Effectiveness of Riparian Management Areas and Hardwood Conversions in Maintaining Stream Temperature

Oregon Department of Forestry
Forest Practices Monitoring Program

Liz F. Dent, Monitoring Coordinator
Jennifer B.S. Walsh, Monitoring Assistant
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Executive Summary

Temperature in forested streams is a critical component of fish habitat. Management alongside forested streams has the potential to significantly affect the amount of solar radiation reaching the stream surface as well as the condition of other environmental parameters that are correlated with stream temperature response. In 1995, the Oregon Department of Forestry conducted a monitoring project to evaluate the effectiveness of the forest practice rule in preventing increases in stream temperature associated with forest harvesting. The project set out to answer the question: Are *the best management practices resulting in unacceptable temperature increases at the site and watershed level?*

Temperatures recorded continuously on 13 stream reaches and one basin were used to analyze the effects of Riparian Management Areas (RMA's) and Hardwood Conversions (HWC's) on maintaining stream temperature throughout the summer lowflow season. RMA's are unmanaged forest buffers of varying widths depending on stream size and type situated between upslope harvest operations and streams. HWC's are managed riparian buffers that are capable of supporting conifers but which are currently dominated by hardwoods. Active management is not permitted within a RMA (OAR 629-635-310) and is permitted within a HWC (OAR 629-640-300). Using various statistical methods, including repeated measures on analysis of variance and distribution tests, stream temperatures recorded immediately below the harvest units and those recorded approximately 500 feet below the harvest units.

Results from this monitoring project are limited by a lack of pre-harvest data and variability among the sample sites. Differences in elevation, harvest methodology, and georegion as well as data collection problems, especially with canopy cover, contributed to a highly variable sample population. However, consistent, if not significant, increases in stream temperature below harvested reaches indicate that the forest protection rules may not always provide adequate protection to meet water quality standards.

In general, the 7-day moving average of maximum, minimum and average temperature increased through the harvest units, whether it was a RMA or a HWC. Average 7-day maximum increase for RMA's was 2.5°F and 2.5°F for HWC's. However, four out of eight streams experienced stream temperature increases greater than 3°F while only on out of five RMA streams showed increases greater than 3°F. When variance in temperature contributed by distance from divide was theoretically accounted for, temperature increases were not significant. Without accounting for the natural downstream increase in temperature, temperature increases throughout the harvest units were statistically significant. Depending on the position of the harvest units within a water shed, stream temperature did or did not decrease downstream again after returning to an unmanaged canopy. Those reaches that were sampled higher in the basin did show a corresponding decrease in temperature 500 ft downstream, while those reaches sampled lower in the basin did not show a decrease in stream temperature 500 ft downstream.

The water quality standard for 7-day moving average of maximum (64°F) was exceeded more often downstream of harvested units than upstream. On all streams the standard was exceeded only 9.4% of the time. However, only three of the thirteen streams never exceeded the water quality standard.

Continued monitoring and assessment will be completed to address the limitations of this monitoring project and attempt to better determine where rules can be improved and how forested stream systems respond to management.

Acknowledgements

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Introduction

In 1994 the Oregon Department of Forestry (ODF) adopted new rules designed to protect the waters of the state during and after forest operations. The revised stream protection rules are designed to meet state standards for water quality and provide adequate protection for fish and other aquatic habitat.

The objectives of the water protection rules are to produce desired future conditions for the wide range of stand types, channel conditions and disturbance regimes existing throughout forest lands in Oregon. The desired future condition for fish bearing streams is growing and retaining riparian vegetation so over time average conditions across the landscape are similar to those of mature streamside stands. Such riparian stands supply nutrients, shade, large woody debris and bank stability to stream systems, contributing to high quality fish and wildlife habitat.

Under the Oregon Forest Practices Rules, Riparian Management Areas (RMA's) are established on streams running through or adjacent to harvest areas (OAR 629-635-310). The width of the RMA depends on the stream size (small, medium or large) and stream type or beneficial use (fish, domestic or none). For example, medium-sized (M), fish-bearing (F) streams have an RMA that is 70 feet wide measured as slope distance from the normal high water mark. All understory vegetation must be retained within 10 feet of the high water mark, all overstory vegetation must be retained within 20 feet of the high water mark, and all trees that lean over the stream must be retained. Trees can be harvested beyond the 20 foot distance and within the 70 foot RMA if there is sufficient basal area in the RMA. Basal area requirements vary with stream size, type and georegion and are described as standard and management targets. The standard basal area target for medium type F streams ranges, depending on the geographic area, from 90 to 140 square feet on each side of the stream, per 1000 feet of stream (OAR 629-640-100).

In addition, there are diameter, mimumum tree numbers and species requirements for the stand composition of the RMA.

Alternative prescription 2 (OAR 629-640-300) can be prescribed for riparian areas capable of supporting coniferous tree communities that are currently dominated by hardwood overstories. The intent of this rule is to achieve the desired future condition by restoring the riparian area to historic coniferous condition "in a timely manner." The practice is intended to provide adequate shade and bank stability while creating conditions that will improve on the future recruitment of large coniferous debris to the channel. Areas to be managed under this prescription will be divided into conversion and retention blocks. No more than half the total stream length to be harvested can be included in conversion blocks. The conversion block must be no more than 500 feet long and must be separated by at least 200 feet of retention block or a 200 foot segment where the general prescription is applied. Operators can clearcut harvest to within 10 feet from the normal high water mark within the conversion block if the following conditions are met: conifer basal area is less than half of the standard target; the site historically supported conifers; and the site is capable of supporting conifers again. All trees within 20 feet of the high water mark and leaning over the stream and all overstory and understory vegetation within 10 feet of the stream must be retained. The operator/landowner will then replant with coniferous species. This treatment is referred to as a hardwood conversion (HWC).

During the summer of 1995 ODF in partnership with Oregon State University (OSU) evaluated the effectiveness of the new rules in maintaining stream temperature. The project monitored stream temperature through RMA's and HWC's along small, medium and large fish bearing streams. In addition, the Department continued to monitor stream temperature throughout the entire basin of Brush Creek. The Brush Creek project is a long-term project that was initiated in 1994.

Purpose

This project will help answer a critical water quality question identified in the Oregon Department of Forestry's 1994 Forest Practices Monitoring Strategic Plan:

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

Objectives

The specific objectives designed to answer the monitoring question are:

Investigate stream and riparian characteristics which influence stream temperature.

Test the effectiveness of riparian management areas and hardwood conversions in maintaining stream temperature at a site and a watershed level.

Determine if riparian management areas and hardwood conversions maintain stream temperatures at or below the Department of Environmental Quality (DEQ) state standard for water quality.

Background and Literature Review

Regulatory Background

Growing concern for fish habitat on forested and agricultural lands has heightened public awareness and regulatory concerns over the effects of land management practices on water quality. Stream temperature is one regulatory parameter used to determine if streams meet water quality standards. The parameter used in Oregon to index water quality is the seven-day moving mean of daily maximum stream temperature (7-day maximum). Standards are a 7-day maximum equal to or less than 64°F for salmonid habitat and 50°F for bull trout. The DEQ documented over 800 Oregon streams as water-quality limited on the 1996 303(d) list (DEQ 1995). Of the streams listed, over 700 were listed, in part, due to water temperature concerns.

Stream temperature on forested streams has been extensively researched and monitored. Studies have investigated the effects of management on stream temperature, developed models to predict stream temperature, and evaluated the effects of elevated temperature on aquatic biota.

Effects of Harvesting and Other Environmental Variables

Many studies have documented increases in stream temperature due to timber harvesting. Degree of impact varies with particular practices and stream characteristics. Clearcut harvesting without leave trees or riparian buffer strips is consistently shown to increase mean, maximum and diurnal fluctuation of stream temperature (Brown and Krygier 1967, Levno and Rothacher 1967, Meehan et al. 1969, Meehan 1970, Feller 1981, Hewlett and Fortson 1982). Maintaining riparian vegetation has been shown to be successful in minimizing or eliminating increases in stream temperature associated with harvesting (Brazier and Brown 1973, Kappel and DeWalle 1975, Lynch et al. 1985, Amaranthus et al. 1989).

Riparian buffer width, while an important factor influencing stream temperature, needs to be considered in the context of the amount of shade provided by the riparian canopy (Brazier and Brown, 1973). The importance of maintaining canopy to protect stream temperature lies in its ability to block incoming solar radiation and maintain a cool, humid microclimate. Other parameters which influence temperature: channel width, depth, stream flow, substrate, gradient, elevation, distance from divide, azimuth, ground water flux and temperature, cool-water tributary input and air temperature (Brown 1970, Adams and Sullivan 1990, Sullivan et al. 1990, Caldwell et al. 1991).

Few basin-level studies have been conducted. Basin stream temperature studies in Washington documented increasing stream temperature in a downstream direction (Sullivan et al. 1990). The relationship appears to be asymptotic. At a given distance, from the divide average stream temperature reaches an equilibrium temperature that approximates the average basin air temperature (Sullivan et al. 1990). The distance required to reach an "equilibrium" temperature varies from basin to basin. At this distance factors such as riparian cover and groundwater input play a less significant role in maintaining stream temperature due to increasing channel width and stream flow. In the 1990 study, average stream temperatures reached a maximum at approximately 24 to 36 miles from the divide. This study did not determine how management affected the basin trend.

Basin trends may not be as predictable on East-side Oregon streams (Beschta et al. 1996, unpublished data). Stream temperature was monitored continuously from headwaters to the mouth using aerial sensor equipment on a tributary to the John Day. Temperatures increased and decreased a number of times from headwaters to the mouth. The trend resulted in headwater temperatures which approximated temperatures at the mouth of the river. This implies that East-side streams may not follow West-side basin trends, and that monitoring at individual points throughout a basin may identify different trends depending on where individual thermistors are placed.

<u>Fisheries</u>

Stream temperature is an important parameter for predicting fish habitat quality (Baltz et al. 1987, Eaton et al. 1995). The effect of stream temperature on aquatic biota, in particular fish and amphibians, varies between species and within the life cycle of a given species (DEQ 1995). Critical chinook salmon life stages occurring during the summer months include juvenile rearing, adult holding and adult migration. For coho salmon, juvenile summer rearing and late summer/early fall migration are the critical life stages affected by increases in summer stream temperature. Bull trout spawning and within-stream migration both occur during summer months. Preferred temperature ranges for these species and the particular life stages are shown in Table 1.

Table 1. Optimum and lethal limit temperature ranges for coho, chinook, and bull trout.

Fish species	DEQ standard	Preferred juvenile temperature range	Adult migration, holding, or spawning	Lethal limit
Coho	64°F	54 -57°F	45 - 60°F	77°F
Chinook	64°F	50 - 60°F	46 - 55°F	77°F
Bull Trout	50°F	39 - 50°F	39 - 54°F*	NA

* Spawning occurs below 50°F.

Increases in stream temperature cause an increase in an organisms' metabolic rate (Warren 1971). If the food supply is not limiting then growth rates can actually increase. Growth rate is positive at temperature ranges of 40 - 66 °F, but approaches zero at the extremes. More commonly, research has found elevated stream temperature results in increased competition for an often limited food supply, potentially displacing juveniles out of their preferred habitat. This can increase susceptibility to predation by warm-water-tolerant species. As food availability goes down so does growth rate. In addition, elevated stream temperatures increase the risk of disease-related mortality.

As stream temperature increases the amount of dissolved oxygen (DO) available to fish and other aquatic biota decreases. This occurs because as temperatures increase, the ability of the water to hold oxygen decreases. Concurrent increases in fish and other organisms' metabolic activity increases their oxygen requirements. The greater demand for oxygen also increases the removal rate of oxygen from the water column. As a result, even if food is abundant at higher temperatures, decreases in DO may metabolically stress salmonids, further increasing their susceptibility to disease.

Refugia. The presence and use of cool water refugia by sensitive species can serve to sustain the population (Bilby 1984, Sedell et al. 1990). A warm-water sensitive species can inhabit patches of cool water habitat when ambient conditions are too warm. Cool-water habitat can be sustained in deep pools, cold springs, hyporheic flow, the junction of cooler tributary streams and in different segments of the same channel.

A study done in Northern California found stratification of stream temperature in deep pools (3 to 9 feet), pools with large gravel bars at the upstream end, and shallow (1.5 feet) pools with subsurface seepage. Differences ranged from 7.0 - 8.0°F between the bottom and surface of the stream (Matthews et al. 1994, Nielsen et al. 1994). Temperature differentials between cool pools and ambient stream have been documented at 6.3°F.

<u>Past ODF Stream Temperature Monitoring</u>

In 1993, ODF monitored stream temperature upstream and downstream of harvest units. Results showed recovery of maximum stream temperature within 1000 feet downstream of harvest units when stream temperatures were elevated through harvest units (Andrus 1993). This was substantiated by a 1994 project monitoring stream temperatures on small type N (non-fish bearing, non-domestic use) streams flowing out of harvest units (Robison et al. 1995). Five out of six of the study streams never reached the DEQ water quality standard. In addition, the greater the maximum temperature observed flowing out of the unit the greater the rate of temperature decrease downstream.

There has been a substantial amount of research on stream temperature, the influential parameters and the effects of elevated stream temperature on aquatic biota. However, implications of management effects on stream temperature trends has rekindled discussions on stream temperature and associated regulatory parameters. Stream temperature is a function of the complex interaction of a number of environmental variables. The following project investigates these parameters further and assesses the effectiveness of the ODF forest practices in maintaining stream temperature.

Study Sites

Stream temperature was monitored on thirteen streams harvested with either a riparian management area (RMA) or a hardwood conversion (HWC) (Table 2). A total of five RMA and eight HWC units were monitored. They were all type F streams of which eight were medium, three large and two were small.

The requirements for site selection were: intact riparian condition 1000 feet upstream and 1000 feet downstream of the harvest unit, and harvesting conducted under the 1994 stream rules. All of the units were harvested prior to the monitoring period so there is no pre-treatment data, with the exception of Brush Creek. Brush Creek was harvested in the fall after one summer of data collection.

Stream characteristics varied greatly. For example, elevations ranged from 200 to 1560 feet, distances from divide varied from 0.20 to 11.5 miles, and wetted widths ranged from 2 to 26 feet. Harvest units vary between 1100 feet to nearly one mile in length. Buffer widths varied from 18 feet to 131 feet. Individual stream characteristics are given in Appendix A.

Table 2. Site description

Site	Stream Name	Georegion	Stream Type and Size	Forest Practice ^	Location
1	Brush Creek Basin with Thistle Burn Tributary	Interior	Entire Basin S-M-L	HWC Clearcut both sides	T.23 S, R.6 W
2	West Agency Creek	Coast Range	S-M type F	HWC	T.5 S, R.8 W Sec 6
3	January Creek	Coast Range	M type F	HWC	T.17 S, R.7 W Sec 14
4	Little Fall Creek	Interior	M type F	HWC	T.17 S, R.2 E Sec 33
5	Coleman Creek	Coast Range	L type F	HWC	T.14 S, R.7 W Sec 36
6	Sheele Creek	Coast Range	M type F	HWC *	T.12 S, R.7 W Sec 3
7	Mill Creek	Coast Range	M type F	HWC *	T.9 S, R.9 W Sec 26,27
8	Cascade Creek	Interior	M type F	HWC *	T.14 S, R.1 W Sec 33
9	Sheythe Creek	Coast Range	M type F	RMA	T.9 S, R.7 W Sec 26, 35
10	Eagle Creek	Coast Range	M type F	RMA	T.8 S, R.8 W Sec 7
11	Talbot Creek	Coast Range	S type F	RMA	T.26 S, R.13 W Sec 31
12	Douglas Creek	Interior	M type F	RMA	T.20 S, R.5 W Sec 10
13	Beaver Creek	Interior	L type F	RMA	T.2 N, R.5 W Sec 15

^ HWC = Hardwood conversion, RMA = Riparian Management Area
* HWC's designed to limit openings on the south side of streams.

<u>RMA's and HWC's</u>

The 1994 stream rules were designed to allow increased flexibility to the landowner and/or operator in managing riparian areas. Therefore, correct application of the riparian rules can result in a variety of vegetative conditions between sites. This variability, coupled with a mosaic of land ownerships (federal property adjacent to private ownership) results in different vegetative conditions under application of the same rules. In addition, three sites harvested under the HWC rule were intentionally designed to limit openings on the south side of the streams. Therefore the results of this study represent a variety of conditions described as either RMA or HWC.

Georegions
The Oregon Forest Practice Rules use the term “georegion” to describe large areas with similar combinations of climate, geomorphology and potential natural vegetation. The Forest Practices Monitoring Program stratifies sample sites on a georegion basis (Figure 1). There were only two georegions sampled in this study. The "Coast Range" includes the cooler, wetter and typically steeper portions of coastal mountains with a combination of igneous and sedimentary rock. The "Interior" region is warmer, drier and typically consists of foothills on both sides of the Willamette valley. For this project there were eight streams in the Coast Range and five in the Interior.

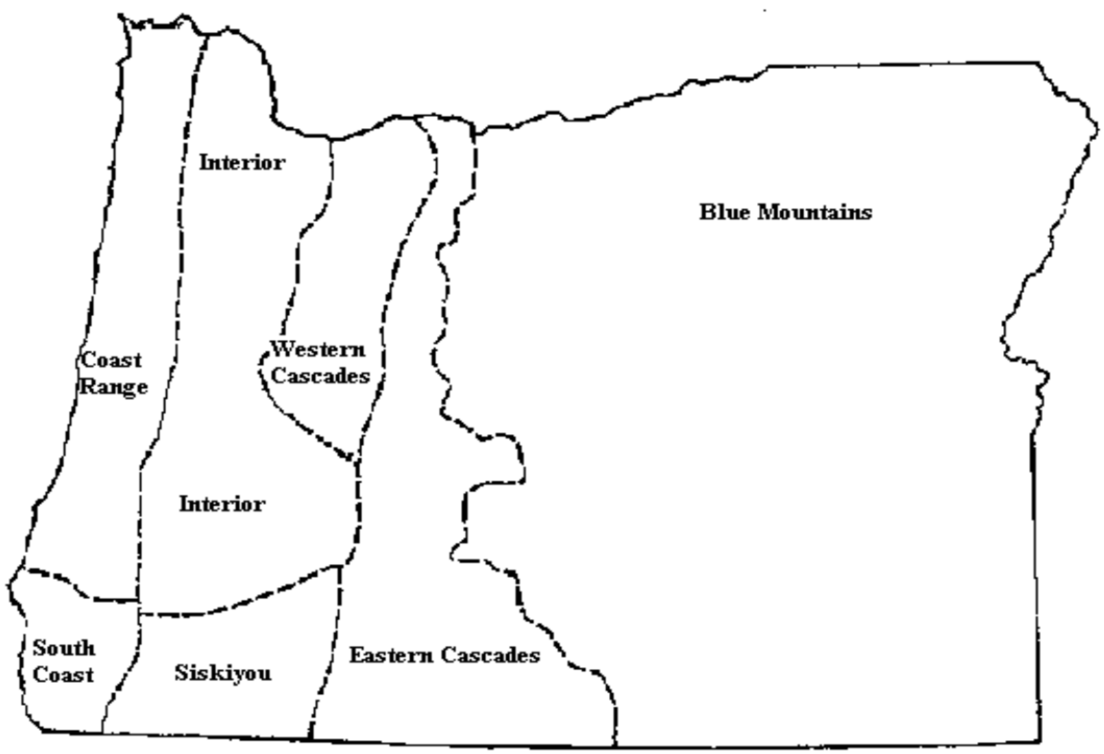

Figure 1. Boundaries of Oregon Department of Forestry georegions.

Field Methods

Stream Temperature
ODF’s stream temperature monitoring protocol (Runyon and Andrus 1994) was used in selecting 16 streams and individual monitoring station locations. In general, stream temperature was monitored on the boundary of the upstream and downstream ends of harvest units and 500 and 1000 feet (ft) downstream of the harvest unit. Additional monitoring sites were established as needed to account for tributary effects. Monitoring schemes for the individual streams are shown in Appendix B. Temperature data were collected every 48 minutes using HOBO-temp monitoring thermistors. Periods of record

varied from stream to stream, but in general data are available from July through September 1995 (Appendix C shows the period of record for each station).

Environmental Data

Physical and vegetative data were collected on each stream. Eleven stations were established upstream, within the harvest unit and downstream of the harvest unit for a total of 33 stations on each stream. The following parameters were measured for each station unless specified otherwise.

Physical Data:

1) *Stream flow* was measured with a Marsh McBurney velocity meter at the downstream edge of the cutting unit and at the farthest downstream temperature monitoring station. Measurements were taken once during the summer.
2) *Aspect* was taken from USGS 1:24 000 maps.
3) *Elevation* was taken from USGS 1:24 000 maps.
4) *Gradient* was measured in percent with a clinometer.
5) *Thalweg depth, wetted* and *bankfull width* and *terrace height* were measured using a meter stick.
6) *Substrate* was characterized as the percent of the cross-section composed of bedrock, boulder, cobble, gravel and fines.
7) *Distance from divide* was measured for each temperature monitoring site from a 1:24000 USGS map. Distance was measured in a downstream direction from the ridge to the monitoring station, following forks contributing the greatest proportion of flow.

Management and Vegetation Data:

1) *Width of left and right buffer* or riparian stand were measured by pacing or with a hip chain.
2) *Harvest unit length* was measured by pacing or with a hip chain.
3) *Cover* was measured using a concave densiometer and fish-eye lens camera.

Analytical Methods

Temperature parameters

Stream temperatures were used from three stations on each stream: station 1, on the upstream boundary of the harvest unit; station 2, on the downstream boundary of the harvest unit; and station 3, 1000 feet downstream of the harvest unit (Figure 2). Due to missing data there were four streams (Beaver, Sheythe, Talbot and West Agency) in which a station 500 feet downstream was used instead of a station 1000 feet downstream. The third stations on Mill and Brush Creeks were located 1640 feet and 2.4 miles, respectively, downstream of the harvest units.

The 7-day moving mean of daily maximum, minimum and average (7-day maximum, minimum, average) stream temperature and diurnal fluctuation were used to analyze effectiveness of RMA's and HWC's in maintaining stream temperature. Period of record when the highest 7-day maximums were observed on all streams was chosen for analyses.

On a subset of streams, the number of days that 7-day maximum was above 55°F and 64°F from July 21 through August 16 was also analyzed.

<u>Environmental Parameters</u>

Environmental data were averaged for the 11 stations upstream of the harvest unit, within the harvest unit and downstream of the harvest unit. These averages were used to investigate relationships between environmental characteristics and stream temperature. Averages for each reach are given in Appendix A.

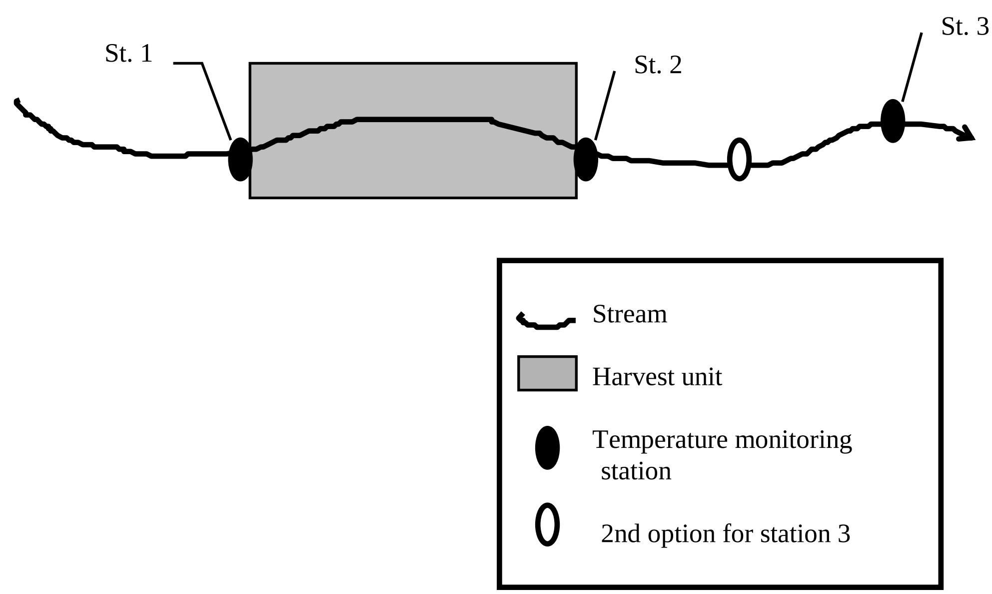

Figure 2. Stations used for statistical analyses.

<u>Statistical Methods</u>

Statistical analyses were used to investigate relationships between environmental parameters and stream temperature and to test for effects of harvesting with RMA's versus HWC's on stream temperature. Three statistical methods were applied: *correlation analysis, repeated measures analysis of variance (ANOVA), and distribution tests*. These analyses were performed on 13 streams. The statistical methods are described below.

1) *Correlation analysis* (SAS/STAT 1988): This procedure tested the relationship between environmental parameters (i.e., distance from divide, stream gradient) and stream temperature. The data were correlated in two ways. Initially, all the stations were pooled and 7-day maximum, minimum and average were correlated against the corresponding average environmental parameters. Secondly, a correlation analysis was performed separately for each station 1, 2 and 3. Results of the station-stratified correlation were applied to the repeated measures ANOVA discussed below. Level of

significance for Pearson correlation coefficients (r) was determined at a p-value less than or equal to 0.001, 0.01 and 0.05.

2) *Repeated measures ANOVA* (SAS/STAT 1988): Repeated measures ANOVA was used rather than a "straight" ANOVA because the data were spatially dependent on each other. Both residuals and "raw" stream temperature data were analyzed.

Residuals. Given the lack of pre-harvest data, residuals were used in the repeated measures ANOVA as a means to account for stream temperature variability attributable to factors other than harvesting. The intention was to account for "natural" increases in stream temperature which occur in a downstream direction. Station-stratified correlation analyses (described above) identified distance as a parameter which significantly (p-value < 0.01) and most consistently (at each station) influenced stream temperature. Station 1 was the only station which provided a distance/temperature relationship which was not affected by the harvest units. Therefore residuals were calculated using the empirical model of stream temperature at station 1 versus distance at station 1. The residual at any station was the difference between the predicted stream temperature (station 1 model) and the actual stream temperature at that station.

Raw Data. Repeated measures ANOVA of "raw" stream temperature data (7-day maximum, minimum, average and diurnal fluctuation not adjusted for distance) was important since residuals were based on correlation using a relatively small data set with a high amount of variability. Therefore, the empirical relationships may not have accurately predicted pre-harvest conditions.

Both of the above repeated measures ANOVA's tested the effect of RMA's and HWC's on stream temperature (7-day maximum, minimum, average and diurnal fluctuation). A statistically significant increase between stations 1 and 2 would indicate a harvest effect. A significant decrease between stations 2 and 3 would indicate downstream cooling. A significant difference between stations 1 and 3 would indicate either a reach level increase or decrease in 7-day maximum, minimum, average and diurnal fluctuation.

3) *Distribution Tests* (SAS/STAT 1988): A Chi-squared test was applied to frequency distributions of stream temperature data to test for harvest effect on frequency with which stream temperature was above 64°F and 55°F. This procedure tests the effectiveness of rules in maintaining stream temperature at or below the DEQ standard. Since the DEQ standard is linked with temperature effects on fisheries, this technique was an index of the potential effects of harvest units on fisheries. This analysis was performed on 11 streams for the period of record in which the highest stream temperatures were observed, July 21 through August 16. It is important to note this analysis assesses a 21-day period while the ANOVA's assess a seven day period.

Brush Creek Basin Trends

The hardwood conversion on Brush Creek was analyzed with the rest of the streams in the analyses described above. In addition, overall basin trends and differences between 1994, 1995 and 1996 will be discussed.

Limitations of the Study

Limitations of the study must be considered when interpreting the data. There were no pre-harvest data and no data 1000 ft upstream of harvest units. Therefore a direct measure of background variability was not available. Other means (described above) were used in an attempt to account for natural variability and to address the influence of environmental parameters, other than harvesting, on increases in temperature. In addition, relatively small sample sizes and high variability in the data reduce the power of statistical methods and increase the possibility of erroneously accepting or rejecting a hypothesis that harvesting with RMA's and HWC's does not affect stream temperature.

There was variability in vegetative condition under the same harvest treatment. This made it difficult to accurately assess the effectiveness of HWC's versus RMA's in maintaining stream temperature. In addition, poor quality canopy data limited the ability to assess the effect of shade on stream temperature.

The ability to determine the effect of RMA's and HWC's on fish habitat is limited. Effect of harvesting on fisheries was determined based on preferred temperature regimes of salmonids. The DEQ water quality standard was used as an index of high quality fish habitat.

Results and Discussion

The DEQ standard is based on 7-day maximum and provides a means of assessing weekly trends versus an instantaneous high. The highest 7-day maximums were recorded on July 20th and August 3rd consistently for all stations. Graphical displays of these data are found in Appendix D. On average the August peak was 0.41°F higher than the July peak. The period of record chosen for analysis was the week of July 31 to August 6, thereby capturing the August 3 peak.

Observations of Changes in 7-day Maximum Stream Temperature through Harvest Units

The average increase in 7-day maximum stream temperature through harvest units was 2.5°F for HWC and 2.1°F for RMA units (Figure 3a,b). At five sites stream temperatures changed very little (< or = 1.0°F) through the harvest units (Cascade, Little Fall, Mill, Beaver, and Eagle Creeks) while for the remainder of the sites, changes in stream temperature varied from 2.1 to 5.7°F.

Stream temperature increases *greater than* 3.0°F were observed on four out of eight HWC sites (Brush, Coleman, January and Agency). Three out of four of these HWC sites had stream temperatures less than 60°F upon entering the harvest unit (Figure 4a,b,c).

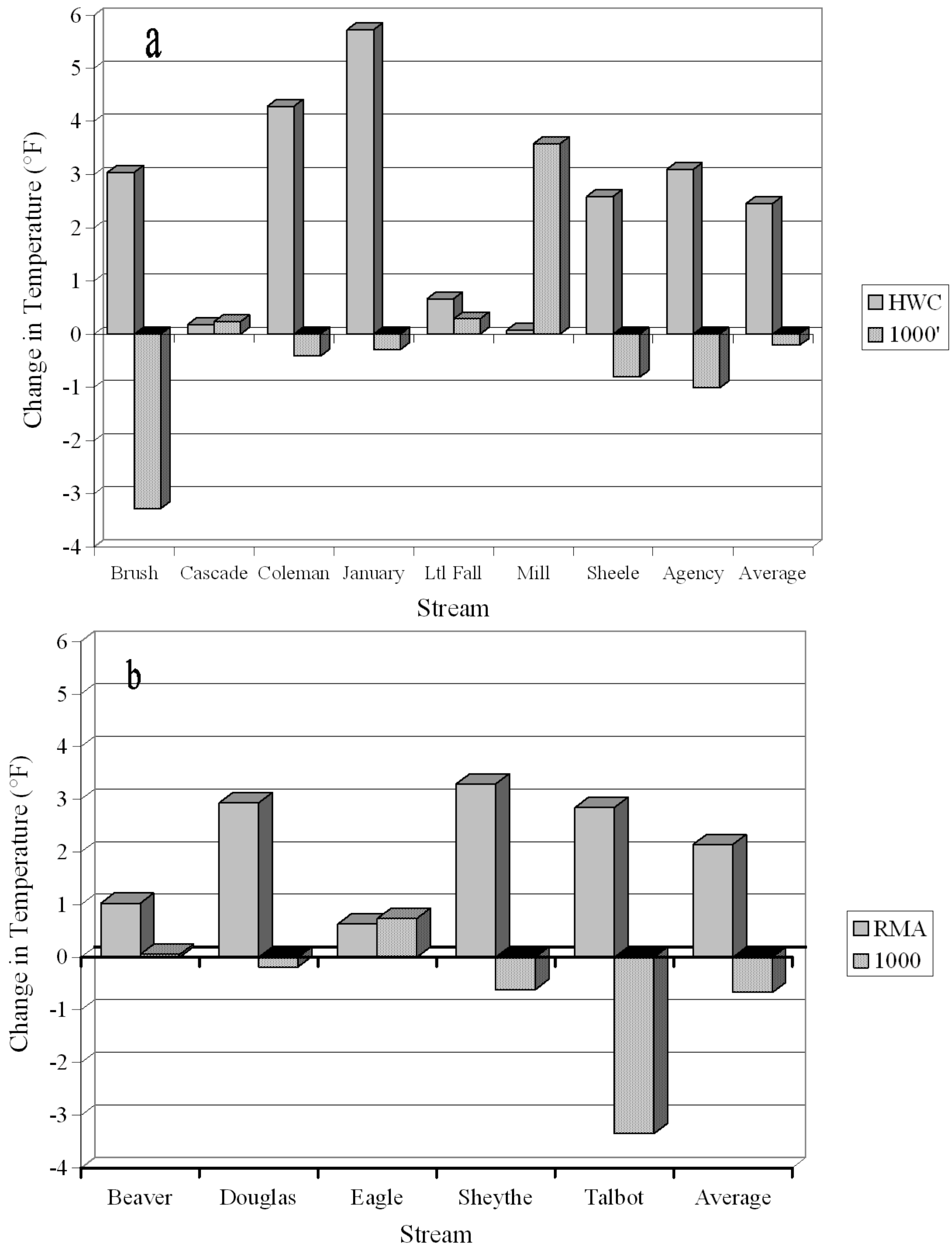

Figure 3. Change in 7-day maximum through harvest units and downstream reaches for (a) HWC and (b) RMA units.

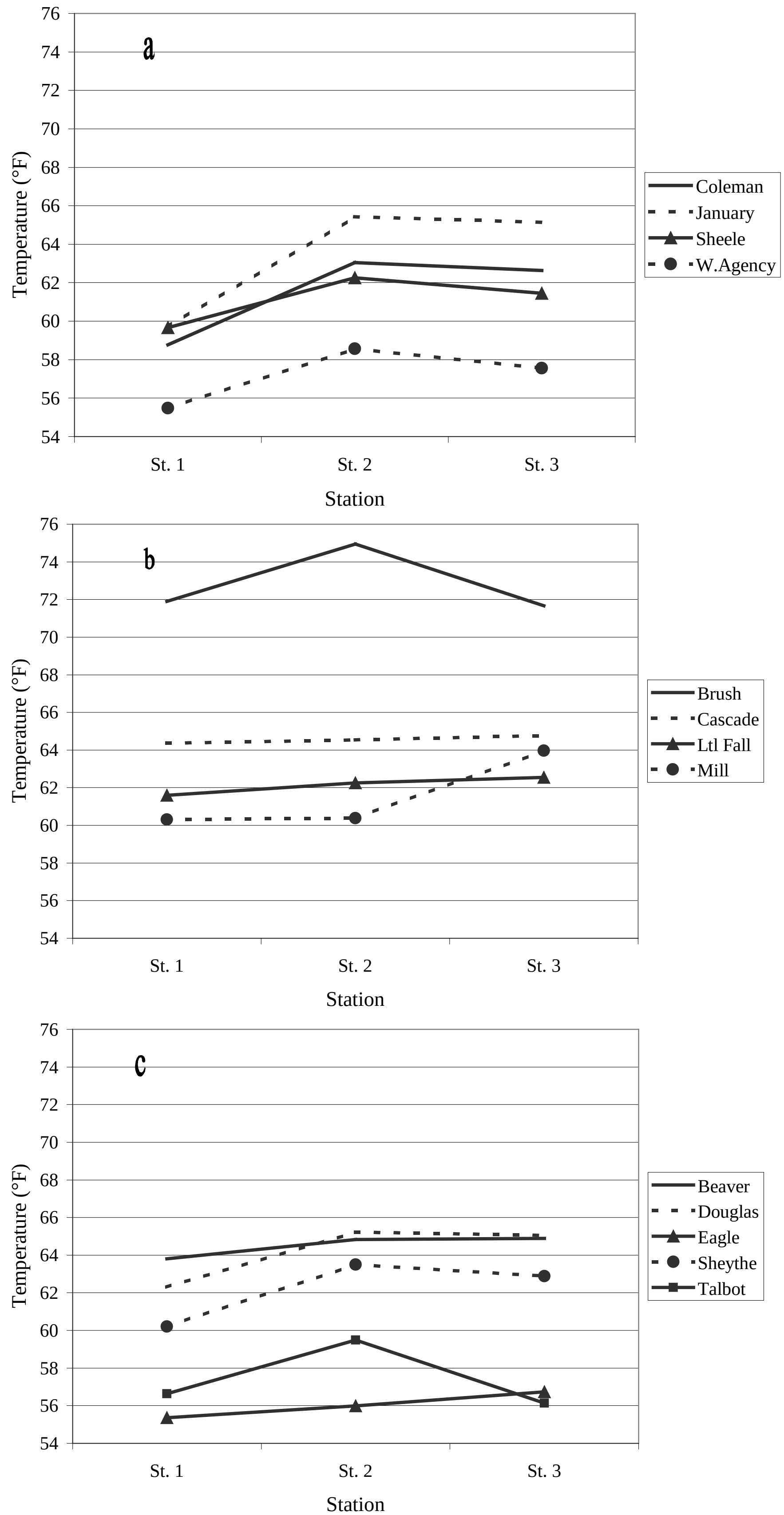

Figure 4. Seven-day maximum stream temperature at stations 1, 2, and 3 for streams harvested with (a and b) HWC's and (c) RMA's

This may have increased the potential for greater changes in temperatures through harvest units. January Creek showed the greatest increase of 5.7°F through the HWC. This sight was a relatively low gradient stream with slightly meandering, beaver-influenced channel morphology. Canopy cover was reduced to less than 10 percent in some areas. These characteristics would have increased the time of exposure of the stream to incoming solar radiation which in turn results in increased stream temperature.

Stream temperature increases *greater than* 3.0°F were observed on only one out of five RMA's. However, stream temperature increases of 2.9 and 2.8°F were observed on Douglas and Talbot Creeks. Douglas Creek had a number of beaver ponds with lower than average canopy cover (10%) throughout parts of the RMA. These characteristics increase the exposure of the streams to solar radiation. Talbot Creek was a small stream, the lowest elevation (200 ft) site, very close to the headwaters (0.20 miles) with narrow RMA widths. These characteristics may have made it more susceptible to a greater flux in temperature through the harvest unit.

Stream temperature increases *less than* 3.0°F were observed on four out of eight HWC sites (Cascade, Mill, Sheele and Little Fall Creeks). Three of these sites, Cascade, Mill and Sheele Creeks were specifically designed to limit the amount of southern exposure that would result from that prescription. Stream temperatures increased on these streams by 0.2, 0.1 and 2.6°F, respectively. The buffers on these streams were designed to remove most of the basal area from the north side of the stream and leave more trees on the south side of the stream, thereby providing increased shade and protection from incoming solar radiation. This approach was marginally successful on Sheele Creek. That may be because Sheele Creek was a cooler stream (59.7°F) upon entering the HWC (Figure 4b). Little Fall Creek was the other HWC site on which minimal increases in 7-day maximum (0.7°F) were observed. This stream was the highest elevation stream (1568 ft) and had the shortest openings (1148 ft) of all the HWC's.

Stream temperature increases *less than* 3.0°F were observed on four out of five RMA streams. Stream characteristics varied greatly other than being harvested with an RMA rather than a HWC.

Observations suggest that the performance of RMA's and HWC's was variable. In some instances temperature increases greater than 3°F were observed on both RMA's and HWC's, possibly attributable to greater exposure to solar radiation. At other sites stream temperature increases were less than 1.0°F for both RMA's and HWC's. Furthermore, the special-prescription HWC sites may have maintained stream temperature more effectively through harvest units than the conventional HWC's. This would be attributable to greater protection from incoming solar radiation afforded by a prescription which limits southern exposure.

The average rates of increase in 7-day maximum through RMA's and HWC's were 0.94 and 1.0°F/1000 ft (standard deviation = 0.75 and 0.79°F), respectively. These rates are somewhat consistent with background rates observed on Brush Creek. The rate of warming upstream from the treatments, on Brush Creek over a three year period ranged from 0.54 to 0.64°F/1000 ft of stream. This occurred over a 2.8 mile reach which began approximately 1.6 miles from the divide. The rate was more variable at 5.5 miles from the divide, 1.52, 0.17, 0.45°F/1000 ft in 1994, 1995, and 1996.

The greatest rates of warming for RMA's and HWC's were observed on Sheythe and West Agency Creeks, 2.05 and 2.30°F/1000 ft respectively (Table 3). The lowest rates of warming for RMA's and HWC's were observed on Eagle and Cascade Creeks, 0.24 and 0.08°F/1000 ft, respectively.

Rate of increase through harvest units was not always proportionate to measures of change in canopy cover. This is most likely a function of poor quality canopy measurements and no pre-harvest data on canopy cover. Without pre-harvest data, change in canopy cover was assumed to be proportionate to the difference in canopy cover between the upstream reach and within the harvest unit. Based on this assumption canopy cover actually increased with some of the harvest units. The maximum decrease in canopy cover was 20% for a HWC and 18% for an RMA (Table 3). Rates of increase on these same sites were 3.1 and 1.2°F/1000 ft, respectively. Minimum decreases for HWC's and RMA's were 0 and 1%. Average decreases in canopy cover for HWC's and RMA's were 4.1 and 3.2%, respectively (standard deviation of 5.8 and 12.4).

Table 3. Stream temperature parameters, cover and distance from divide for each stream.

Stream	Treatment	7-day Maximum Below unit (°F)	7-day Minimum Below unit (°F)	7-day Average Below unit (°F)	Change in 7-day maximum through unit (°F)	Rate of warming through harvest unit (°F/1000ft)	Change in Canopy cover (%)	Distance From Divide at bottom of unit (miles)
Brush	HWC	75.0	62.7	69.0	+ 3.0	1.0	+ 6	9.0
Cascade	HWC	64.5	56.9	60.5	+ 0.18	0.08	- 7	3.55
Coleman	HWC	63.1	56.1	59.4	+ 4.3	1.3	- 3	4.16
January	HWC	65.4	58.4	61.7	+ 5.7	1.7	- 10	2.69
Little Fall	HWC	62.3	54.9	58.2	+ 0.66	0.58	- 10	6.23
Mill	HWC	60.4	57.6	58.9	+ 0.07	0.01	- 5	4.41
Sheele	HWC	62.2	54.5	57.6	+ 2.6	1.0	0	3.80
W Agency	HWC	58.6	53.4	55.7	+ 3.1	2.3	- 20	0.88
Beaver	RMA	64.8	59.6	62.5	+ 1.0	0.29	- 14	5.22
Douglas	RMA	65.2	59.1	61.8	+ 2.9	0.89	+ 9	3.11
Eagle	RMA	56.0	53.5	54.8	+ 0.63	0.24	+ 8	2.57
Sheythe	RMA	63.5	55.9	58.8	+ 3.3	2.0	- 1	3.52
Talbot	RMA	59.5	53.2	56.3	+ 2.8	1.2	- 18	0.64

While some of the above observations suggest a treatment effect it is necessary to perform statistical analyses on the data to determine if the observations are statistically significant. The potential disadvantage of statistical analyses is pooling streams together that vary greatly in site and vegetative characteristics and treating them as two populations. A larger sample size would have countered the high variability. However, the benefit of statistical analyses is to objectively determine rule effectiveness. In addition, since the rules apply to a wide variety of streams, it is appropriate to analyze them accordingly.

Relationship Between Environmental Parameters and Stream Temperature

Previous studies indicate that stream temperature will increase as width, depth, stream flow and distance from divide increases and velocity, elevation and gradient decrease (Beschta and Weatherred 1984, Sullivan and Adams, 1989, Sullivan et al 1990, Caldwell et al. 1991). As buffer width and canopy cover increase, stream temperature changes are minimized (Levno and Rothacher 1967, Brown and Krygier 1970, Meehan 1970, Brazier and Brown 1973, Lynch et al 1985). In the following correlation analyses, 7-day maximum, minimum and average stream temperatures for all stations were correlated against environmental parameters to explore these hypotheses.

As depth, wetted width, bankfull width, bank height, percent bedrock and distance from divide increased, 7-day maximum, minimum and average increased. As gradient andelevation increased 7-day maximum, minimum and average stream temperature decreased. These results were consistent with findings from other studies (Table 4).

As buffer width increased, 7-day maximum and average stream temperature decreased. The buffer width relationship was only significant for 2 of 6 comparisons (Table 4), however, the negative relationship was consistent with findings from previous studies.

Past studies have shown that as canopy cover increases lower stream temperatures will be observed. Our data did not reveal this relationship. Rather than disprove previous studies, however, it is more likely the data from this study did not accurately represent actual canopy cover at all the sites. This may be attributable to three factors. First, correct procedure may not have been followed when measures of cover were collected. This was determined by revisiting the sites after the sampling period and spot checking the data. Vastly different measurements for some sites were documented. Secondly, even with proper use of a densiometer, two people can obtain different measurements, reducing the accuracy of the measure. Finally, the high variability observed in change in canopy cover (+9 to -20%) reduced the ability to define a relationship between canopy cover and temperature using correlation analysis. Future monitoring will emphasize accurate measurements of canopy cover.

Some of the physical parameters were cross-correlated with each other. For example as distance from divide increased, elevation and gradient decreased while width, bankfull width, bank height and maximum depth increased. As wetted width increased, bankfull width and maximum depth increased. Significant correlation simply shows a parameter and temperature have consistent linear trends beyond a level explained by random chance.

Table 4. Correlation relationships, Pearson correlation coefficients (r), and p-values for statistically significant findings with all stations pooled. Positive relationships are noted with a "+" and negative relationships with a "-". Actual p-value is less than or equal to reported value.

Temp Statistic	Depth	Wet width	Bank-full width	Left bank height	Right bank height	% Fines	% Gravel	% Cobble	% Bolder	% Bed-rock	% Channel Grad.	% Cover	Left buffer width	Right buffer width	Dis-charge	Harvest length	Dist. from divide	Elev-ation
7-day Max																		
r	+0.42	+0.67	+0.52	+0.45	+0.40					+0.52	-0.51			-0.37			+0.81	-0.36
pvalue	0.01	0.001	0.001	0.01	0.01					0.001	0.001			0.05			0.001	0.05
7-day Min																		
r	+0.46	+0.48	+0.36	+0.59	+0.44			-0.33		+0.45	-0.64						+0.67	-0.47
pvalue	0.01	0.01	0.05	0.001	0.01			0.05		0.01	0.001						0.001	0.01
7-day Avg																		
r	+0.44	+0.59	+0.56	+0.52	+0.43					+0.52	-0.59			-0.36			+0.77	-0.42
pvalue	0.01	0.001	0.01	0.001	0.01					0.001	0.001			0.05			0.001	0.01

It does not suggest that any *one* parameter drives stream temperature. For example, distance does not *cause* increases in width, just as distance does not *cause* increases in stream temperature. On the contrary, *many* parameters show significant and consistent relationships with stream temperature, supporting the hypothesis that stream temperature at a given site is a result of a combination of several environmental parameters.

The morphological descriptors (depth, width, bank height, gradient, elevation, and distance from divide) are all factors which generally increase or decrease in a downstream direction or as streams get larger. Distance from divide provides an easy-to-measure parameter which captures the downstream dynamics and inter-relatedness of environmental parameters. It was also the most consistently correlated parameter with stream temperature when correlation analyses were performed on individual stations. Therefore, in the following assessment of the effectiveness of RMA's and HWC's in maintaining stream temperature, the relationship between distance from divide and stream
temperature was used as a tool to account for increases in temperature which might have occurred in a downstream direction regardless of harvest activities.

<u>Effect of RMA and HWC Harvest Units on Stream Temperature</u>
Stream temperature upstream from harvest units was compared to stream temperature downstream of harvest units. Repeated measures ANOVA was performed on the residuals of stream temperature versus distance and on the "raw" data (7-day maximum, minimum, average and diurnal fluctuation).

Calculating residuals. Station 1 is the only station at which stream temperature was not affected by RMA's and HWC's. Therefore, the empirical relationship between distance and temperature at station 1 was used to predict the increase in stream temperature that might have occurred in a downstream direction without harvest activities. Stream temperature was regressed versus distance from divide for station 1 data to develop the following empirical equations:

Equation 1: $$\text{7-day Maximum}_{(st.\ 1)} = (1.69) * \text{Distance}_{(st.\ 1)} + (55.13)$$
$$(R^2 = 0.72,\ p\text{-value} = 0.0003)$$

Equation 2: $$\text{7-day Minimum}_{(st.\ 1)} = (0.76) * \text{Distance}_{(st.\ 1)} + (52.90)$$
$$(R^2 = 0.49,\ p\text{-value} = 0.0076)$$

Equation 3: $$\text{7-day Average}_{(st.\ 1)} = (1.23) * \text{Distance}_{(st.\ 1)} + (53.75)$$
$$(R^2 = 0.65,\ p\text{-value} = 0.0009)$$

Predicted 7-day maximum, minimum, and average stream temperatures (Y^) at stations 2 and 3 were calculated using the slope and intercept defined by equations 1, 2 and 3.

$$Y\hat{}_{1,2,3} = m_1(\text{distance}_{1,2,3}) + B_1$$

Wherein,
m_1 = slope empirically defined from equations 1, 2 or 3.
$(distance_{1,2,3})$ = distance from divide at stations 1, 2 or 3 (miles).
B_1 = intercept empirically defined from equations 1, 2 or 3 (°F).

The difference between the predicted stream temperature and the actual stream temperature (residual) for each station was then calculated.

$$Residual_{1,2,3} = Observed_{1,2,3} - Y\hat{}_{1,2,3}$$

Wherein,

$Residual_{1,2,3}$ = residual at stations 1, 2, or 3.
$Observed_{1,2,3}$ = the observed stream temperature (°F) at stations 1, 2, or 3.
$Y\hat{}_{1,2,3}$= predicted stream temperature at stations 1,2, or 3 (°F).

The empirical equations for 7-day maximum, minimum and average had to be extrapolated to calculate residuals for two sites: Brush stations 2 and 3. All other sites were at distances from the divide that were within the upper and lower extremes of distances for station 1 (Figure 5a,b,c).

Georegion Differences. Figure 5a,b,c differentiates data from the Interior versus Coast Range georegions. A separate statistical analysis of streams stratified by georegion was not appropriate due to small sample sizes. Furthermore, there were more sites in the Coast Range than in the Interior which were closer to the headwaters. Where distances were similar, temperatures observed on Coast Range sites were generally cooler than those of the Interior.

Effect of RMA's and HWC's on 7-day maximum, minimum and average. A repeated measures ANOVA on the residuals revealed no significant difference between stations. In addition there was no significant difference between performances of HWC's and RMA's. This result was consistent for 7-day maximum, minimum and average. These results indicate that when the data were adjusted to account for the effect of distance from divide, there was no significant effect of harvest units on stream temperature. This would indicate that RMA's and HWC's are effective at maintaining stream temperature through harvest units.

A repeated measures ANOVA of the raw temperature data showed a significant difference between stations in 7-day maximum, minimum and average. Stream temperatures were significantly higher at station 2 (immediately downstream from the harvest unit) than at station 1 (upstream from the harvest unit). Likewise, stream temperatures were significantly higher at station 3 (500 to 1000 feet downstream of the harvest unit) than at station 1 (p-value < 0.01 and 0.001). There was no significant difference between stations 2 and 3 for any of the temperature parameters.

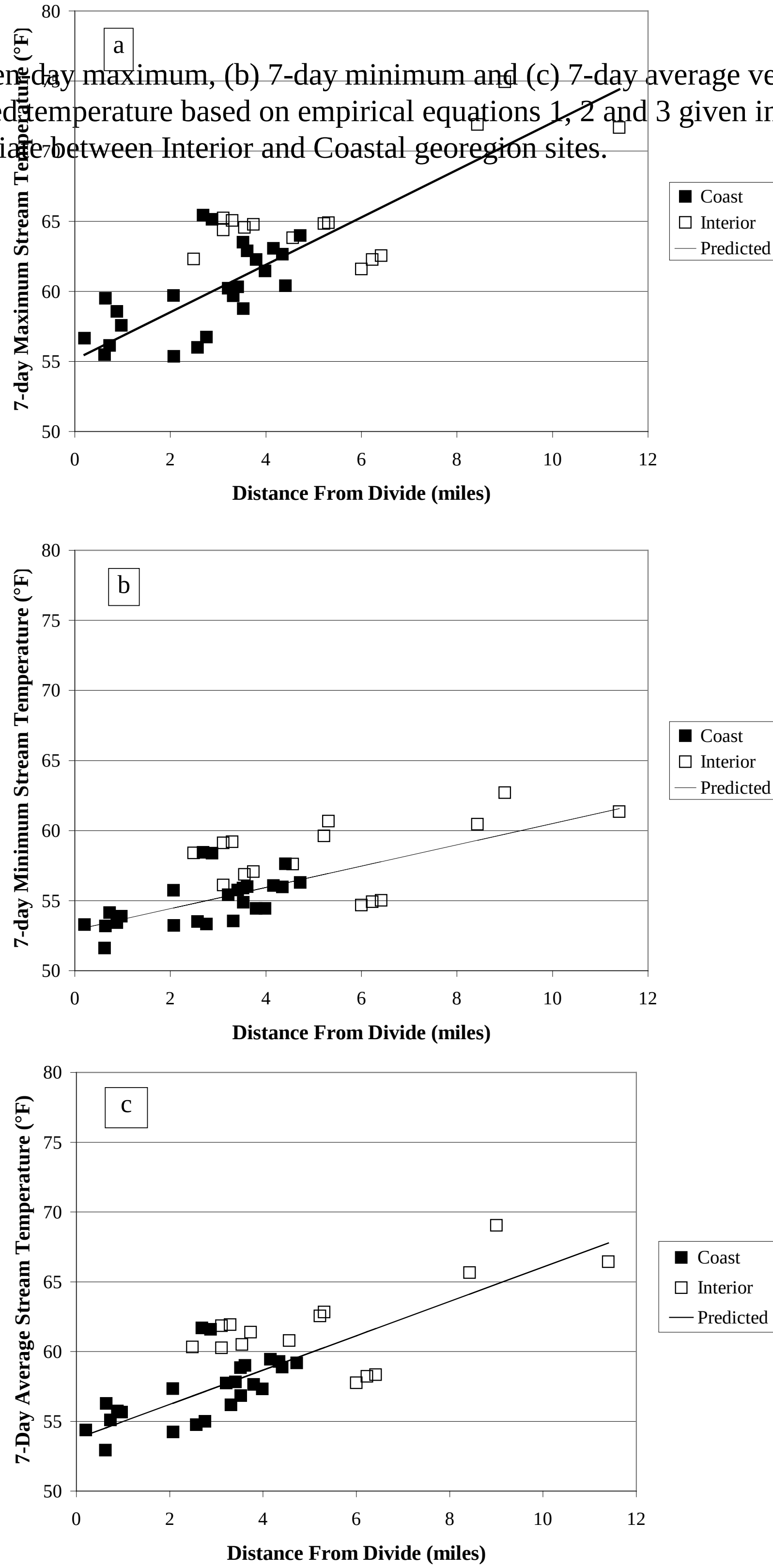

Figure 5. (a) Seven-day maximum, (b) 7-day minimum and (c) 7-day average versus distance. Predicted temperature based on empirical equations 1, 2 and 3 given in text. Symbols differentiate between Interior and Coastal georegion sites.

The ANOVA results from the raw data indicated stream temperatures increased through harvest units and remained elevated 1000 feet downstream. Specifically, 7-day maximum increased by an average of 2.1°F through RMA's and 2.5°F through HWC's. Increases were not countered by decreases downstream. As a result, temperatures remain significantly higher, 2.2°F for RMA reaches and 1.5°F for HWC reaches, 1000 ft downstream of harvest units than above harvest units (Figure 6). There was no significant difference between RMA's and HWC's.

Results from these two analyses are contradictory. Results from an ANOVA of the residuals indicated no statistical effect of harvest units on stream temperature. Stream temperatures increase naturally in a downstream direction. When the data were analyzed in an attempt to account for this (using residuals), the increases in stream temperature observed through the harvest units were sufficiently small that they were not statistically significant. The raw data results indicate the opposite. Stream temperatures were significantly higher downstream of harvest units than upstream of harvest units. Furthermore, increases observed through harvest units were not countered by cooling in the downstream reach.

Contradictory results may be a manifestation of a relatively small sample size and high variability within the data. Modest regression relationships (r^2 = 0.41, 0.35, 0.55) from empirical equations 1, 2 and 3 result in a lack of precision in predicting pre-harvest stream temperature. Thus the residual analysis may lead to erroneously accepting the null hypothesis that there is no significant effect of harvesting on stream temperature.

Both analyses indicate no statistical difference between RMA's and HWC's. As described previously, some of the HWC's were intentionally designed to reduce southern exposure and resulted in smaller increases in 7-day maximums than conventional HWC's. The above analyses were also repeated without these streams (Cascade, Mill and Sheele) to ensure that results were not affected by this differential treatment. Results of these analyses were consistent with those described above.

Effect of RMA's and HWC's on Diurnal Fluctuation. Diurnal fluctuation is the change in stream temperature occurring in a 24-hour period at one station (Daily maximum - Daily minimum). Diurnal fluctuation was averaged for each station for July 31 - August 6 and analyzed using a repeated measures ANOVA.

There was no significant difference in diurnal fluctuation between stations, suggesting that harvesting does not increase diurnal fluctuation. However, diurnal fluctuation was significantly different between treatments ($p\text{-value} < 0.05$). Diurnal fluctuation was higher downstream of HWC's than it was downstream of RMA's, 7.5 and 4.7°F respectively. Diurnal fluctuation associated with intact riparian areas was 5.8° F (Figure 7). Higher diurnal fluctuation with HWC's indicates that overall energy loading may be greater for HWC's than RMA's.

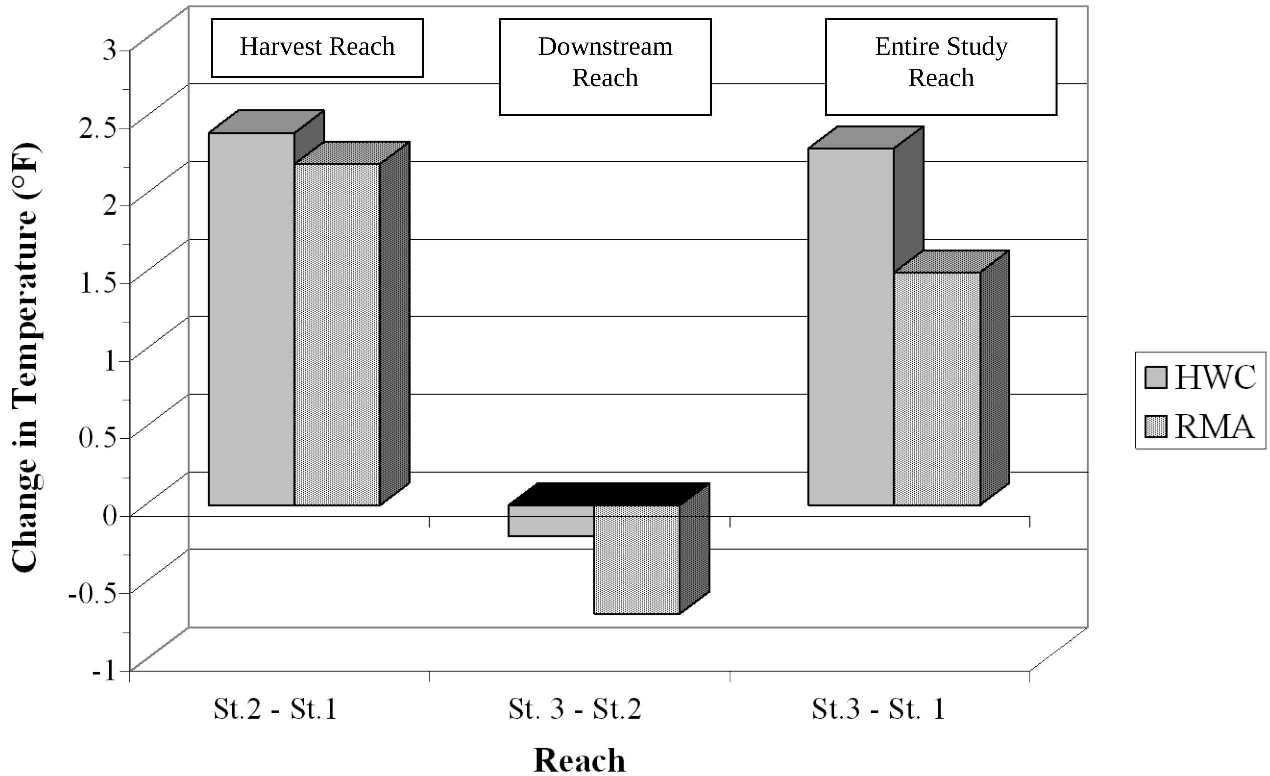

Figure 6. Change in 7-day maximum for harvest, downstream and study reaches

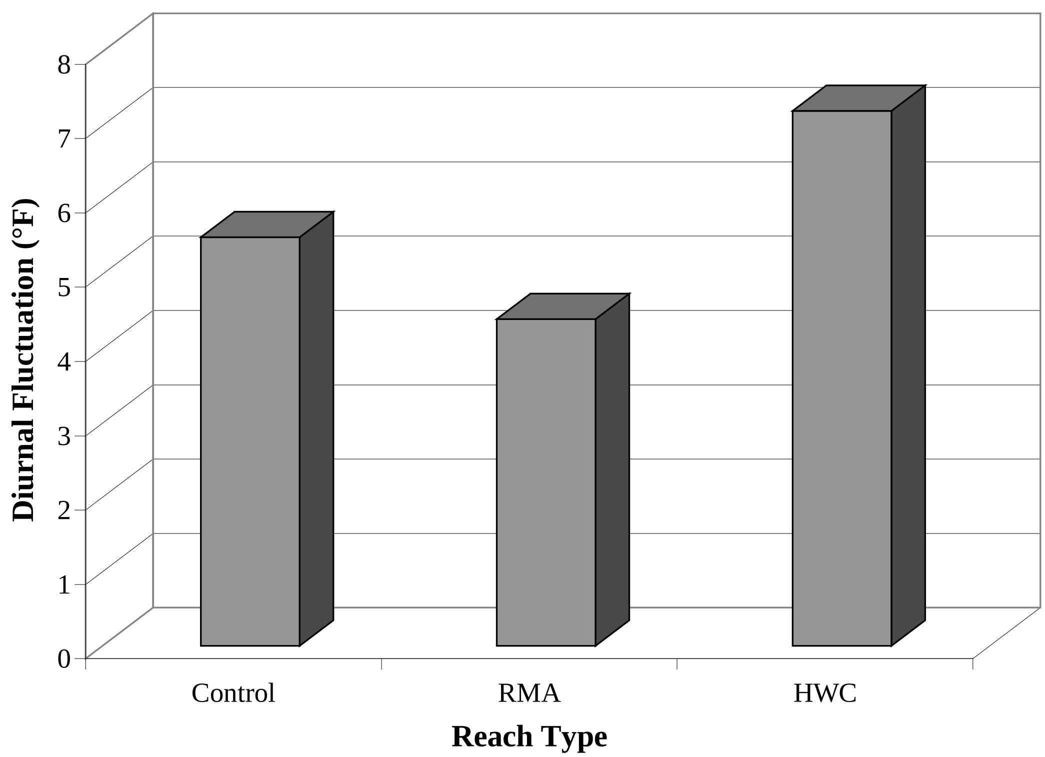

Figure 7. Diurnal fluctuation for control, RMA and HWC reaches.

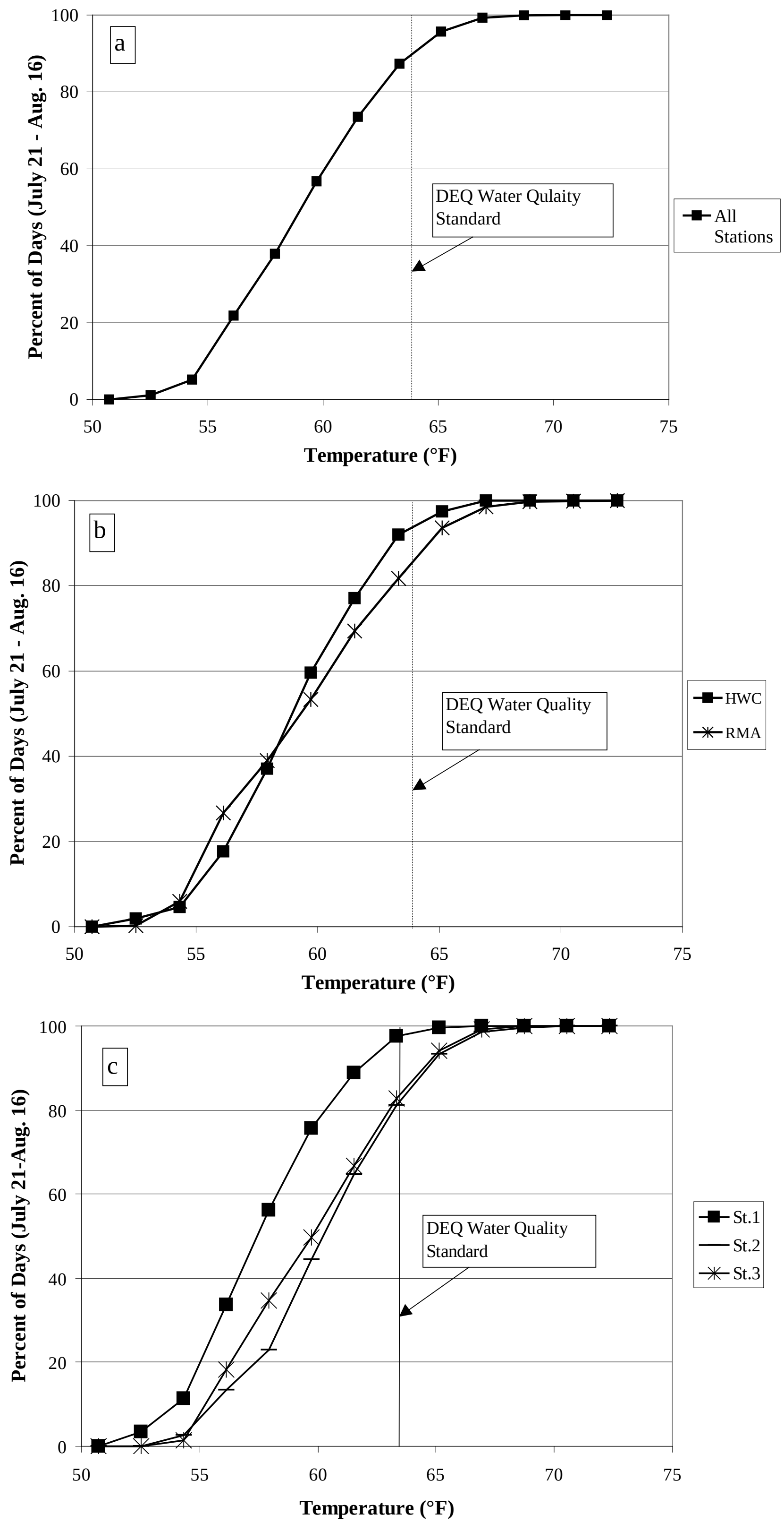

Figure 8. Cumulative frequency of 7-day maximum versus stream temperature for (a) all streams and all stations (b) RMA's versus HWC's and (c) stations 1,2 and 3.

Distribution Tests and Water Quality Standards

DEQ standards for water quality were used to assess the frequency effects of stream temperature on fish habitat. A temperature of 55°F is considered preferred habitat for juvenile cutthroat and coho salmon. A 7-day maximum of 64°F is linked with the upper limit of preferred habitat for many salmonid species and is the DEQ standard for salmonid habitat.

The number of days 7-day maximum was greater than or equal to 55°F, less than or equal to 64°F, or greater than 64°F was analyzed from July 21 through August 16. This was the period of the summer in which the highest stream temperatures were observed. Using this period represents the worst case scenario.

Frequency distributions were compared for all stations, between HWC's versus RMA's and upstream and downstream of harvest units (between stations) (Figures 8a,b,c). Eleven of the thirteen streams were analyzed in this way. Brush and Cascade were not included in this analysis due to missing data.

For all streams, stations, and harvest types stream temperature was less than or equal to 64°F 90.6% of the time. Of that time, 7-day maximum was less than or equal to 55°F 11.4% of the time. There was no difference in overall distributions between HWC's and RMA's (Figure 8a and b).

When distributions were compared between stations, there was greater frequency of temperatures exceeding 64°F downstream of harvest units (Station 2 and 3) then above harvest units (Figure 8c). This trend was the same for HWC's as it was for RMA's.

Only three out of eleven streams never exceeded the water quality standard. Three streams exceeded the DEQ standard less than 3%, and two streams exceeded it between 7 and 9% of the time. Three other streams exceeded it between 20 and 38% of the time. The latter three are all located in the Interior georegion. Two streams (Beaver and Douglas Creeks) were harvested with RMA's and one stream (January Creek) was harvested with a HWC. Change in 7-day maximum for January Creek was 5.7°F, the highest observed out of all 13 streams. Changes on Beaver and Douglas were 1.0°F and 2.9°F respectively. Stream temperatures were initially high upon entering the harvest units on Beaver and Douglas Creeks, 63.8°F and 62.3°F respectively. Therefore it took a relatively small increase to exceed the standard. Temperatures were elevated on January Creek from 59.7°F to 65.4°F.

Frequency distributions suggest stream temperature exceeded water quality standards more commonly downstream of harvest units than upstream of harvest units. When streams were assessed individually, it is apparent that the majority of the streams (eight of eleven) exceeded the standard less than 10% of the time. However, of the eleven streams analyzed only three of them never exceeded the standard. Standards were exceeded for the longest period of time (20- 38%) on three streams. These sites were all in the Interior georegion.

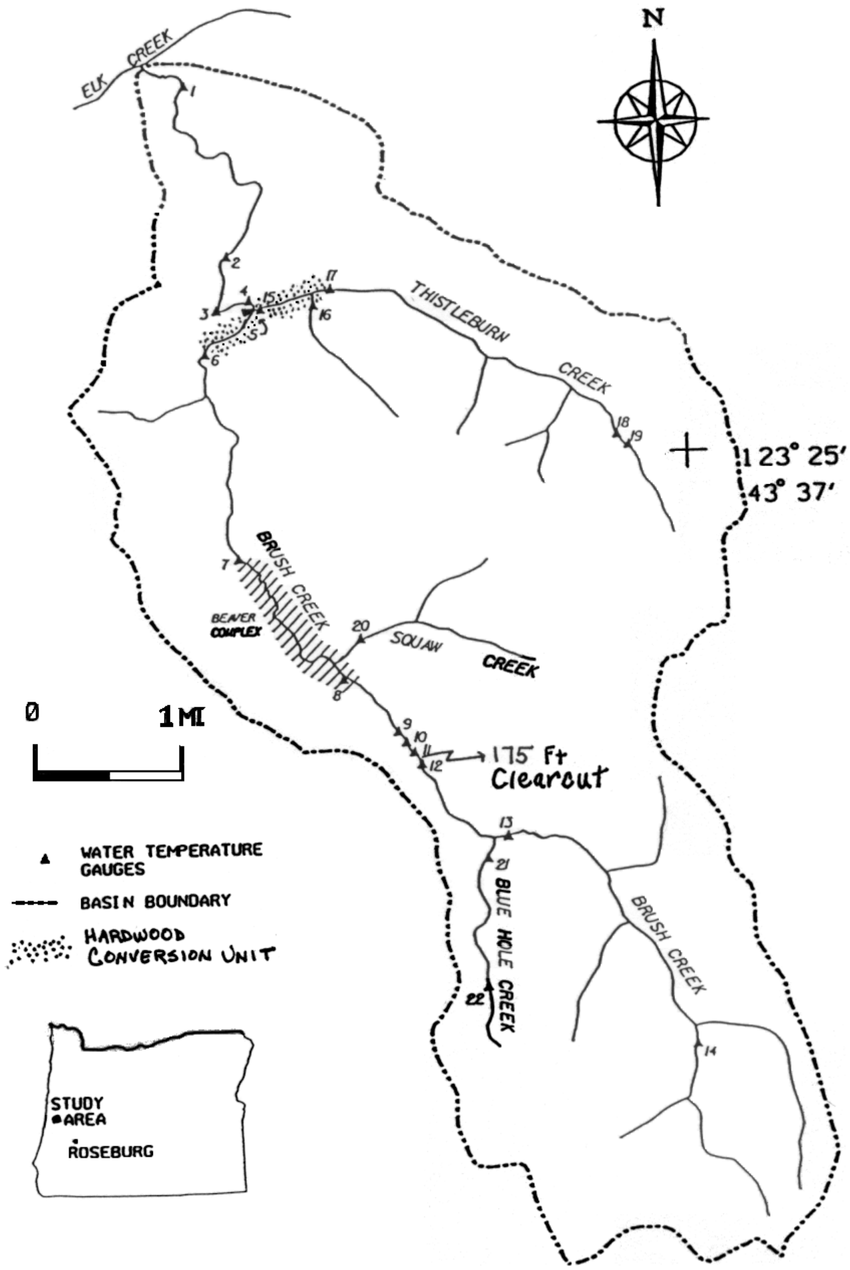

Figure 9. Brush Creek harvest units and locations of air and stream monitoring stations.

Brush Creek

Brush Creek

Brush Creek is a tributary to the Umpqua River Basin. It is located in the interior georegion and has one major tributary, Thistleburn (Figure 9). The basin is 13,000 acres in size and provides significant potential for coho, steelhead and sea-run cutthroat production. The watershed is a focus of a locally organized and managed watershed group emphasizing sound forest management practices tied to the enhancement and monitoring of fish habitat.

Thistleburn and Brush Creek both were harvested with HWC prescriptions in Fall 1994. The Brush Creek HWC is located 8.5 miles from the divide. The Thistleburn HWC is located at the confluence of Thistleburn and Brush Creeks. Higher up on mainstem Brush Creek, approximately 5 miles from the divide, a 175 foot unbuffered clearcut was harvested in spring of 1994. This unit was harvested under a site-specific prescription and prevented the need for new road construction and stream crossings. There is also a large beaver complex, consisting of a number of large beaver dams, between the two harvest units.

In 1994, 22 water temperature and 3 air temperature gages were installed throughout the basin. The purpose of the temperature project is to test the effectiveness of the HWC and the 175 foot site-specific prescription in maintaining stream temperature. The inherent basin trend is also being documented.

The HWC was harvested in fall of 1994, therefore the 1994 stream temperature data represent a pre-harvest period. Stream temperature data from 1995 and 1996 represent post-harvest years for the HWC. However, all data for the 175 foot clearcut are post-harvest data since the unit had already been harvested in 1994. Missing data on Thistleburn precludes it from this analysis.

Air Temperature. Air temperature was monitored in the headwaters area, 1.5, 5 and 6 miles downstream from the divide. A repeated measures ANOVA was performed to test for differences between years. There was no significant difference in 7-day maximum, minimum or mean air temperature between 1994, 1995 and 1996.

Figure 10 shows the 7-day maximum for 1994, 1995 and 1996. Stream temperature tends to increase in a downstream direction, a trend consistent with results presented earlier from the correlation analysis. Changes in temperature associated with the 175 foot clearcut and the HWC initially raise stream temperature above the basin trend.

Changes in temperature associated with the 175 foot clearcut. Temperature increases observed through the 175 foot clearcut ranged from 1.8 (1995) to 6.9°F (1994). These increases were countered by decreases within 1000 ft downstream of 2.3 (1995) and 6.3°F (1994). Previous repeated measures ANOVA indicated temperature increases through

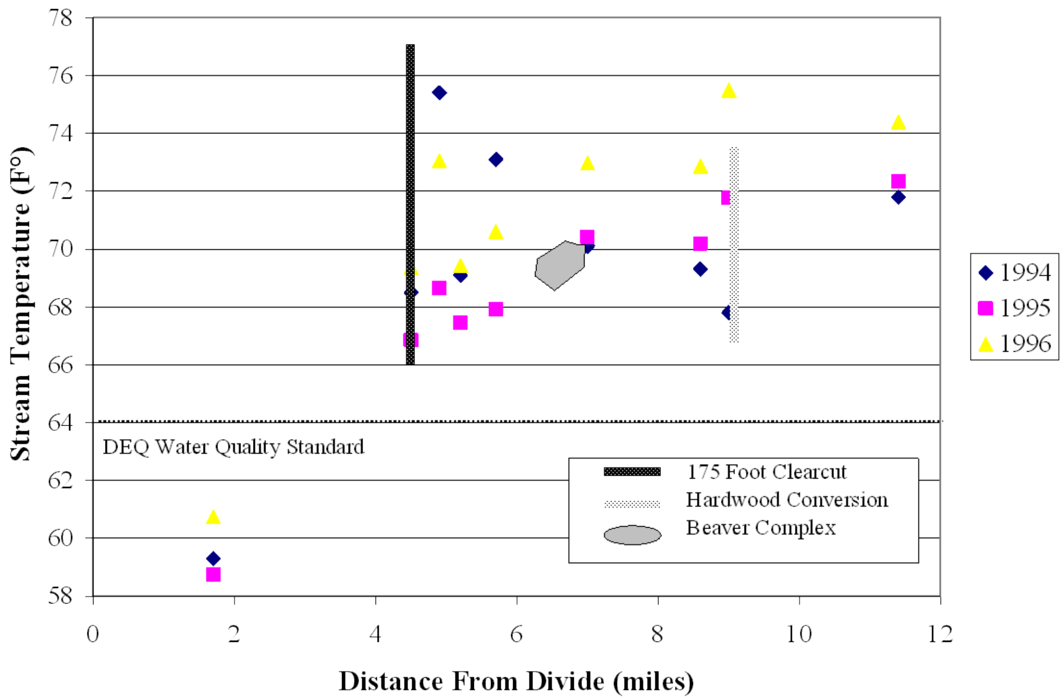

Figure 10. Seven-day maximum versus distance from divide for July 1994, 1995 and 1996.

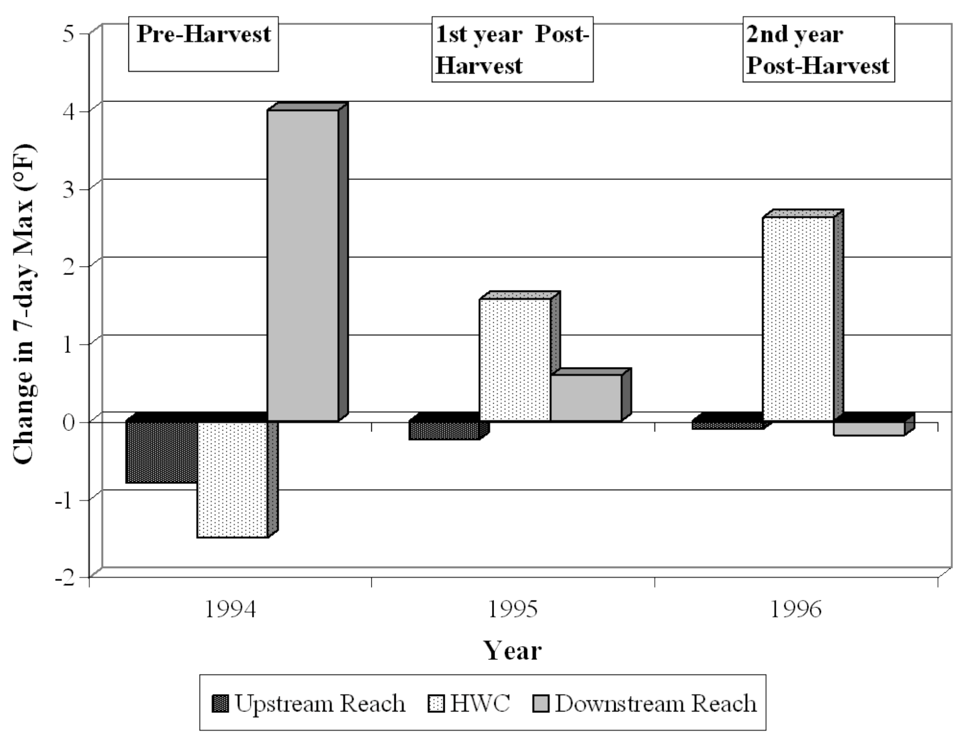

Figure 11. Change in 7-day maximum in the upstream, HWC and downstream reaches on Brush Creek for 1994 (pre-harvest), 1995 and 1996 (1st and 2nd year post-harvest).

harvest units were not countered by downstream decreases. The 175 foot unit was not included in that analysis due to the nature of the unit. Past ODF monitoring (Robison et al. 1995) found that greater increases through harvest units were countered by greater downstream rate of cooling. Results from the 175 foot clearcut are consistent with this finding. Significant groundwater input through the downstream reach is a plausible mechanism that would contribute to such rapid cooling.

Differences between years for the HWC. A repeated measures ANOVA was performed on the 7-day maximum, minimum and average of stream temperature for the HWC. For the HWC, 7-day maximum, minimum and average temperatures were higher in post-harvest years than pre-harvest years (p-value < 0.10) (Figure 11). Increases in 7-day maximum through the HWC ranged from 1.6 to 2.6°F in post-harvest years. A decrease of 1.5°F was observed in the same reach in the pre-harvest year.

Stream temperature increases were not countered by decreases at the station 2.4 miles downstream of the HWC. In post-harvest years, stream temperatures increased by 0.59°F (1995) and decreased by 0.18°F (1996) through the downstream reach. Stream temperature increased in this same reach by 4.0°F during the pre-harvest year. It may be that stream heating has been propagated upstream due to the HWC. Therefore increases which took place farther downstream in pre-harvest years (4°F 2.4 miles downstream of HWC) were occurring higher up in the system due to the HWC (1.6 to 2.6°F through HWC).

The Brush Creek study indicates that stream temperatures increased through the HWC in post-harvest years and increases were not countered by downstream cooling. Elevated stream temperature may have been propagated upstream in post-harvest years due to the effects of the HWC. This trend was not observed higher in the basin where the 175 foot clearcut was located. Stream temperature increased through the 175 foot clearcut, however increases were countered by downstream cooling.

Summary and Conclusion

The purpose of this study was to test the effectiveness of RMA's and HWC's in maintaining stream temperature and meeting water quality standards. Relationships between stream temperature and physical and riparian characteristics were also investigated. Results indicate stream temperatures increased through harvest units but that those increases may be within the expected downstream trends.

Effectiveness of RMA's and HWC's varied between streams. The average increase in 7-day maximum was 2.1°F through RMA's and 2.5°F through HWC's. Observed increases were as low 0.63 and 0.07°F and as high as 3.3 and 5.7°F for RMA's and HWC's, respectively. Statistical analyses revealed that 7-day maximum, minimum and average stream temperatures were significantly higher downstream of harvest units than upstream of harvest units. In addition, increases were not countered by cooling in downstream reaches. These findings were supported by an analysis which revealed that 7-day maximum temperatures exceeded the water quality standard more frequently downstream of harvest units than upstream of harvest units. Finally when pre- and post-harvest data were compared on Brush Creek (only stream with pre-harvest data), changes through the HWC were higher in post-harvest years than pre-harvest years and higher than the overall basin trend. Results indicate that Brush Creek temperatures have not returned to pre-harvest conditions after two post-harvest years.

While this is compelling evidence to indicate that the rules are not uniformly effective at maintaining stream temperature, it is critical to note that this study lacks sufficient pre-harvest data. Stream temperatures inherently increase in a downstream direction. The rate of change varies with distance from divide. Greater rates of change are observed closer to the headwaters than farther down in the basin. The relationship most likely varies between basins as well. The Brush Creek project and correlation analysis of distance and temperature provide data to support this hypothesis.

When the data were adjusted in an attempt to account for the relationship between distance and temperature, observed changes in stream temperature were not statistically significant. This result indicates that inherent increases in stream temperature account, in part, for changes in temperature observed through harvest units. How much of the observed increase is attributable to an inherent increase and how much is attributable to the effects of harvesting has not been adequately answered with this study.

Physical parameters were found to influence stream temperature in ways consistent with previous studies. Characteristics which may make a stream sensitive to unacceptable increases in stream temperature include stream reaches that are: predominately bedrock, low gradient, wide and shallow, at a greater distance from the divide and lower in elevation.

Vegetative manipulation in the harvest units resulted in a wide variety of buffer widths and canopy cover. Average decreases in cover due to harvesting were low. Changes in temperature were not always consistent with change in riparian cover. This may have been due in part to high variability in canopy cover measures associated with the harvest units. There was some indication that special-prescription HWC's designed to minimize solar exposure by leaving more trees on the south side, may have been more effective at maintaining stream temperature than the remaining HWC's. There was also indication that as buffer widths decreased, 7-day maximum and average stream temperature increased.

There was no statistical difference between the performance of RMA's and HWC's in terms of increases in 7-day maximum, minimum and average. However, diurnal fluctuation associated with HWC's were higher than diurnal fluctuations associated with RMA's.

Results of this study suggest RMA's and HWC's do not always protect streams from increases in temperature. Only three of eleven streams never exceeded the DEQ water quality standard. However, the strength of this conclusion is tempered by the inability to adequately account for increases in stream temperature which naturally occur in a downstream direction. Given the limitations of the study, continued monitoring and research is needed to better understand background variability and the effectiveness of the forest practice rules in maintaining stream temperature at a site-specific and basin-level.

Recommendations

1) *Modify monitoring protocol with advice of a Technical Advisory Committee (TAC) to address limitations of the study*.

Future temperature monitoring will be coupled with more accurate measurements of shade, incoming solar radiation and buffer characteristics. In addition, pre- and post-harvest data should be collected for all the parameters. Other considerations for protocol review include monitoring temperature control basins/reaches at distances from divide corresponding to managed reach distances and monitoring managed and unmanaged basins and reaches over the same time frame to reduce both spatial and temporal variability.

2) *Review hardwood conversion and riparian management area rules with the advice of a TAC to explore how basin characteristics or site-specific plans might be used to better ensure that potential site and cumulative effects are minimized***.**

> a) Identify basin characteristics (distance from divide) where increases in temperature might be countered by downstream cooling. On the Brush Creek Basin study, harvest-related increases observed higher in the basin (closer to the divide) were countered by downstream cooling, while harvest-related increases observed lower in the basin were not. This suggests there is a zone in which management-related increases will not be countered by downstream cooling which in turn is a function. This is due in part to naturally occurring increases in temperature which occur in a downstream direction. Current forest practices monitoring on 4 basins in Oregon may give further insight as to how this zone varies regionally and between basins. With more basin-level data, practices could be designed to restrict the use of hardwood conversions to areas in a basin where downstream cooling is more likely to counter potential harvest-related increases.
>
> b) Define individual site and basin characteristics which influence the success of hardwood conversions in maintaining stream temperature so that site-specific prescriptions can be developed in place of the alternative prescription. A risk assessment of the potential for harvest-related increases in temperature and downstream cooling could be incorporated in the site-specific plan.

3) *Further test the relationship between temperature, shade and buffer widths under correct application of the rules.*

Because of the questionable data, shade measurements and buffer widths in this study did not provide adequate opportunity to test and explore relationships between stream temperature, differences in shade over the stream, and differences in riparian buffer width. Forest practices 1996/1997 riparian monitoring project has accurate pre- and post-harvest shade measurements as well as incoming solar radiation. Stream temperature monitoring will be coupled with this study in the 1997 field season to further test the relationships between temperature, shade and buffer widths under correct application of the rules.

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Appendix A

Physical and vegetation characteristics averaged by reach.

Appendix A

Table A1. Average physical and vegetative characteristics for each reach.

Stream	Sta-tion	Reach Type *	Stream size +	Reach Length (Ft)	Cover (%)	Lt.Buffer Width (Ft)	Rt.Buffer Width (Ft)	Elevation (Ft)	Aspect	Gradient (%)
Brush	1	control	L	0	50	95	121	280	N	2
	2	HWC	L	3018	56	18	39	280	N	1
	3	downstream	L	12677	57	121	66	200	N	1
Beaver	1	control	L	0	63	131	120	540	E	1
	2	RMA	L	3477	49	61	89	540	E	1
	3	downstream	L	492	60	131	75	540	E	1
Cas.Brush	1	control	M	0	65	.	.	800	W	2
	2	HWC	M	2329	58	.	.	680	W	4
	3	downstream	M	492	63	131	131	680	W	2
	4	downstream	M	984	63	131	131	680	W	2
Coleman	1	control	L	0	65	131	131	900	NE	.
	2	HWC	L	3346	62	64	51	880	NE	1
	3	downstream	L	492	51	118	108	880	NE	1
	4	downstream	L	984	51	118	108	880	NE	1
Douglas	1	control	M	0	30	98	98	720	SW	1
	2	RMA	M	3280	39	40	119	720	SW	1
	3	downstream	M	492	49	94	131	680	SW	1
	4	downstream	M	984	43	66	131	680	SW	1
Eagle	1	control	M	0	56	131	105	880	W	3
	2	RMA	M	2624	64	69	131	800	W	2
	3	downstream	M	492	60	131	131	800	W	3
	4	downstream	M	984	60	131	131	800	W	.
January	1	control	M	0	65	131	131	700	SE	2
	2	HWC	M	3280	55	44	126	600	SE	2
	3	downstream	M	492	58	49	131	560	SE	.
	4	downstream	M	984	45	75	117	560	SE	3
Litl. Fall	1	control	U	0	63	131	131	1560	SW	1
	2	HWC	U	1148	53	41	131	1560	SW	2
	3	downstream	U	492	63	131	131	1520	SW	1
	4	downstream	U	984	55	131	131	1520	SW	2
Mill	1	control	L	0	58	118	118	280	W	1
	2	HWC	L	5248	53	85	82	240	W	1
	3	downstream	L	1640	45	117	95	240	W	1
Sheele	1	control	M	0	61	112	121	840	N	2
	2	HWC	M	2558	61	62	31	760	N	2
	3	downstream	M	492	57	115	107	760	N	4
	4	downstream	M	984	28	66	98	760	N	2
Sheythe	1	control	M	0	61	122	118	560	SE	3
	2	RMA	M	1607	60	67	128	480	SE	1
	3	downstream	M	984	65	131	119	440	SE	1
Talbot	1	control	S	0	63	131	131	280	NW	4
	2	RMA	S	2296	45	23	131	200	NW	6
	3	downstream	S	492	55	104	131	200	NW	3
Wst.Agency	1	control	S	0	.	.	.	1760	S	5
	2	HWC	S	1345	47	41	41	1560	S	3
	3	downstream	S	984	67	111	127	1340	S	3

* Control = the reach upstream of the harvest unit, usually > 1000 feet of intact riparian condition.
HWC = Harvest unit with hardwood converion, RMA = harvet unit with riparian management area
Downstream = the reach downstream of the harvest unit with intact riparian areas.

\+ Stream size as defined in the Oregon Forest Practice rules. L = large, M = Medium, and S = small

Table A1 (continued). Average physical and vegetative characteristics for each reach.

Stream	Sta-tion	Reach Type *	Max Depth (Ft)	Wetted Width (Ft)	Bankful Width (Ft)	Lt.Bank Height (Ft)	Rt.Bank Height (Ft)	Fines (%)	Gravel (%)	Cobble (%)	Bolder (%)	Bedrock (%)
Brush	1	control	1.06	19.89	30.12	4.06	3.41	10	11	8	4	67
	2	HWC	0.59	24.90	40.13	4.89	5.90	8	6	10	0	76
	3	downstream	0.82	21.56	31.79	4.50	5.58	8	15	22	6	49
Beaver	1	control	0.54	11.64	28.31	5.97	6.26	30	51	2	0	18
	2	RMA	1.21	14.76	21.77	7.48	7.04	63	33	0	0	5
	3	downstream	0.80	15.50	24.27	5.92	6.97	31	46	0	0	23
Cas.Brush	1	control	0.71	13.25	21.81	2.28	2.83	41	15	29	12	2
	2	HWC	0.65	13.87	22.69	2.72	4.64	18	21	21	38	2
	3	downstream	0.57	10.17	20.62	4.20	3.77	25	17	9	44	5
	4	downstream	0.57	10.17	20.62	4.20	3.77	25	17	9	44	5
Coleman	1	control	0.47	9.43	26.32	5.41	4.76	8	13	40	40	0
	2	HWC	0.54	12.41	23.62	3.83	4.24	17	19	51	13	0
	3	downstream	0.63	12.14	28.14	3.84	4.14	8	15	71	0	6
	4	downstream	0.63	12.14	28.14	3.84	4.14	8	15	71	0	6
Douglas	1	control	0.89	5.00	9.84	5.33	4.92	38	0	50	0	13
	2	RMA	1.84	19.23	30.27	7.54	5.81	84	13	0	0	4
	3	downstream	1.48	10.31	22.26	3.87	6.33	89	4	0	0	7
	4	downstream	1.56	13.12	16.40	4.92	3.69	100	0	0	0	0
Eagle	1	control	0.76	9.38	19.68	4.10	4.03	22	32	19	9	18
	2	RMA	0.35	7.63	29.61	2.97	2.59	21	61	3	0	15
	3	downstream	0.81	11.81	23.38	3.02	3.14	21	24	24	6	23
	4	downstream	0.59	10.28	21.10	2.41	4.26	7	17	43	0	33
January	1	control	0.45	8.40	15.65	3.65	3.26	30	20	44	0	6
	2	HWC	0.66	8.88	25.00	2.66	1.83	60	14	26	0	0
	3	downstream	0.38	8.42	15.63	2.30	3.39	41	15	24	0	20
	4	downstream	0.44	5.65	20.52	3.17	2.30	44	28	21	0	7
Litl. Fall	1	control	1.31	25.67	35.83	4.55	6.27	8	8	43	43	0
	2	HWC	0.95	22.17	35.59	2.73	2.93	5	27	44	16	-0
	3	downstream	1.31	25.67	35.83	4.55	6.27	8	8	43	43	0
	4	downstream	1.08	22.83	36.01	4.26	5.48	10	10	32	18	32
Mill	1	control	1.13	10.59	19.88	3.33	3.93	43	19	29	2	0
	2	HWC	0.86	8.57	27.09	3.43	3.64	30	46	22	2	1
	3	downstream	0.00	0.00	36.44	3.28	8.75	32	66	0	0	2
Sheele	1	control	0.61	14.30	26.04	3.54	4.10	31	9	27	0	33
	2	HWC	0.58	14.22	21.20	4.58	3.62	32	22	22	22	2
	3	downstream	0.77	17.88	25.83	6.23	6.15	22	17	20	41	0
	4	downstream	1.00	11.07	20.50	3.20	4.76	32	32	30	6	0
Sheythe	1	control	0.80	8.41	17.29	2.72	2.68	35	18	41	4	3
	2	RMA	0.84	10.50	20.88	4.72	2.38	41	23	35	2	0
	3	downstream	0.52	8.28	22.55	3.28	3.35	36	34	31	0	0
Talbot	1	control	0.02	1.38	5.54	1.75	2.10	100	0	0	0	0
	2	RMA	0.11	1.91	6.05	1.61	1.61	95	4	2	0	0
	3	downstream	0.23	3.94	7.54	2.23	2.23	46	33	2	0	19
Wst.Agency	1	control	0.16	5.71	22.63	1.51	1.51	26	26	47	0	0
	2	HWC	0.62	6.60	17.52	3.09	3.16	13	34	24	16	0
	3	downstream	0.30	5.99	14.35	3.79	4.55	0	27	38	16	19

* Control = the reach upstream of the harvest unit, usually > 1000 feet of intact riparian condition.
HWC = Harvest unit with hardwood converion, RMA = harvet unit with riparian management area
downstream = the reach downstream of the harvest unit with intact riparian areas.

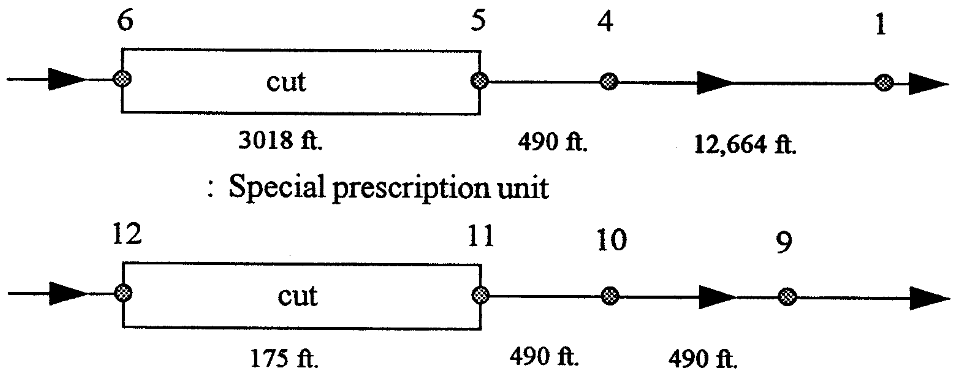
\+ Stream size as defined in the Oregon Forest Practice rules. L = large, M = Medium, and S = small

Appendix B

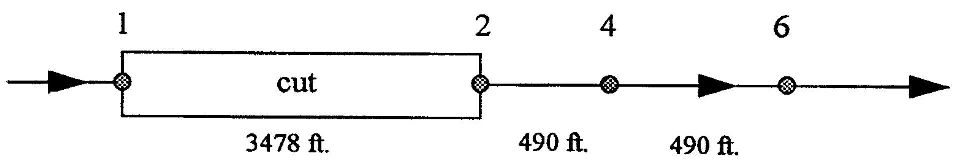
Monitoring schematics for each stream's experimental design.

Appendix B. Schematic of each stream's specific experimental design. Stations are at the top of the diagram and distances between stations are below.

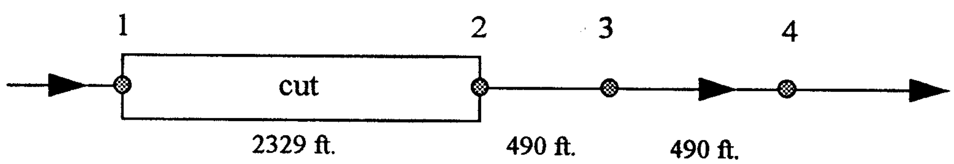
A. Brush Creek: HWC



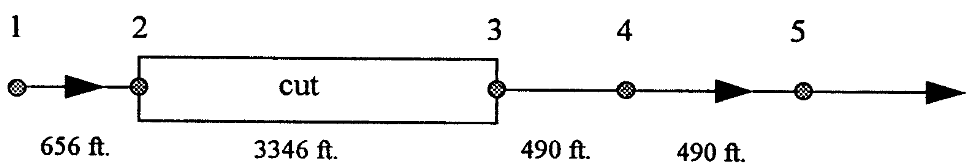
B. Beaver Creek: RMA



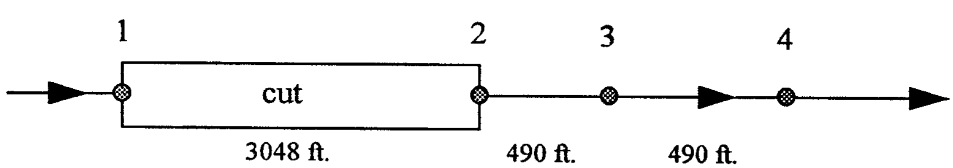
C. Cascade Brush: HWC



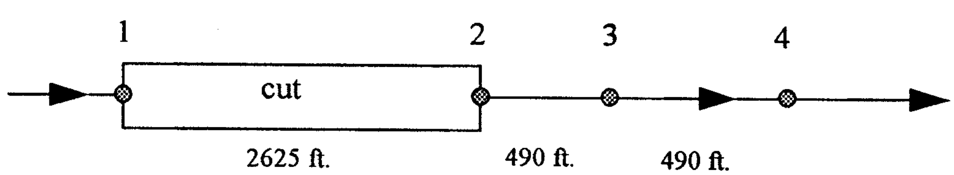
D. Coleman Creek: HWC



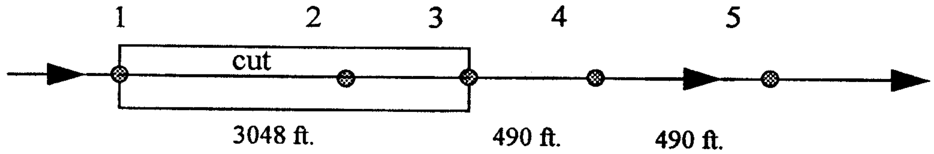
E. Douglas Creek: RMA



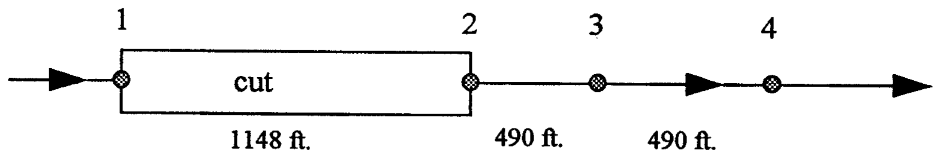
F. Eagle Creek: RMA



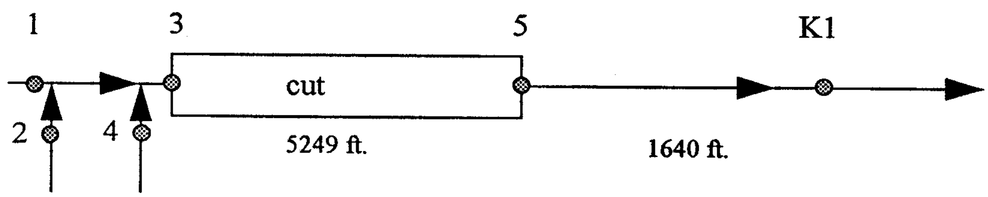
G. January Creek: HWC



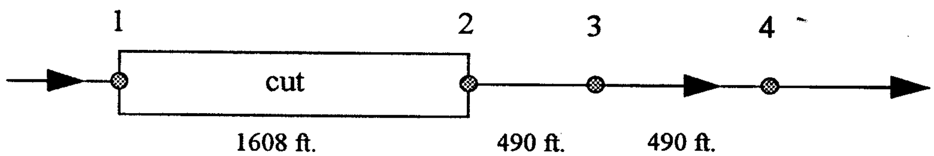
H. Little Fall Creek: HWC



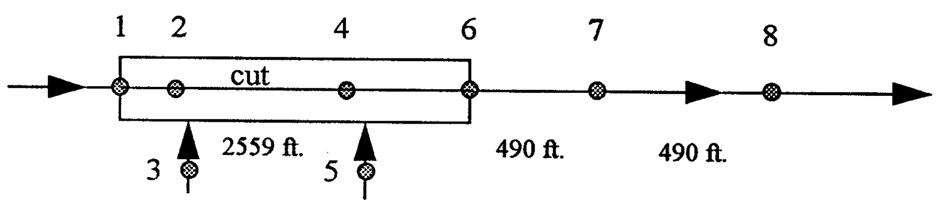
I. Mill Creek: HWC



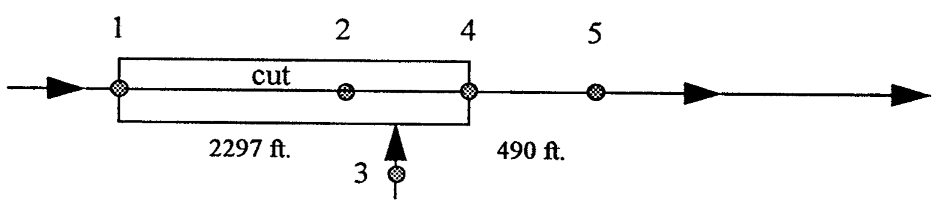
J. Sheythe Creek: RMA



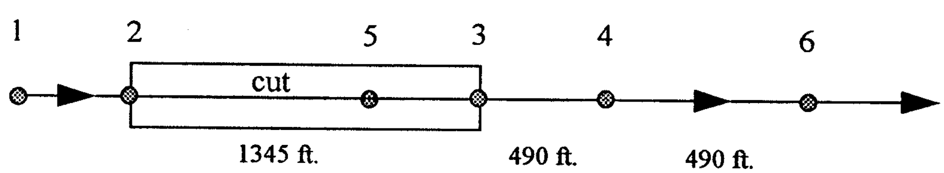
K. Scheele Creek: HWC



L. Talbot Creek: RMA



M. West Agency Creek: HWC



Appendix C

Period of record for water temperature data on each stream and station.

APPENDIX C

BEAL CREEK

Station #	Period of Record
1	7/06-09/02
2	no data
3	07/06-09/02
4	no data

BRUSH & THISTLEBURN

Station #	Period of Record	
1	06/18-09/12	
2	08/14-09/12	
3	06/07-07/11	
4	08/23-09/12	
5	07/13-08/10	
6	06/07-08/10	
7	06/16-09/12	
8	06/16-09/12	
9	06/16-09/12	
10	08/15-09/12	
11	06/16-09/12	
12	06/07-08/10	
13	08/14-09/12	
14	06/07-08/10	
15	no data	
16	06/07-07/11	
17	06/16-08/10	
18	06/07-08/10	
19	no data	
20	06/15-09/12	
21	06/07-09/12	
22	06/07-09/12	
A1	06/13-07/11	
A2	06/13-07/11	07/26-08/13
A3	07/25-08/22	

GRIFFITH CREEK

Station #	Period of Record
1	07/20-08/17
2	no data
3	no data
4	07/20-08/17

JANUARY CREEK

Station #	Period of Record
1	07/15-09/20
2	no data
3	07/15-09/20
4	07/15-09/11
5	07/15-09/11

LITTLE FALL CREEK

Station #	Period of Record
1	07/15-10/07
2	07/15-10/07
3	07/15-10/07
4	07/15-10/07

MILL CREEK

Station #	Period of Record	
1	05/19-09/14	
2	05/19-06/21	08/18-09/14
3	05/19-05/30	06/23-08/16
4	06/23-09/14	
5	06/23-09/14	

BEAVER CREEK

Station #	Period of Record
1	07/18-0911
2	07/18-09/08
3	no data
4	07/18-09/11
5	07/18-09/11
6	08/02-09/11

STARKER BRUSH CREEK

Station #	Period of Record
1	07/04-08/31
2	no data
3	07/04-08/31
4	07/04-08/31
5	07/04-08/31
6	07/04-08/31

CASCADE BRUSH CREEK

Station #	**Period of Record**
1	05/19-07/16 07/21-09/09
2	0519-07/16 07/21-09/09
3	05/19-07/16 07/21-09/09
4	07/05-09/02

SHEELE CREEK

Station #	**Period of Record**
1	05/28-09/10
2	06/29-09/05
3	06/01-09/05
4	06/01-09/05
5	06/01-07/12
6	06/01-09/05
7	07/14-09/02
8	07/14-09/02
A1	06/14-07/12 08/09-09/05

COLMAN CREEK

Station #	Period of Record
1	07/14-09/06
2	07/14-09/06
3	07/14-09/06
4	07/14-09/06
5	07/14-09/06

DOUGLAS CREEK

Station #	Period of Record
1	07/07-09/03
2	07/07-09/03
3	07/07-08/19
4	07/07-09/03

SHEYTHE CREEK

Station #	Period of Record
1	06/30-09/07
2	06/29-10/05
3	06/30-10/11
4	06/30-10/11

EAGLE CREEK

Station #	Period of Record
1	07/01-08/28
2	07/01-08/28
3	07/01-08/28

TALBOT CREEK

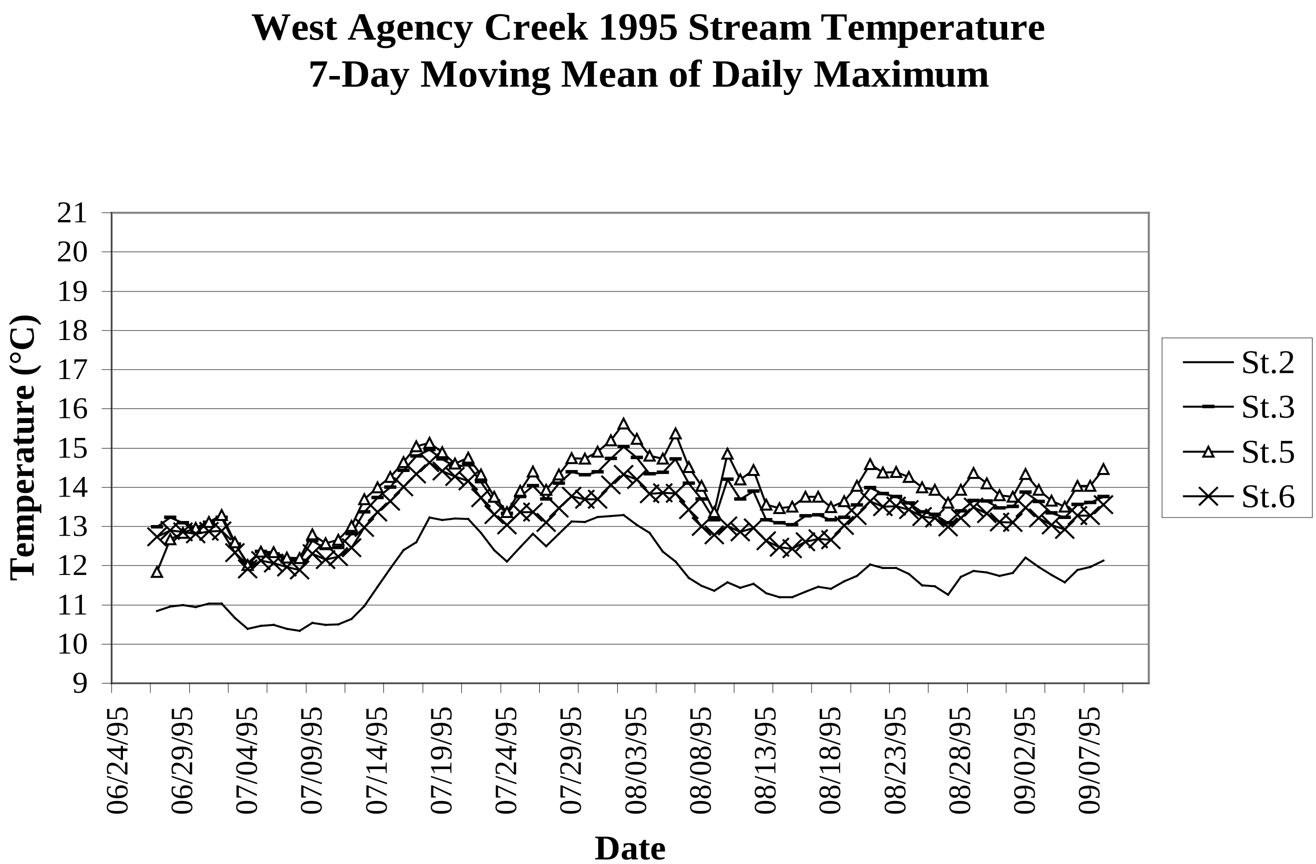
Station #	Period of Record
1	07/11-08/30
2	07/11-08/30
3	07/11-08/30
4	07/11-08/30
5	07/11-08/30

WEST AGENCY CREEK

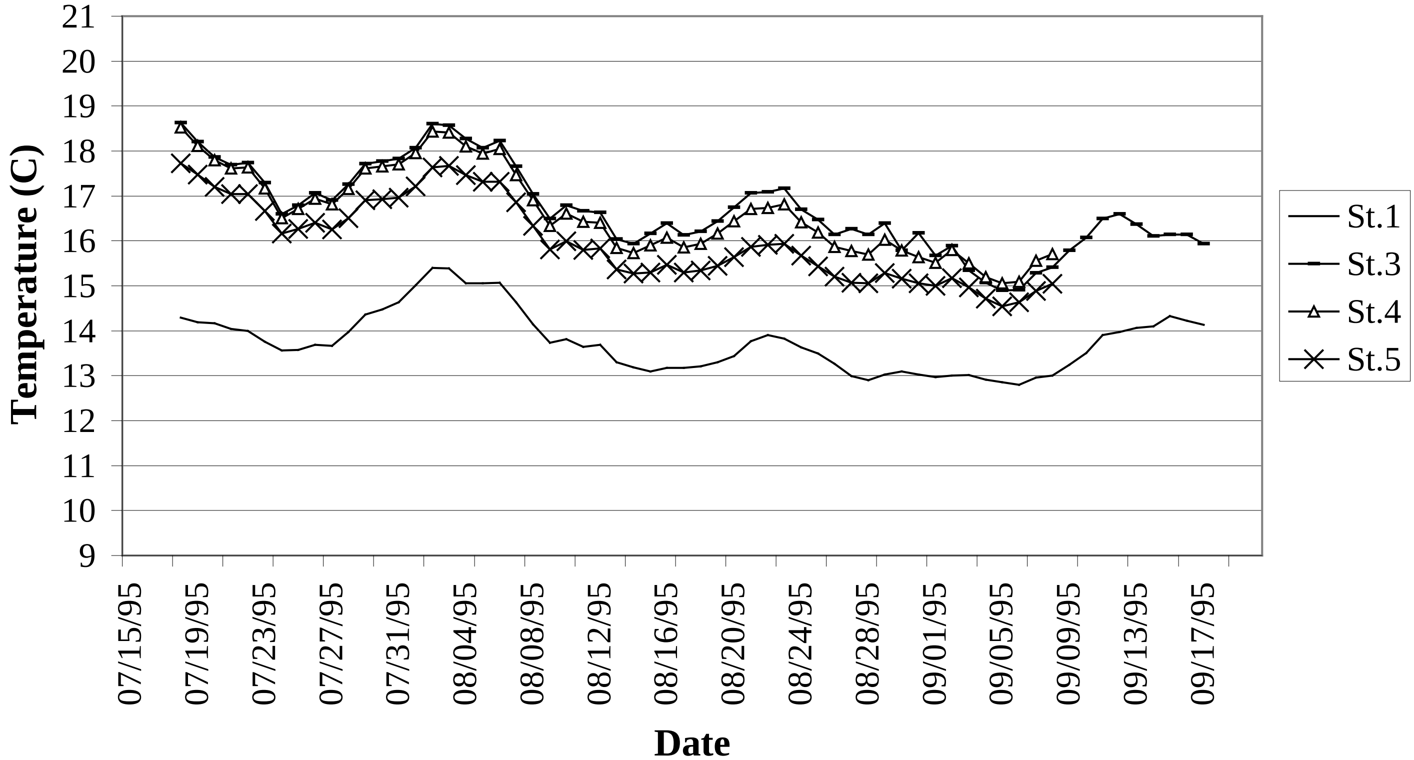
Station #	Period of Record
1	no data
2	0624-09/11
3	06/24-09/11
4	no data
5	06/24-09/11
6	06/24-09/11

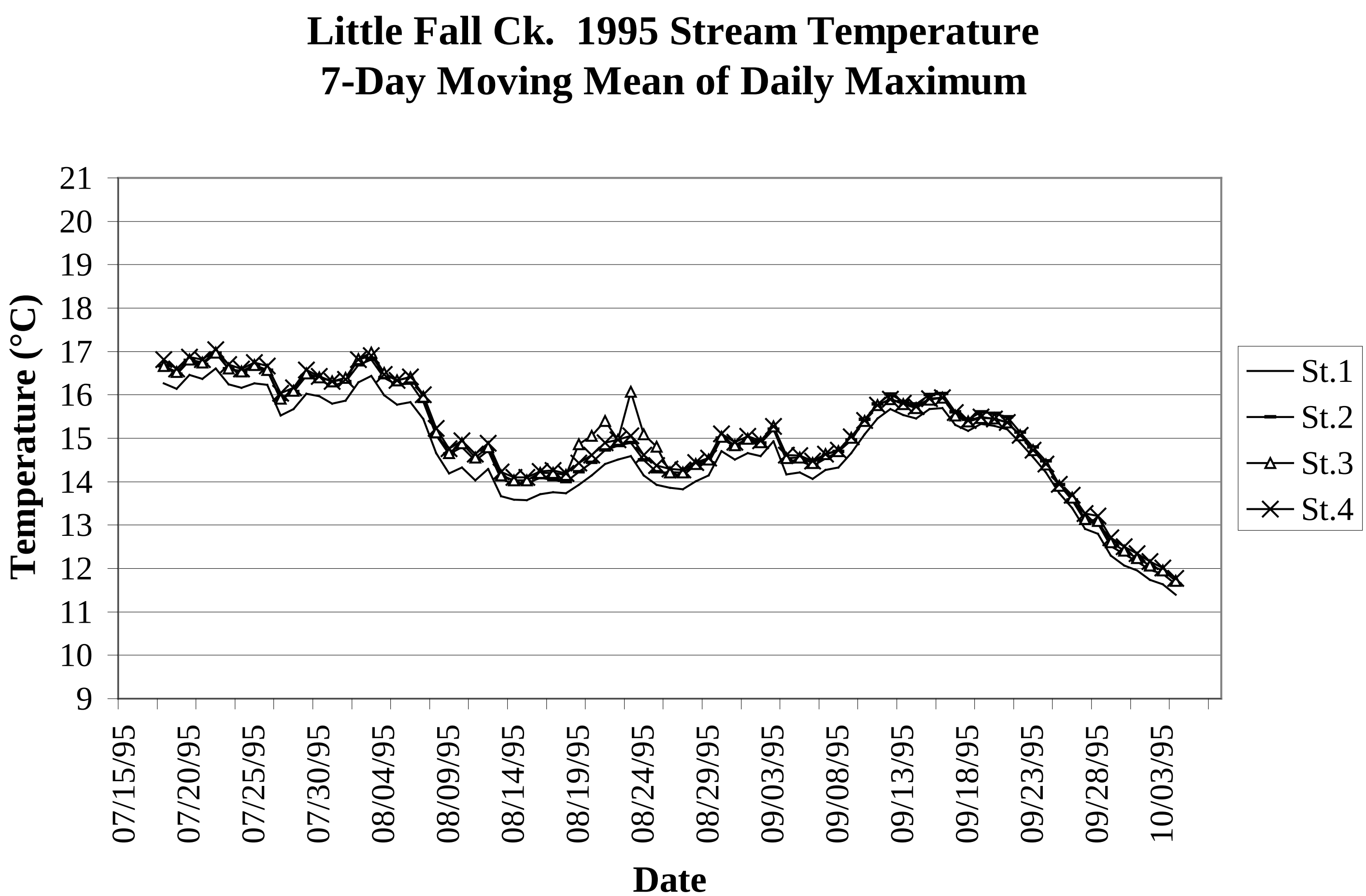
Appendix D

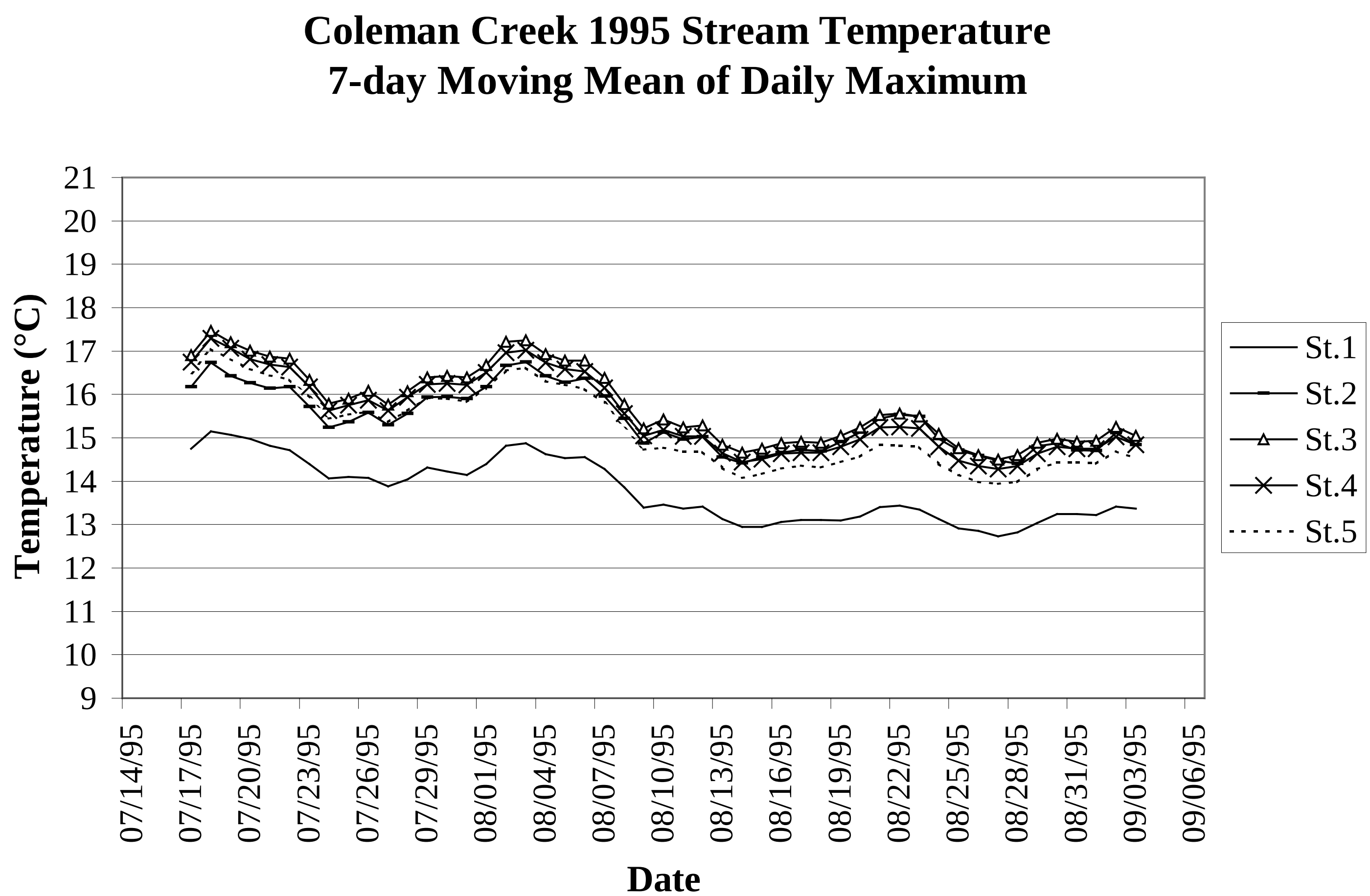
Seven-day moving mean of daily maximum for each stream.
July through August 1995.

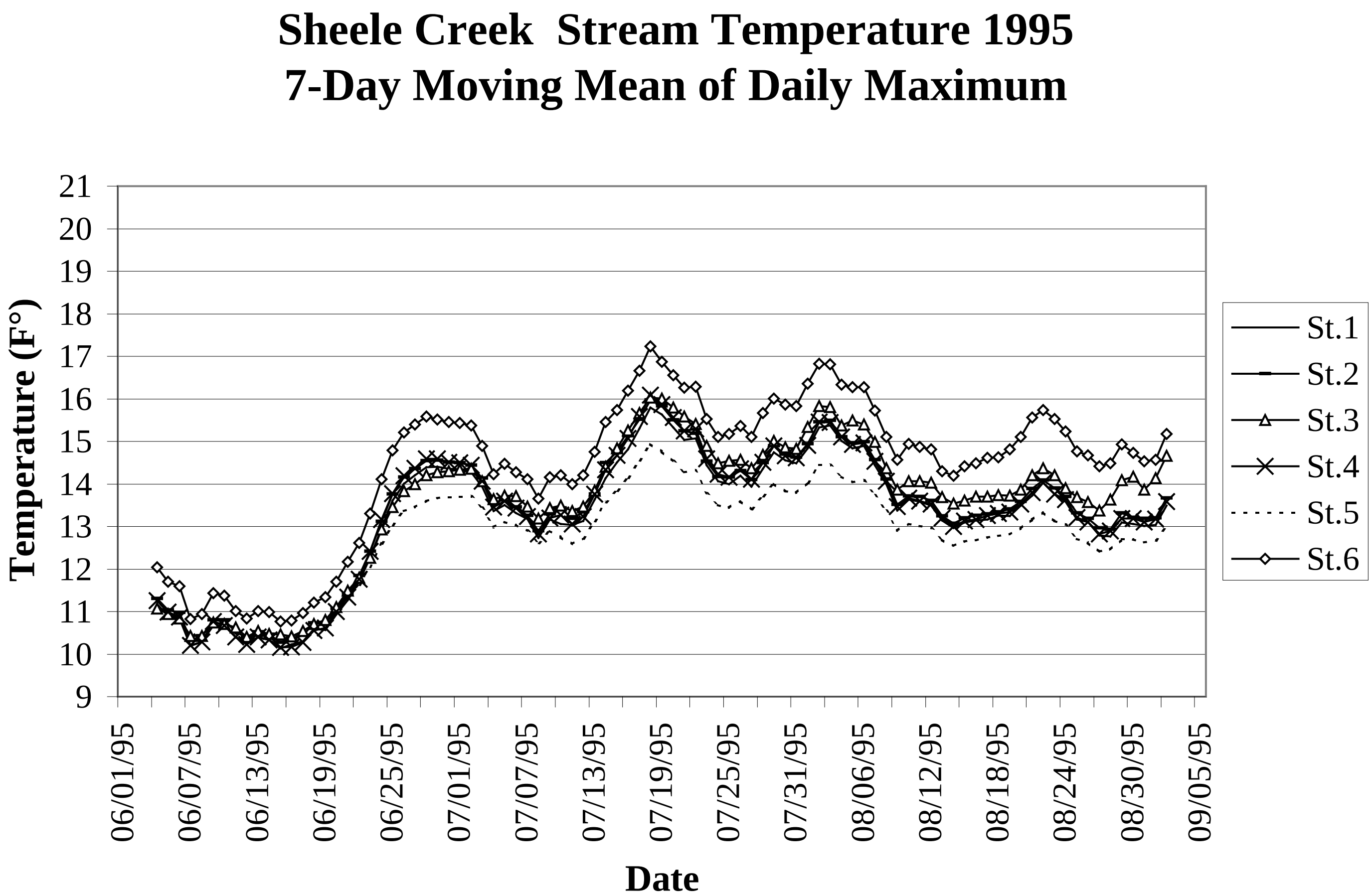

West Agency Creek 1995 Stream Temperature
7-Day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
06/24/95
06/29/95
07/04/95
07/09/95
07/14/95
07/19/95
07/24/95
07/29/95
08/03/95
08/08/95
08/13/95
08/18/95
08/23/95
08/28/95
09/02/95
09/07/95
Date
St.2
St.3
St.5
St.6

January Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum

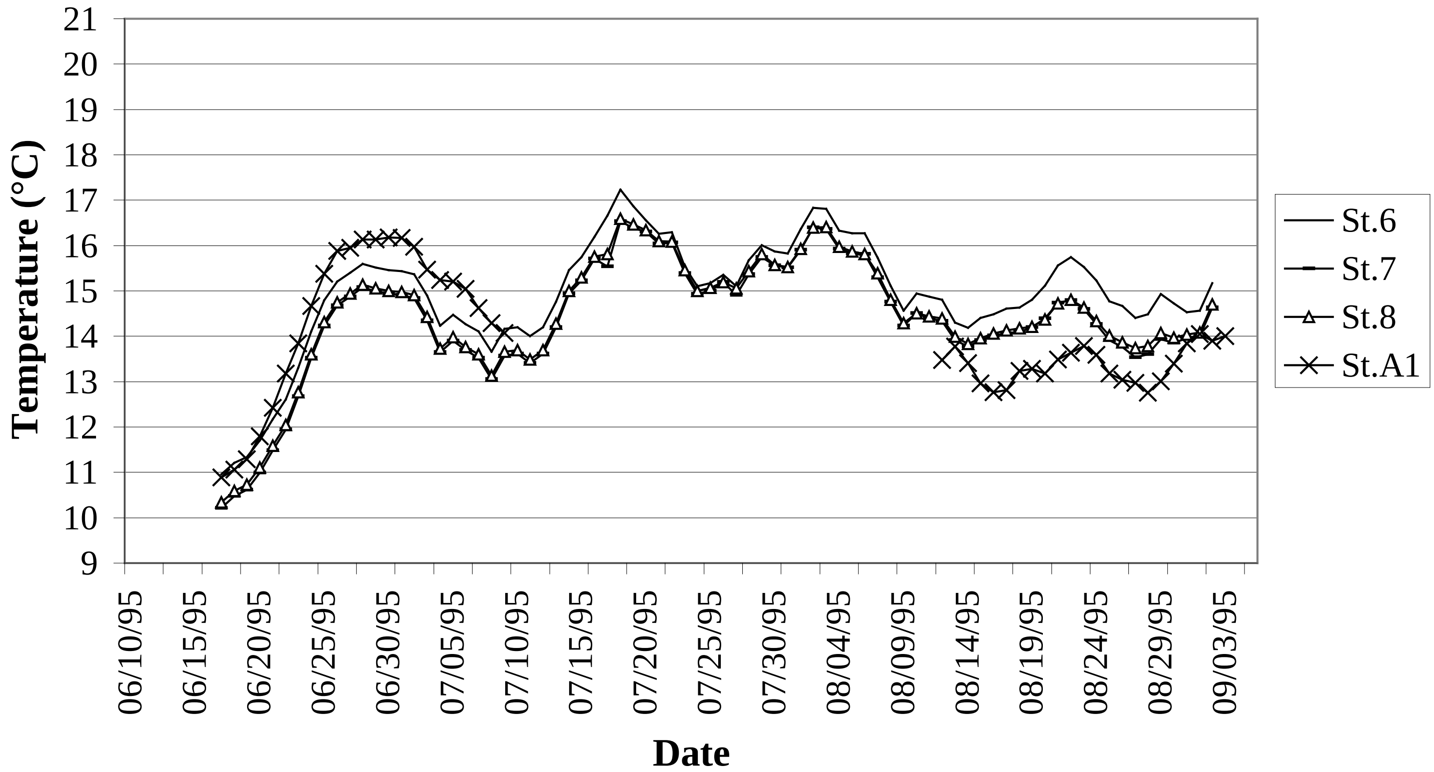


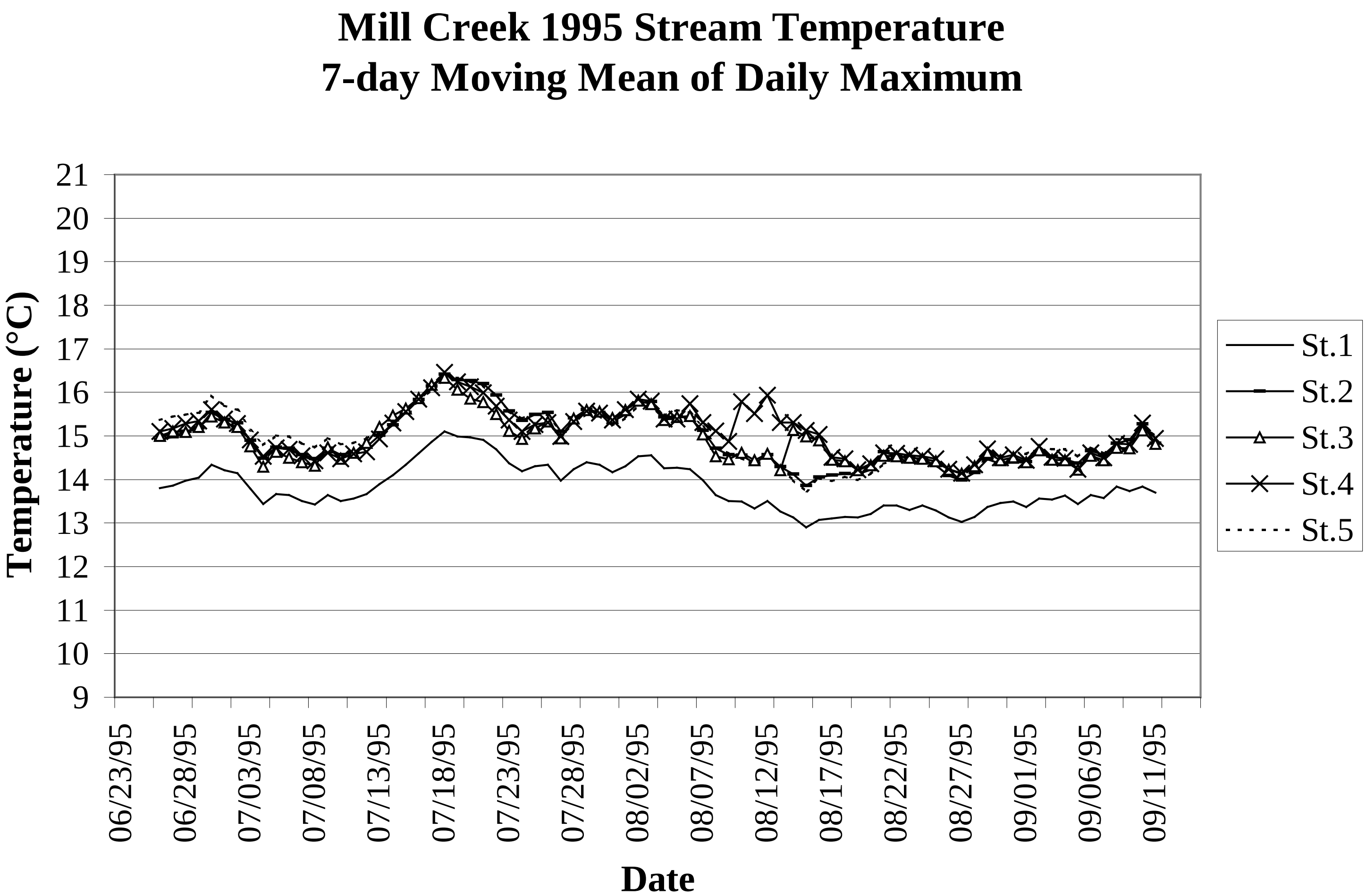

Little Fall Ck. 1995 Stream Temperature
7-Day Moving Mean of Daily Maximum
21
20
19
18
17
16
15
14
13
12
11
10
9
Temperature (°C)
07/15/95
07/20/95
07/25/95
07/30/95
08/04/95
08/09/95
08/14/95
08/19/95
08/24/95
08/29/95
09/03/95
09/08/95
09/13/95
09/18/95
09/23/95
09/28/95
10/03/95
Date
St.1
St.2
St.3
St.4


Coleman Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
07/14/95
07/17/95
07/20/95
07/23/95
07/26/95
07/29/95
08/01/95
08/04/95
08/07/95
08/10/95
08/13/95
08/16/95
08/19/95
08/22/95
08/25/95
08/28/95
08/31/95
09/03/95
09/06/95
Date
St.1
St.2
St.3
St.4
St.5

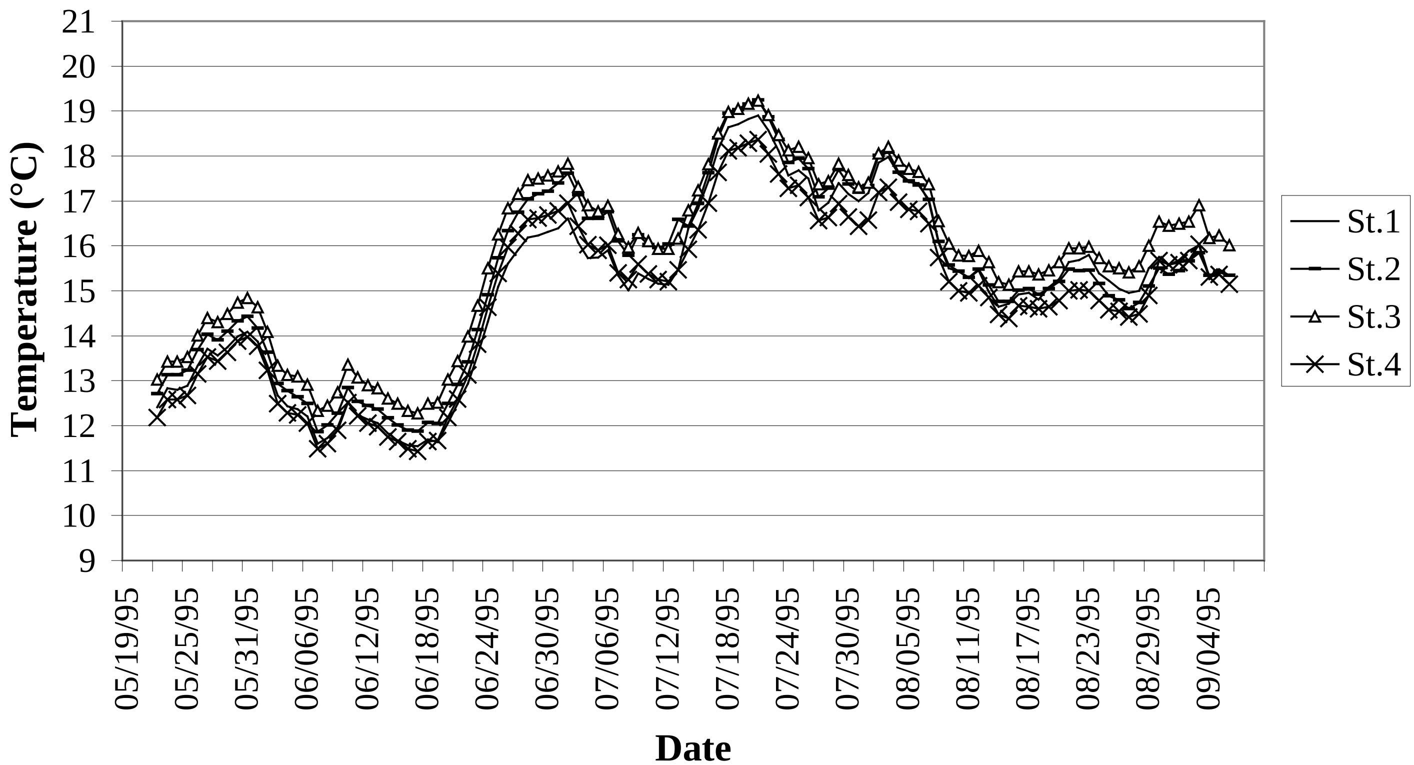

Sheele Creek Stream Temperature 1995
7-Day Moving Mean of Daily Maximum
Temperature (F°)
21
20
19
18
17
16
15
14
13
12
11
10
9
06/01/95
06/07/95
06/13/95
06/19/95
06/25/95
07/01/95
07/07/95
07/13/95
07/19/95
07/25/95
07/31/95
08/06/95
08/12/95
08/18/95
08/24/95
08/30/95
09/05/95
Date
St.1
St.2
St.3
St.4
St.5
St.6

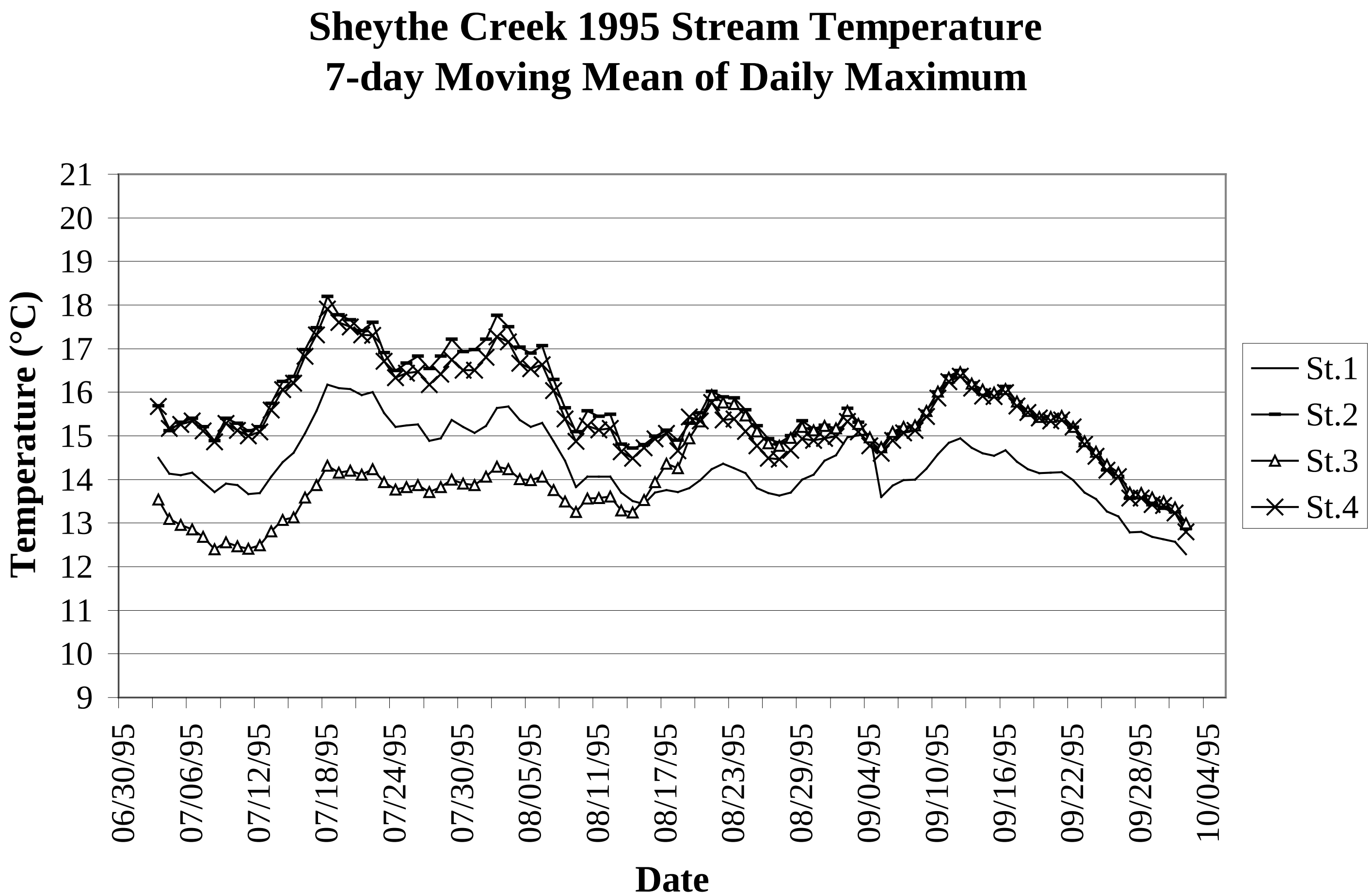
Sheele Creek (Continued)
7-day Moving Mean of Daily Maximum



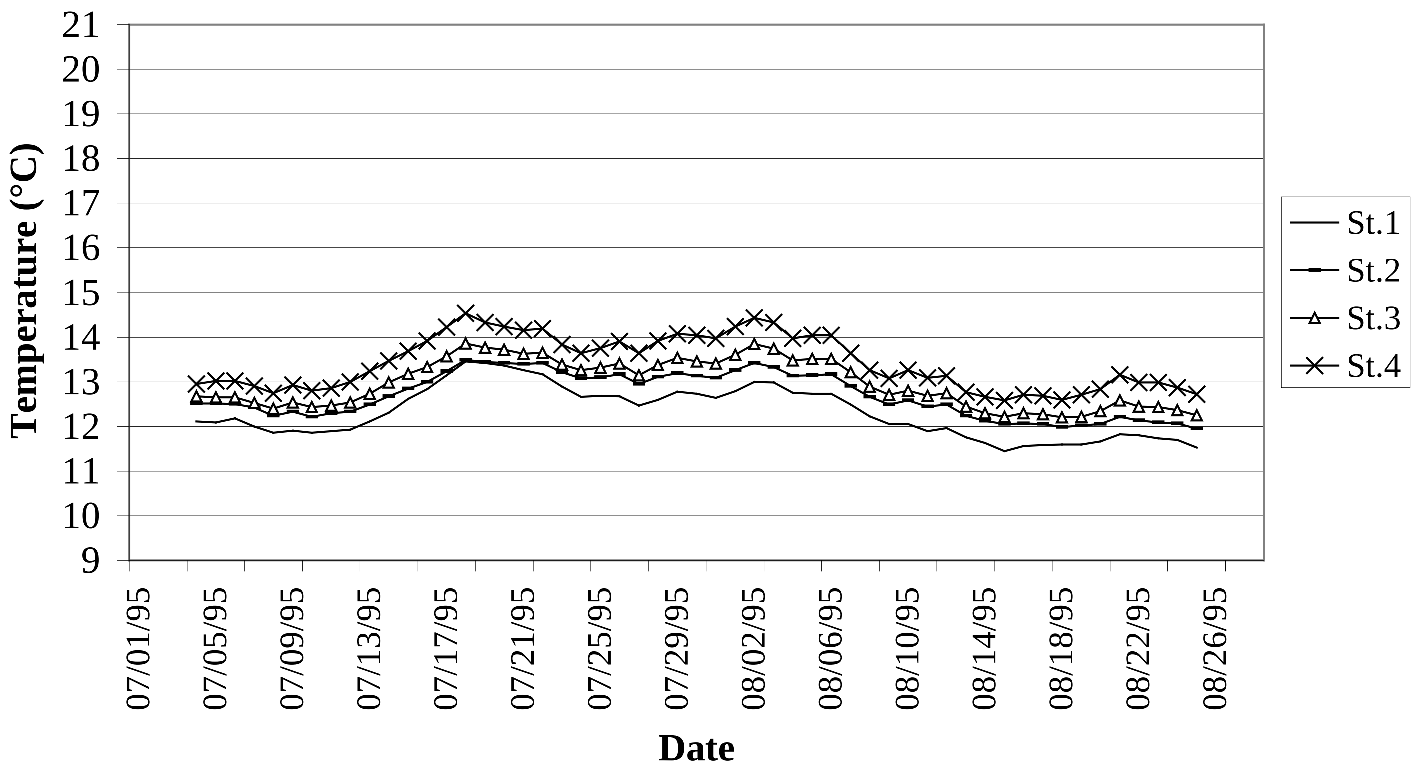

Mill Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
06/23/95
06/28/95
07/03/95
07/08/95
07/13/95
07/18/95
07/23/95
07/28/95
08/02/95
08/07/95
08/12/95
08/17/95
08/22/95
08/27/95
09/01/95
09/06/95
09/11/95
Date
St.1
St.2
St.3
St.4
St.5

Cascade Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum

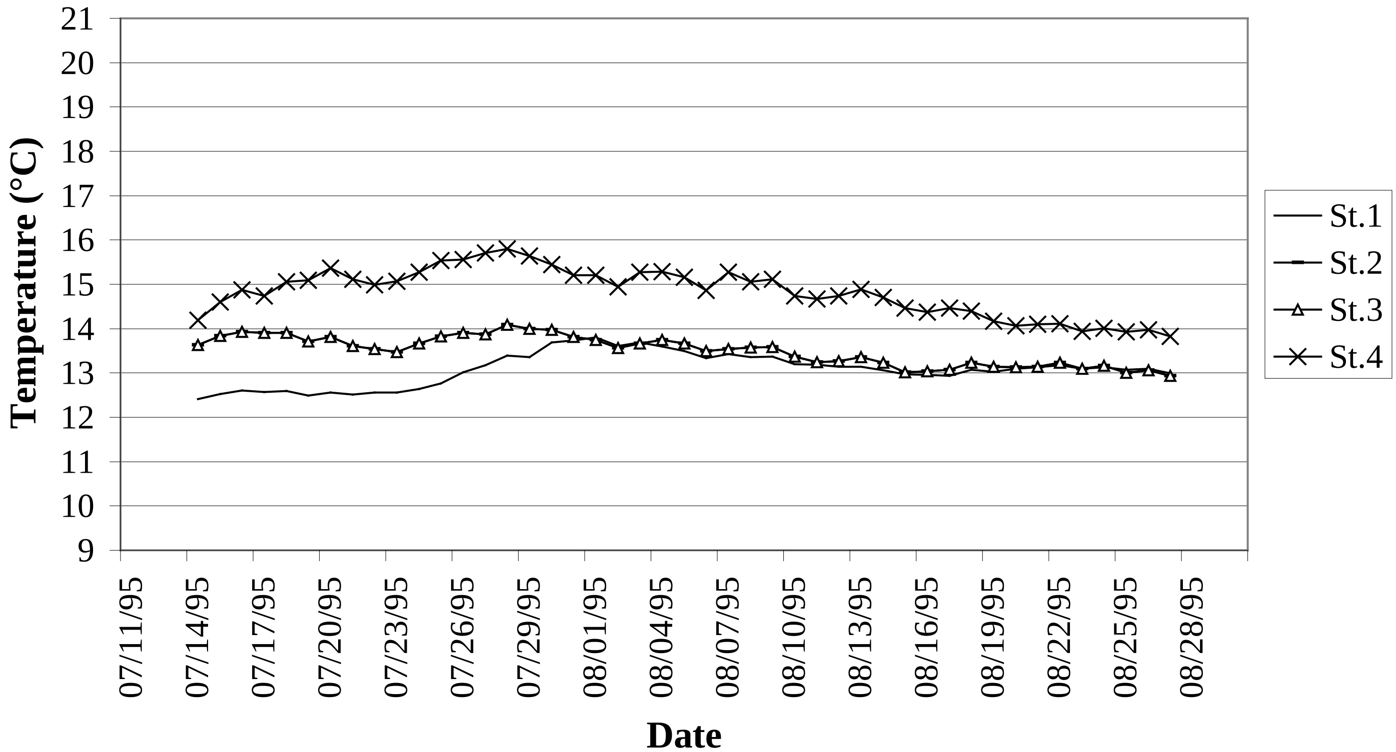



Sheythe Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
06/30/95
07/06/95
07/12/95
07/18/95
07/24/95
07/30/95
08/05/95
08/11/95
08/17/95
08/23/95
08/29/95
09/04/95
09/10/95
09/16/95
09/22/95
09/28/95
10/04/95
Date
St.1
St.2
St.3
St.4

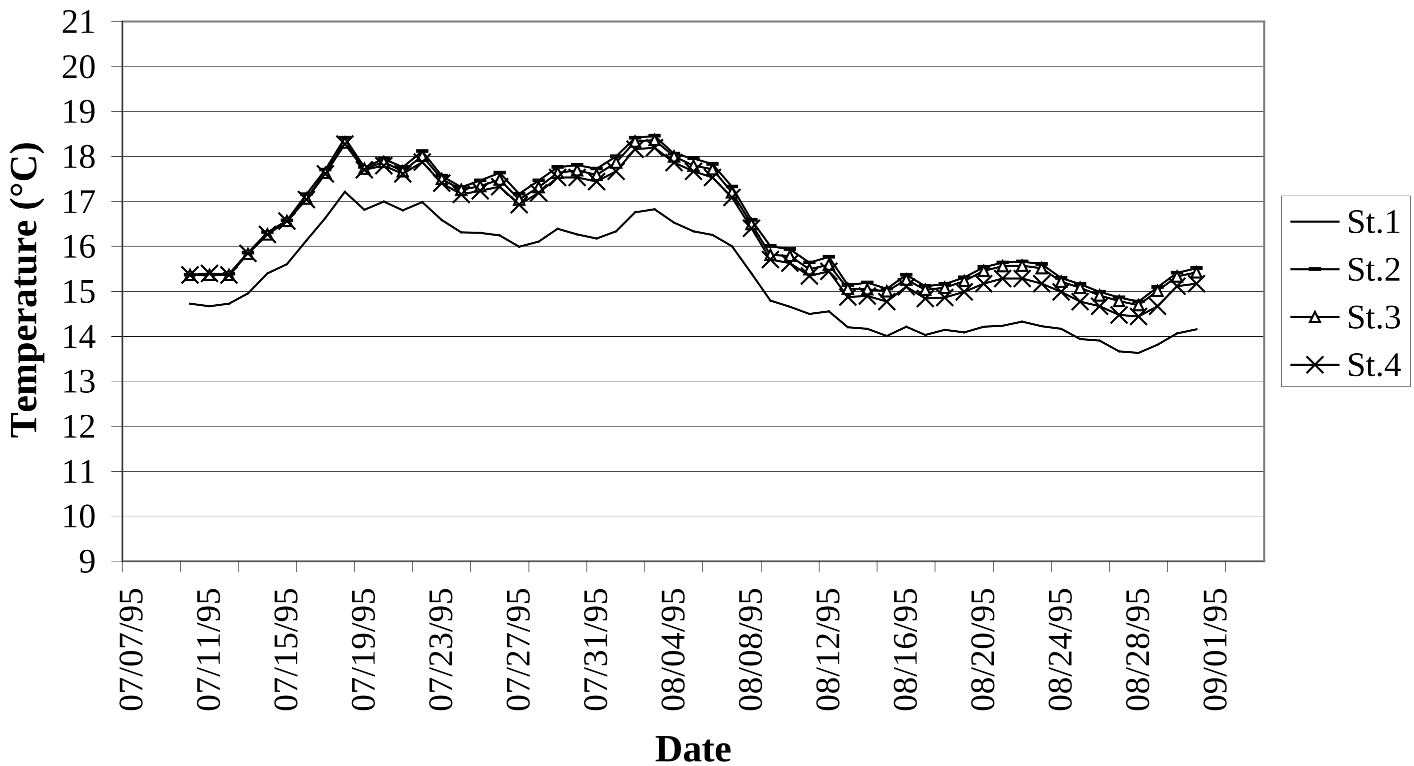
Eagle Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum

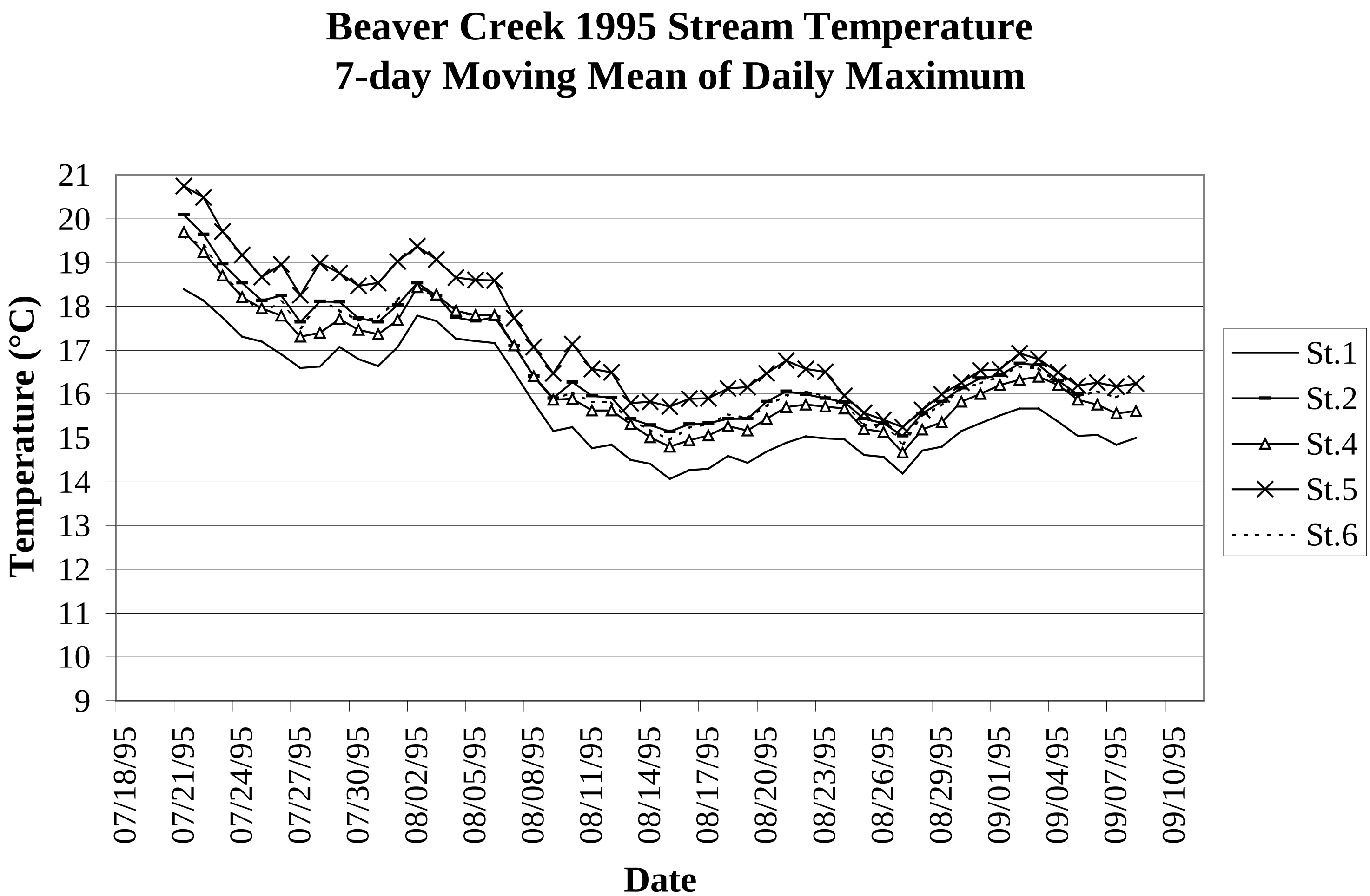


Talbot Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum



Douglas Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum




Beaver Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
07/18/95
07/21/95
07/24/95
07/27/95
07/30/95
08/02/95
08/05/95
08/08/95
08/11/95
08/14/95
08/17/95
08/20/95
08/23/95
08/26/95
08/29/95
09/01/95
09/04/95
09/07/95
09/10/95
Date
St.1
St.2
St.4
St.5
St.6