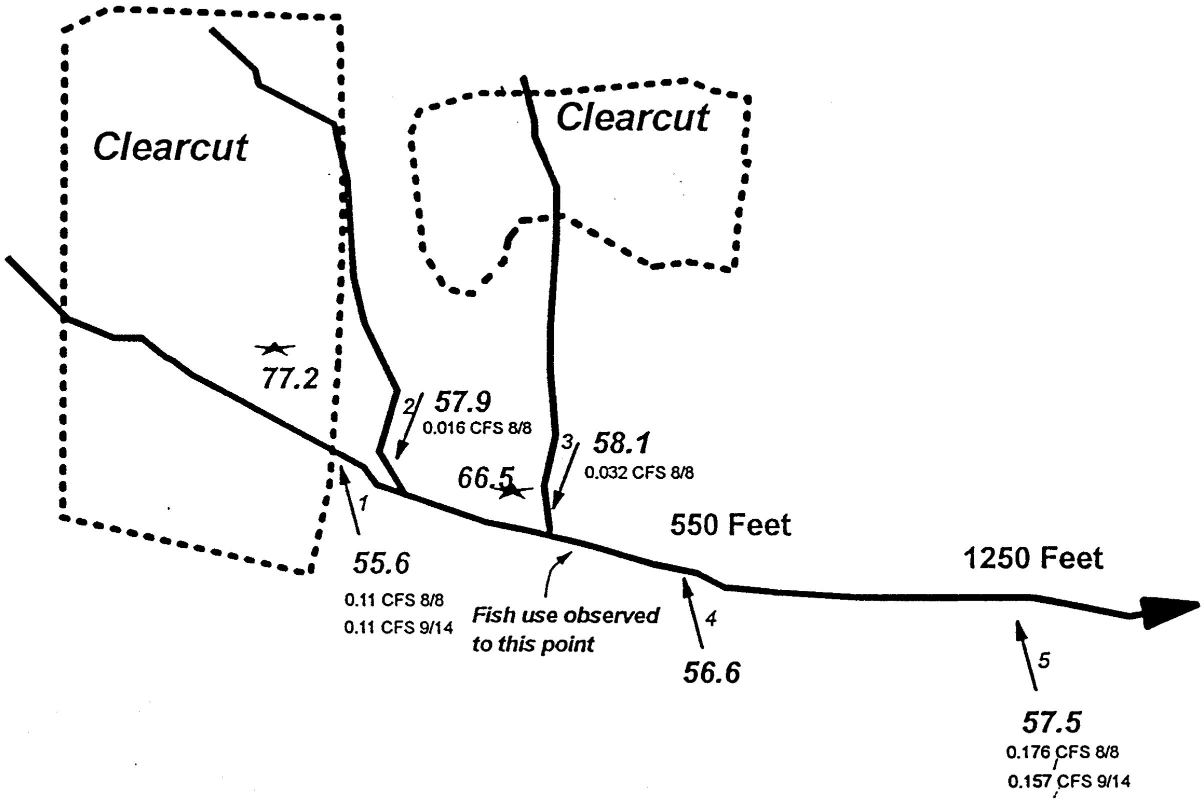


Appendix A Page 26B

1994 WATER TEMPERATURE MONITORING

Walker Creek

July 19 - 25

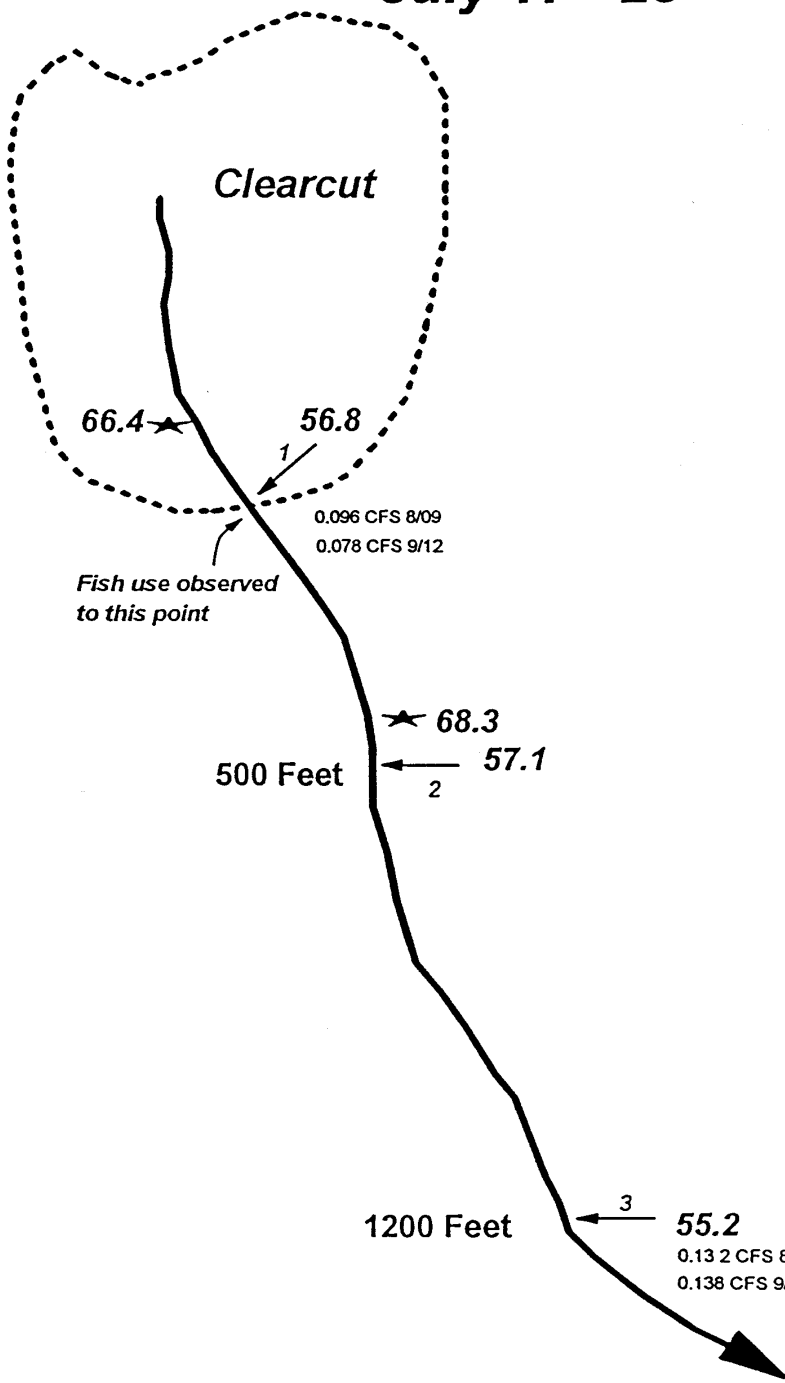


Appendix A Page 26C

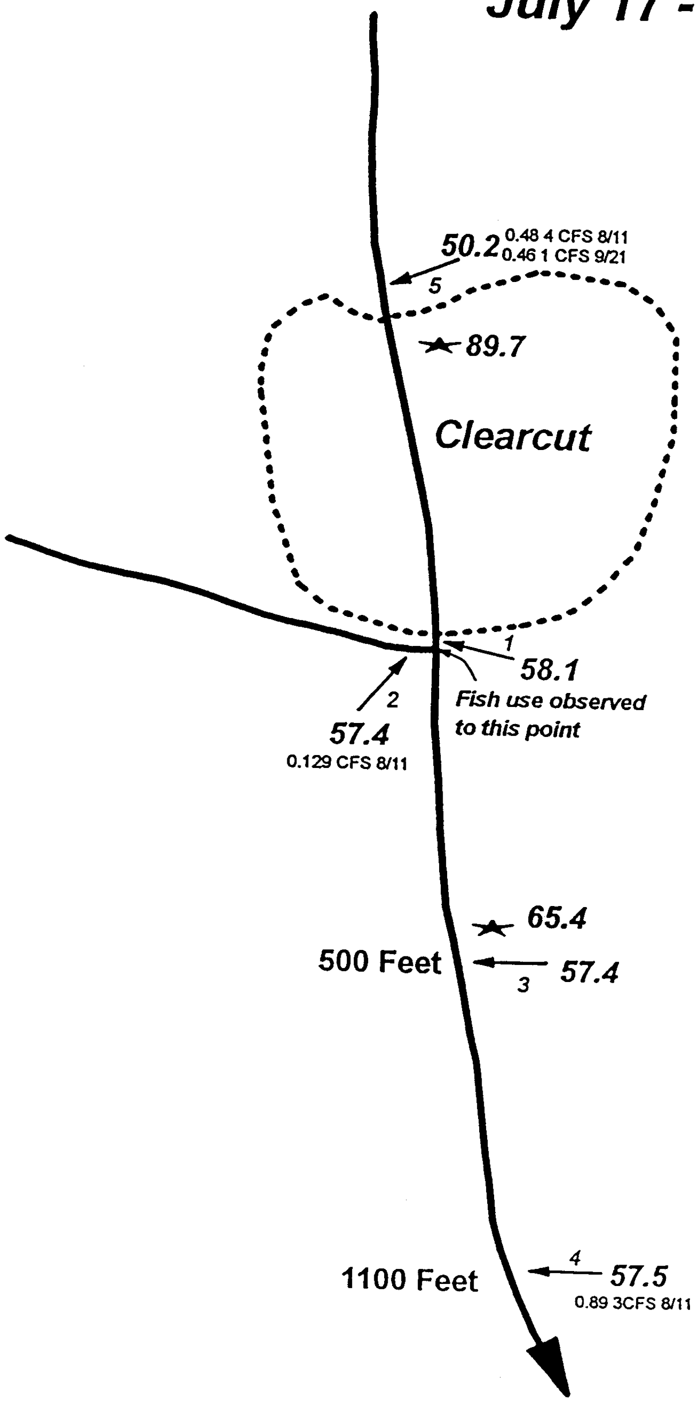
1994 WATER TEMPERATURE MONITORING

Booker Creek

July 17 - 23



Appendix A Page 26D
1994 WATER TEMPERATURE MONITORING
Oliver Creek
July 17 - 23

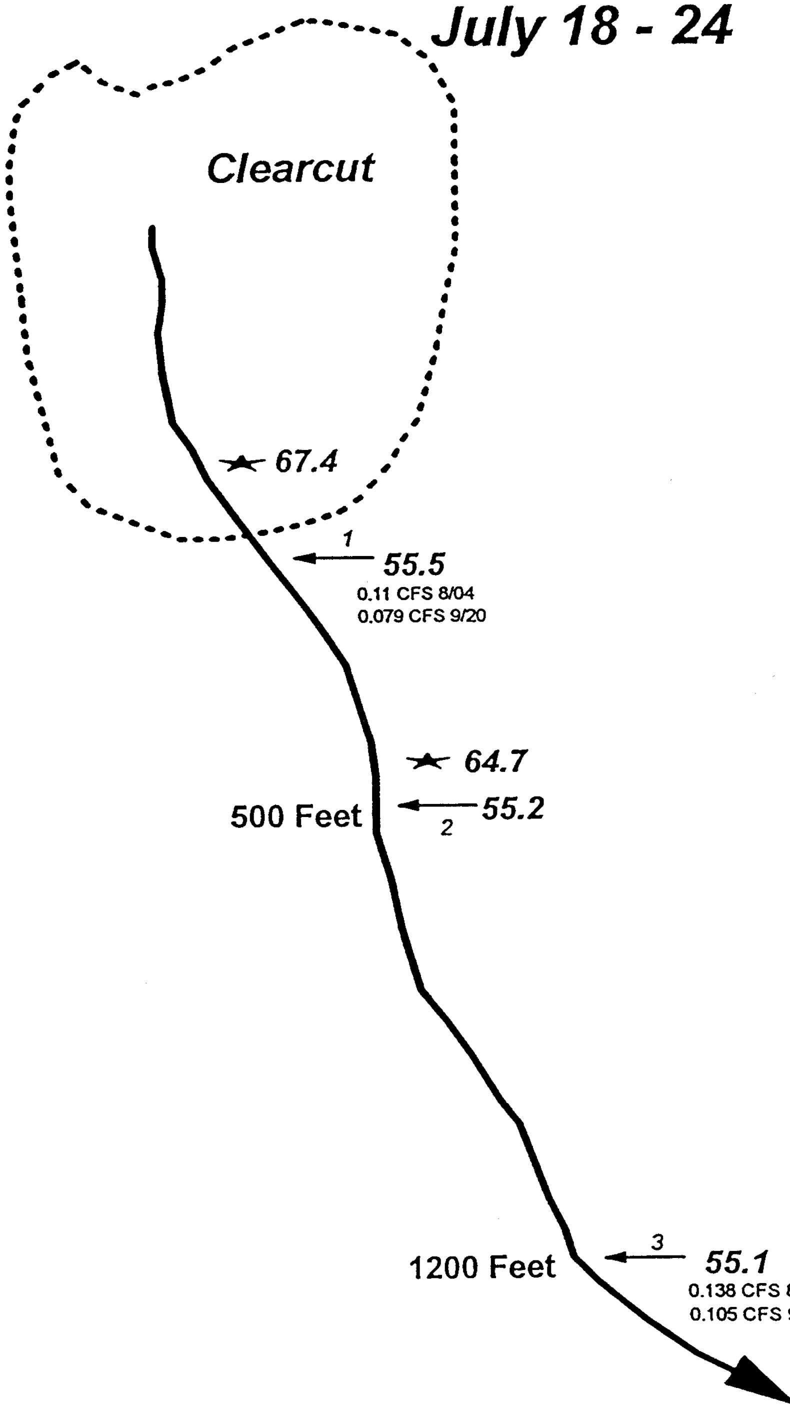


Appendix A Page 26E

1994 WATER TEMPERATURE MONITORING

Hamer Creek

July 18 - 24

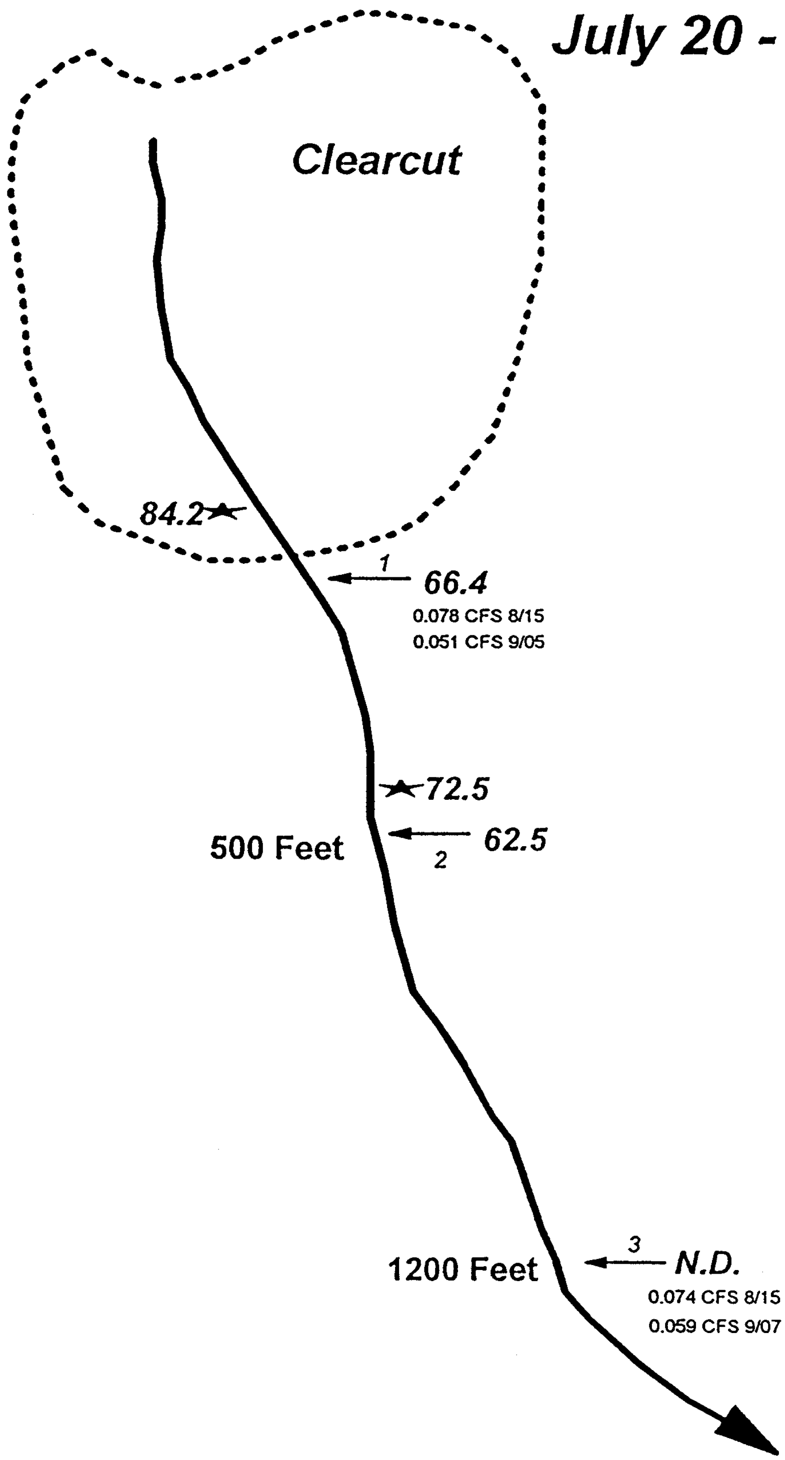


Appendix A Page 26F

1994 WATER TEMPERATURE MONITORING

Tributary to Rock Creek

July 20 - 26

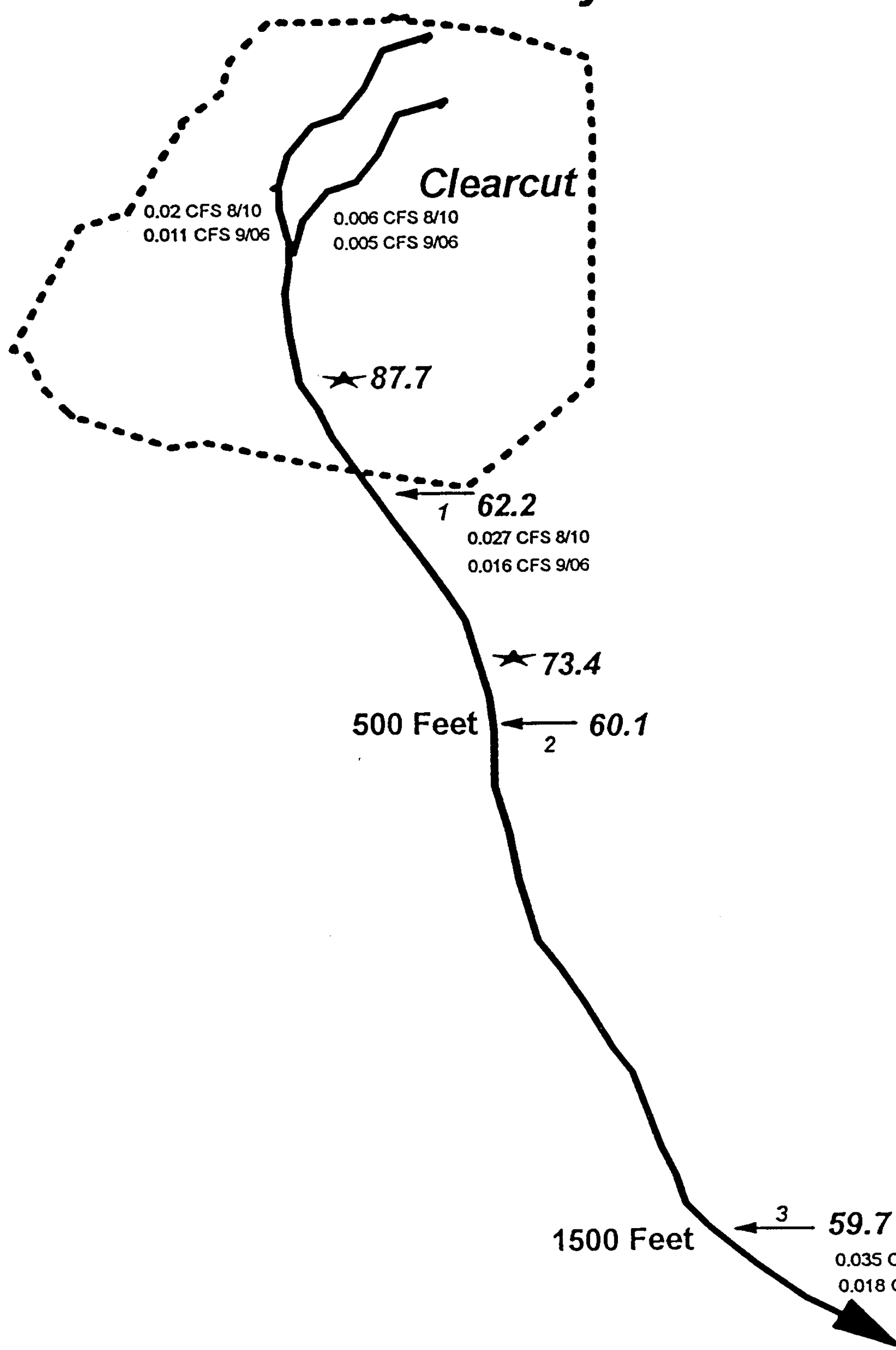


Appendix A Page 26G

1994 WATER TEMPERATURE MONITORING

Cedar Creek

July 20- 26



APPENDIX B

Photographs of Sites and Field Methods

Oregon Department of Forestry

1994 Water Temperature Monitoring

(All photographs taken in the summer of 1994 unless otherwise noted)

Photo 1. ***An example of one water temperature gauge and the portable data logger.***

Photo 2. ***An example of the temporary weir used for flow measurements.***

Photo 3. ***Tributary to Rock Creek clearcut site. Stream channel marked in black.***

Photo 4. ***Aerial photograph of Oliver creek clearcut site. Stream channel marked in black. (October, 1992).***

Photo 5. ***Booker Creek clearcut site. The harvest unit was subject to a moderately hot broadcast burn the previous year.***

Photo 6. ***Brush Creek basin looking downstream from the headwaters.***

Photo 7. ***Brush Creek streamside alder conversion unit.***

Photo 8. ***The channel of lower Brush Creek in August, 1994.***