WATER RESOURCES BULLETIN
VOL. 17, NO. 5 AMERICAN WATER RESOURCES ASSOCIATION OCTOBER 1981

EFFECTS OF CLEARCUTTING AND SLASHBURNING ON STREAM TEMPERATURE IN SOUTHWESTERN BRITISH COLUMBIA[1]

M. C. Feller[2]

ABSTRACT: A paired watershed study was conducted in western hemlock/western redcedar/Douglas fir forests of southwestern British Columbia to assess the effects of clearcutting and clearcutting plus slashburning treatments on stream water characteristics. In the case of stream temperatures, both treatments increased summer temperatures as well as summer daily temperature fluctuations. These effects lasted for seven years in the case of the clearcut stream but longer in the case of the clearcut and slashburned stream. Clearcutting increased winter stream temperatures whereas slashburning caused a decrease. These changes lasted less than four years. Clearcutting and slashburning had a greater impact on stream temperatures than did clearcutting alone.
(KEY TERMS: British Columbia; clearcutting; slashburning; stream temperature.)

INTRODUCTION

The forested watersheds of coastal British Columbia yield a variety of products. Two of the most important are timber and high quality water. It is therefore important to understand the interactions between forests and streams and also the effects of forestry operations on streams and stream water quality in particular.

One stream water quality parameter is temperature. Water temperature is a factor determining the distribution, growth, and survival of aquatic organisms either directly or indirectly through its effect on other stream parameters such as dissolved oxygen. Temperature also affects the self purification capacity of streams and therefore their aesthetic and sanitary qualities. These effects of temperature have been the subject of numerous studies and comprehensive reviews, most of which have been summarized by F.W.P.C.A. (1972), Lantz (1971), and U.S. E.P.A. (1976).

The effects of forestry operations on stream temperature have been the subject of a number of studies, the literature to 1973 being reviewed by Anderson (1973) and Patton (1973). These reviews, together with more recent studies (Burton and Likens, 1973; Corbett, *et al.*, 1978; Hornbeck and Federer, 1975; Lee and Samuel, 1976; Lynch, *et al.*, 1975; Swift and Baker, 1973) all indicate that forest removal increases summer stream temperatures. The amount of increase is quite variable, but declines with time since forest removal, depending primarily on watershed aspect, the degree of vegetation, particularly riparian vegetation, removal, and the rate of revegetation. Water flowing out of a devegetated area may or may not be cooled as it moves downstream through forested areas, depending on the amount and temperature of inflow water. All studies concur that effects of forest removal on stream temperature can be minimized by leaving a streamside buffer strip of vegetation which effectively shades the stream.

Most studies of the effects of clearcutting on stream temperature have considered summer temperature regimes only. This is presumably because summer is the most active time of year biologically and is consequently the time when man induced changes in stream temperature have greatest impact on aquatic ecosystems. Gibbons and Salo (1973) in a review of the literature on the effects of logging on fish of western North America, considered that one of the two most important research needs with respect to the effects of clearcutting on stream temperatures, was to determine the effects of vegetation removal on winter temperatures. Schmiege, *et al.* (1974), considered that in southeast Alaska where sustained periods of low air temperatures occur, a slight alteration of stream temperature in winter might be more critical than summer increases, but this was an area in which information was lacking.

Eschner and Larmoyeau (1963) found that clearcutting in West Virginia resulted in lower minimum stream temperatures in winter. Anderson, *et al.* (1976), considered that clearcutting, by increasing exposure of streams, could cause their margins to freeze during winter. However, Levno and Rothacher (1969) found that clearcutting and slashburning in western Oregon apparently caused the winter maximum water temperatures to increase. At Coweeta in North Caroline, Swift and Messer (1971) also found that a variety of cutting treatments generally increased weekly maximum stream temperatures in winter. In southeast Alaska, Meehan, *et al.* (1969), found that clearcutting caused little, if any, change in winter stream temperatures. Thus, the effects of forest removal on winter stream temperatures have been variable, but have been smaller in magnitude than the effects on summer temperatures.

[1] Paper No. 81026 of the *Water Resources Bulletin*. Discussions are open until June 1, 1982.
[2] University Research Fellow, Faculty of Forestry, University of British Columbia, Vancouver, British Columbia, Canada V6T 1W5.

In 1970 a small watershed project was initiated to study the effects of typical coastal British Columbia forest harvesting operations on stream water quality. The effects of forest harvesting on stream temperature are discussed here.

THE STUDY AREA

The study area has been described in detail elsewhere (Feller, 1977) and will only be briefly described here.

Three watersheds lying between 140 and 450 m above sea level were studied in the University of British Columbia Research Forest at Haney, approximately 60 km east of Vancouver in southwestern British Columbia. The area has a marine, warm temperature, rainy climate with an annual precipitation of 220-270 cm, nearly all of which is rain. Temperatures are mild, with an average daily mean of 17°C for the warmest month (July) and 0° for the coldest month (January). Soils are shallow, coarse textured, and of glacial origin, overlying acid igneous bedrock. Topography is generally hilly with occasional bedrock knolls. The watersheds were covered with *Tsuga heterophylla* (western hemlock), *Thuja plicata* (western redcedar), and *Pseudotsuga menziesii* (Douglas-fir) forests which originated from a fire in 1868. Part of one watershed (Watershed C) is covered by forest which originated after logging in the 1920's. Riparian vegetation in the undisturbed forests was relatively dense and included *Alnus rubra* (red alder), *Rubus spectabilis* (salmonberry), *Salix* spp. (willows), and *Acer circinatum* (vine maple).

Selected physical characteristics of the watersheds are given in Table 1.

METHODS

Weirs were constructed on the streams draining two small (23 and 68 ha) watersheds. The larger watershed was split into upper and lower sections by constructing another weir on the stream about 600 m upstream from the first. This resulted in the collection of data from three distinct drainage areas: a small entire watershed (stream A) and the lower (stream B) and upper (stream C) sections of the second watershed (designated Watershed B). Thus, stream B and stream C are the lower and upper sections of the same stream, respectively.

Stream temperature was continuously recorded just upstream of the weir ponds using Lambrecht type 258 and Weathermeasure remote recording thermographs. Charts were calibrated every one to two weeks and were usually found to be accurate to within 0.5°C. Measurement began in July 1971 for streams A and B, and March 1972 for stream C, and has continued with some interruptions to September 1980.

The forests in watersheds A and B were clearcut from June through November 1973. The areas clearcut were 14 ha or 61 percent of watershed A and 13 ha or 19 percent of watershed B – the entire large watershed. Watershed C (the upper portion of watershed B) remained undisturbed as a control. Road construction was kept to the minimum and avoided the streams but no streamside buffer strips were left and logs were sometimes yarded across the streams. The clearcut area in watershed A was planted with Douglas-fir seedlings soon after cutting. The clearcut area in watershed B was broadcast slashburned in late August 1974, then soon after planted with Douglas-fir seedlings. The watersheds have since remained untreated. The layout of the experimental watersheds is shown in Figure 1.

RESULTS AND DISCUSSION

Summer (May 1-September 30) Temperatures

In their undisturbed watersheds the streams were protected by a moderately dense shrub and tree canopy. This, together with many fallen trees, shaded them in summer. Prior to clearcutting, maximum instantaneous summer temperatures were 16.1°C, 16.7°C, and 15.2°C for streams A, B, and C, respectively. During the seven years (1974-1980) following clearcutting, the temperature of the undisturbed stream (C) has not exceeded 17°C whereas the temperatures of the two treated streams have exceeded 19°C at times (Table 2). Maximum instantaneous stream temperatures following clearcutting have been 21.8°C for stream A (recorded the July immediately following clearcutting), 20.3°C for stream B (recorded in August 1977), and 17.0°C for stream C (recorded in August 1977).

From Table 2 it is apparent that clearcutting increased the maximum temperatures in both streams A and B. Slashburning appeared to have increased temperatures in stream B even

TABLE 1. Selected Physical Characteristics of the Study Watersheds.

Watershed	Area (ha)	Channel Length (m) Main	Channel Length (m) Tributaries	Drainage Density (m/ha)	Stream Direction	Average Stream Slope	Maximum Instantaneous Discharge* (l/sec)	Minimum Instantaneous Discharge* (l/sec)
A	23.1	670	275	41	N→S	5	470	0.3
B	68.0	610	870	62	N→S	5½	1200	0.6
C**	44.0	855	460	30	NNE→SSW	3	900	0.4

*Measured during the period 1 October 1971 to 1 October 1980.
**Watershed C is the upper portion of Watershed B.

more than clearcutting alone. This is suggested by the elevated maximum temperatures in stream B in 1977, 1979, and 1980 when maximum temperatures in the clearcut stream (A) were below 17°C. Stream A had lower discharges than stream B, summer discharges being approximately 80 percent of those of stream B and had 940 m of its channel and tributaries affected by clearcutting, compared to 960 m for stream B. Thus, the clearcutting would be expected to have a greater effect on temperatures of stream A than of stream B. The increased temperatures caused by slashburning can be attributed to burning of slash covering the stream, thus increasing the amount of solar radiation reaching the stream water. The slashburn also blackened logs and other materials with which the stream came into contact. Increased energy absorption by these materials and its transfer to stream water by conduction might also explain the higher stream temperatures following the burn.

Annual cumulative frequency distributions of the daily variations in stream temperatures for the summer period are shown in Figure 2. Prior to treatment, the maximum variations in temperature were less than 3°C for streams A and B. The first year following clearcutting of stream A, a variation of 3° was exceeded more than 40 percent of the time. By the third year, 3° was exceeded around 15 percent of the time, by the fourth year 3° was exceeded around 5 percent of the time, and during the sixth and seventh years (1979 and 1980), 3° was never exceeded and daily temperature variations were close to those expected had the stream remained undisturbed. The relatively slight variations found in stream A during 1980 may indicate enhanced protection of the stream by vegetation, relative to the situation prior to clearcutting. It may also be associated with the very cool summer (Table 2).

Clearcutting also caused an increase in the daily temperature changes of stream B, but to a lesser extent than for stream A (year 1974 in Figure 2). Slashburning, however, increased even further the daily temperature changes in stream B. These changes have remained higher than expected for each of the seven years following burning. From Figure 2 it is apparent that clearcutting and slashburning have had a greater impact on stream daily temperature changes than just clearcutting alone. This can be attributed to burning of the slash covering the stream, increasing exposure of the stream to solar radiation inputs, and radiative energy losses.

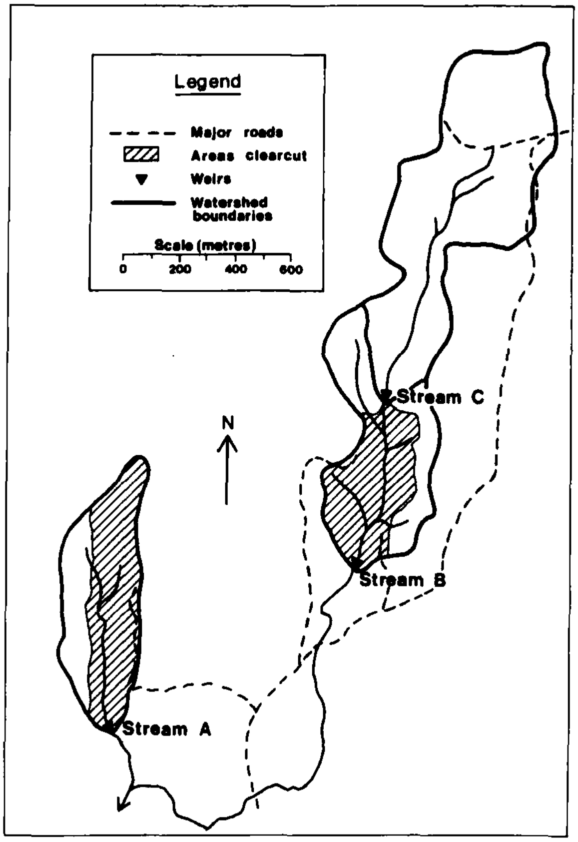

Figure 1. Layout of the Experimental Watersheds.

Stream temperature changes caused by treatment were not readily amenable to statistical analysis. Standard regression

TABLE 2. The Number of Hours Per Year That Temperatures of 17, 18, and 19°C Have Been Exceeded in the Study Streams.*

Year		17°C Stream A	17°C Stream B	18°C Stream A	18°C Stream B	19°C Stream A	19°C Stream B	July-August Daily Mean Maximum Air Temperature (C°)
1972	Before Clearcutting	0	0	0	0	0	0	23.4
1973	Before Clearcutting – A During Clearcutting – B	0	0	0	0	0	0	21.0
1974	After Clearcutting – A After Clearcutting – B	120	4	78	0	48	0	20.3
	After Slashburning – B	6	32	– –	3	– –	0	
1975	After Treatment – A & B	0	**	0	**	0	**	19.3
1976	After Treatment – A & B	0	73	0	20	0	0	20.6
1977	After Treatment – A & B	0	211	0	130	0	61	24.0
1979	After Treatment – A & B	0	251	0	47	0	5	24.3
1980	After Treatment – A & B	0	50	0	11	0	0	16.1

*Temperatures of stream C have never exceeded 17°C.
**Data are incomplete.

techniques could not be used due to the nonrandom effects of climate, problems of serial correlation, and the potential alteration of the variance of seasonal temperature distributions by logging (Brown and Krygier, 1970). Consequently a paired t-test analysis was carried out in the following way: for a given week, the weekly maximum or minimum stream temperature of the control stream was subtracted from that of stream A or B. This was done whenever possible for each of the weeks during the summer period. The differences for the year 1972 were compared to the differences in each subsequent year in which sufficient data were available by using a paired t-test, pairing corresponding weeks, and testing the null hypothesis that there was no difference between the average difference for any year and that for 1972.

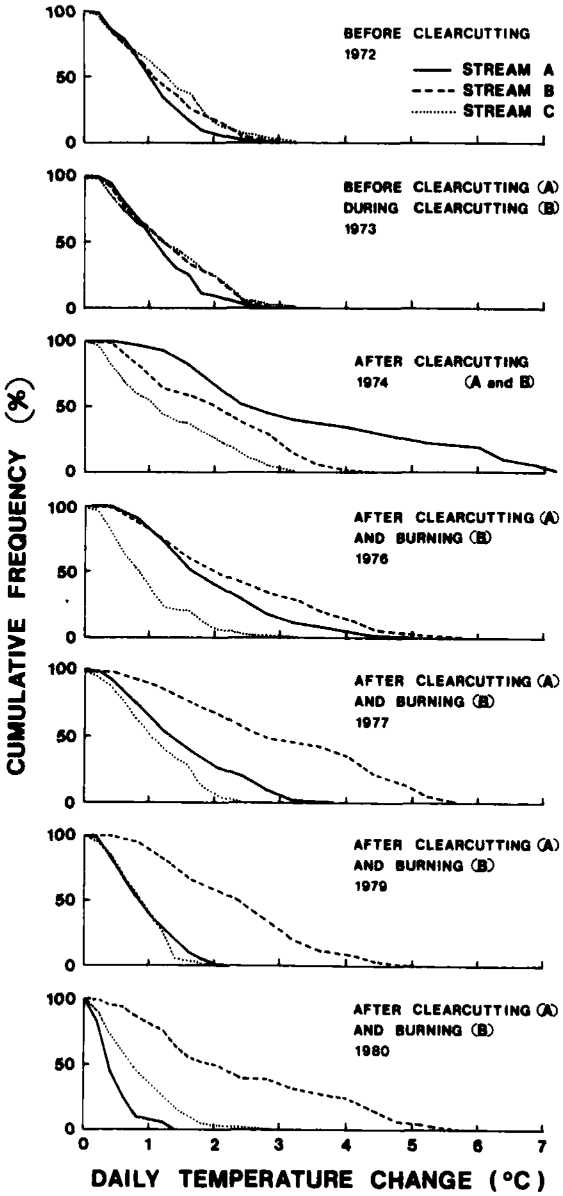

Figure 2. The Annual Frequency Distributions of Daily Temperature Changes in the Three Study Streams for the Summer Periods (May 1-September 30). Due to instrument malfunctions, data for 1975 and 1978 were incomplete and have not been presented.

Unlike stream B, stream A remained undisturbed for most of the 1973 summer, thus allowing a check on the influence of climate on the difference between the weekly maximum or minimum stream temperatures of stream A and those of stream C. The 1973 differences were not significantly different from the 1972 differences despite differences in climate. Although not conclusive, due to the limited number of comparisons, it does allow some confidence in the results of the statistical analysis.

This analysis showed that the clearcut stream (A) had significantly increased weekly maximum temperatures in 1974, 1976, and 1979, but significantly decreased weekly maximum temperatures in 1980. The 1980 decrease could be due to increased cover by riparian vegetation or it could be associated with the exceptionally cool summer. Weekly minimum temperatures in 1974, 1976, 1979, and 1980 were not significantly affected by clearcutting. Data were not available for other years.

The clearcut and slashburned stream (B) had significantly increased weekly maximum and minimum temperatures in 1974 following clearcutting, and in 1976, 1979, and 1980 following slashburning, except for weekly minimum temperatures in 1976 which were not significantly affected.

The slashburn had an immediate effect on the temperature of stream B, causing it to rise, at weir B, from 12.8°C to peak at 16.0°C within six hours of the commencement of burning. This direct effect of the burning lasted for approximately 13 hours before the normal diurnal temperature pattern resumed.

Further evidence for slashburning having a greater effect on stream temperature than just clearcutting alone was obtained by comparing the weekly maximum and minimum stream temperatures of September 1974 (the month immediately following the burn) with those of September 1973 using a paired t-test analysis identical to that described above. There was no significant difference in either maximum or minimum temperatures for the clearcut stream between these two Septembers. This stream was partially clearcut in September 1973 and completely clearcut by September 1974. In the case of the slashburned stream, there was no significant difference in the minimum temperatures but maximum temperatures were significantly higher.

The effects of burning on stream temperature in subsequent years are compounded with those of clearcutting but a decline with time in the significance of the increase in weekly maximum temperatures of stream A and the lack of any such decline for stream B further suggests that clearcutting and slashburning had a greater effect on summer stream temperatures than did clearcutting alone. Very similar results were found in western Oregon by Levno and Rothacher (1969).

Winter (November 1-February 28) Temperatures

At Haney, data from the first four winters following clearcutting (data for subsequent winters are not available) were analyzed statistically in a way identical to that described above for summer temperatures.

In the case of stream A, no significant difference was detected in maximum or minimum temperatures the first winter following clearcutting. During this period the stream was heavily covered by branches containing needles. These may have sheltered the stream in much the same way as the pre-existing forest. The second winter following clearcutting, by which time all needles had dropped off the branches, both maximum and minimum temperatures were significantly increased. No significant changes in maximum temperatures were found in subsequent years but minimum temperatures remained significantly higher for another year before returning to normal.

In the case of stream B, both maximum and minimum temperatures were significantly increased the first winter after clearcutting. The first winter following slashburning, both maximum and minimum temperatures were significantly decreased. No significant effects were found for maximum or minimum temperatures in the subsequent two winters.

Why slashburning should have an opposite effect to that of clearcutting is not immediately obvious. Detailed energy budgets for the streams might provide an explanation, but such budgets are unavailable. Despite this problem, it seems as if winter stream temperatures were able to recover from the effects of the clearcutting and slashburning treatments more rapidly than summer stream temperatures.

CONCLUSIONS

The clearcutting and slashburning treatments applied to the study streams significantly altered their temperature regimes. Summer stream temperatures were increased, as were the daily temperature fluctuations during summer. The summer temperature regime of the clearcut stream returned to its pretreatment state after 6-7 years whereas that of the clearcut and slashburned stream showed little sign of returning to its pretreatment state after seven years.

Winter stream temperatures were increased by clearcutting but decreased by slashburning, although the decrease lasted only one year. These changes were of shorter duration than changes in summer temperatures.

In general, clearcutting and slashburning had a greater impact on stream temperatures than did clearcutting alone.

ACKNOWLEDGMENTS

I thank J. Walters and the staff of the University of British Columbia Research Forest for the use of facilities, and K. M. Tsze and C. Perrin for assistance in the data collection. Drs. J. P. Kimmins and A. Kozak of the Faculty of Forestry, University of British Columbia, provided valuable discussion and comments on the manuscript.

LITERATURE CITED

Anderson, H. W., 1973. The Effects of Clearcutting on Stream Temperature. A Literature Review. State of Washington, Dept. of Natural Resources, Report No. 29.

Anderson, H. W., M. D. Hoover, and K. G. Reinhart, 1976. Forests and Water: Effects of Forest Management on Floods, Sedimentation, and Water Supply. USDA For. Serv. Gen. Tech. Rep. PSW-18.

Burton, T. M. and G. E. Likens, 1973. The Effect of Strip-Cutting on Stream Temperatures in the Hubbard Brook Experimental Forest, New Hampshire. Bioscience 23:433-435.

Corbett, E. S., J. A. Lynch, and W. E. Sopper, 1978. Timber Harvesting Practices and Water Quality in the Eastern United States. J. For. 76:484-488.

Eschner, A. R. and J. Larmoyeux, 1963. Logging and Trout: Four Experimental Forest Practices and Their Effect on Water Quality. Progr. Fish-Cult. 25(2):59-67.

Federal Water Pollution Control Administration, 1972. Water Quality Criteria. Report of the National Technical Advisory Committee to the Secretary of the Interior. U.S. Environmental Protection Agency, Washington, D.C., 234 pp.

Feller, M. C., 1977. Nutrient Movement Through Western Hemlock-Western Redcedar Ecosystems in Southwestern British Columbia. Ecology 58:1269-1283.

Gibbons, D. R. and E. O. Salo, 1973. An Annotated Bibliography of the Effects of Logging on Fish of the Western United States and Canada. USDA For. Serv. Gen. Tech. Rep. PNW-10.

Hornbeck, J. W. and C. A. Federer, 1975. Effects of Management Practices on Water Quality and Quantity. Hubbard Brook Experimental Forest, New Hampshire. U.S.D.A. For. Serv. Gen. Tech. Rep. NE-13, pp. 58-65.

Lantz, R. L., 1971. Influence of water temperature on fish survival, growth and behavior. *In:* Forest Land Uses and Stream Environment, J. T. Krygier and J. D. Hall (Editors). Oregon State University, Corvallis, pp. 182-193.

Lee, R. and D. E. Samuel, 1976. Some Thermal and Biological Effects of Forest Cutting in West Virginia. J. Environ. Qual. 5:362-366.

Levno, A. and J. Rothacher, 1969. Increases in Maximum Stream Temperatures After Slash Burning in a Small Experimental Watershed. U.S.D.A. For. Serv. Res. Note PNW-110.

Lynch, J. A., W. E. Sopper, E. S. Corbett, and D. W. Aurand, 1975. Effects of Management Practices on Water Quality and Quantity: The Penn. State Experimental Watersheds. U.S.D.A. For. Serv. Gen. Tech. Rep. NE-13, pp. 32-46.

Meehan, W. R., W. A. Farr, D. M. Bishop, and J. H. Patric, 1969. Some Effects of Clearcutting on Salmon Habitat of Two Southeast Alaska Streams. U.S.D.A. For. Serv. Res. Pap. PNW-82.

Patton, D. R., 1973. A Literature Review of Timber Harvesting Effects on Stream Temperatures: Research Needs for the Southwest. U.S.D.A. For. Serv. Res. Note RM-249.

Schmiege, D. C., A. E. Helmers, and D. M. Bishop, 1974. The Forest Ecosystem of Southeast Alaska. 8. Water. U.S.D.A. For. Serv. Gen. Tech. Rep. PNW-28.

Swift, L. W., Jr. and S. E. Baker, 1973. Lower Water Temperatures Within a Streamside Buffer Strip. U.S.D.A. For. Serv. Res. Note SE-193.

Swift, L. W. and J. B. Messer, 1971. Forest Cuttings Raise Temperatures of Small Streams in the Southern Appalachians. J. Soil Wat. Conserv. 26:111-116.

U.S. Environmental Protection Agency, 1976. Quality Criteria for Water. U.S.E.P.A., Washington, D.C., 256 pp.