Dennis Creek

A Look at Water Quality Following Logging In the Okanagan Basin

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PREFACE

Because of the importance of water in the Okanagan and the public concern over the effects of logging on water supplies in this area, this report will be of interest to a wide cross-section of people. By being a scientific document, considerable discussion of background data, procedures, analyses and results is included which may only be of interest to the technically-oriented reader. For those wishing to omit technical details, a review of the following sections will still provide a useful summary of the study and its results: Abstract, Introduction (p . 1), Location of study area (p. 1), Logging history (p. 4), study design (p. 6), Conclusions (p. 26). The sections on suspended sediment (p. 19), Colour (p. 19), water quality in Penticton Creek (p. 21) and Duration of water quality changes (p. 22) will also be of interest to the general reader.

ABSTRACT

The effects of forest harvesting on water quality in Dennis Creek, a high elevation tributary of Penticton Creek in the Okanagan Valley, British Columbia, were monitored during the second year following clearcutting of 25% of the measured portion of the Dennis Creek watershed. Water samples were taken above and below the logged areas, from an adjacent unlogged watershed and from the main Penticton Creek. Logging appears to have resulted in a significant increase in water colour and minor increases in potassium, sodium chloride, electrical conductivity, total organic carbon and dissolved solids. Sediment concentrations increased, but remained at negligibly low levels. Calcium, silica, and hardness also increased slightly, but the changes could not definitely be attributed to logging effects. No significant changes were detected in total Kjeldahl nitrogen, nitrate, total phosphorus, magnesium, alkalinity, pH, sulphate or total inorganic carbon. With the exception of colour, values of all parameters remained well within desirable drinking water standard limits. In addition, with the exception of one sample, nitrogen levels also remained below the minimum threshold limit for potential over-production of aquatic plants.

RÉSUMÉ

Les effets de l'exploitation forestière sur la qualité des eaux du ruisseau Dennis, un tributaire à haute altitude du ruisseau Penticton situé dans la vallée de l'Okanagan, dans la Colombie-Britannique, furent suivis au cours de la deuxième année suivant la coupe à blanc de 25% de la partie mesurée du bassin. Les échantillons d'eau furent pris en amont et en aval des superficies coupées, dans un bassin voisin non exploité, et dans le ruisseau Penticton. Il paraît que la coupe a produit des petites augmentations des paramètres suivants: potassium, sodium, chlorure, conductivité électrique, carbone organique total et solides dissous. La couleur de l'eau augmenta considérablement tandis que la concentration des sédiments en suspension a augmenté mais elle est restée très basse. Le calcium, la silice, et la dureté de l'eau ont augmenté légèrement mais il n'a pas été possible d'attribuer ces changements aux effets de la coupe avec certitude. Les paramètres suivants ne changèrent pas significativement: azote Kjeldahl total, nitrate, phosphore total, magnésium, alcalinité, pH, sulfate au carbone inorganique total. A l'exception de la couleur, les valeurs de tous les paramètres restèrent au-dessous du minimum de pollution qui rend l'eau impropre à boire. En plus, à l'exception d'un seul échantillon, les niveaux d'azote sont restés au-dessous du limite minimum pouvant causer la surproduction des plantes aquatiques.

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INTRODUCTION

The recent expansion of timber harvesting at higher elevations in the Okanagan basin has prompted concern over the possible impacts of forestry operations on water quality in this area (3, 27). Two potential impacts are of particular importance; namely, deterioration of the quality of water for drinking and nutrient enrichment of lakes. The latter could contribute to nuisance levels of aquatic plant growth, such as the expansion of aquatic weeds along the shoreline of Okanagan Lake (19). In 1973, a short-term study was conducted, in co-operation with Northwood Properties Ltd., to provide specific information on local logging-water quality interactions. Its objective was to identify and quantify the effects of logging and related activities on water chemistry and sediment levels in Dennis Creek, a high elevation tributary of Penticton Creek in the Okanagan Valley. The results are presented in this report.

DESCRIPTION OF STUDY AREA

Location

The study area is located in the upper reaches of the Penticton Creek watershed, which is situated east of Penticton in south central British Columbia (Fig. 1) Penticton Creek supplies water to the city of Penticton, flow being regulated by a headwaters storage reservoir. Dennis Creek, which drains the logged area, and James Creek, which served as a control, both drain into Penticton Creek a short distance below the reservoir and Water Survey of Canada stream gauging weir 08NM168. The respective watershed areas are 9.6 sq km[1] for Dennis Creek, 8.1 sq km for James Creek and 35.5 sq km above the weir on Penticton Creek.

Physiography

The upper Penticton Creek watershed terrain is mountainous, with elevations ranging from 1500 to 2100 metres. In Dennis Creek watershed, land slopes below 1800 metres' elevation are mostly less than 20%, but range up to 40% in small areas. About 40% of the drainage area is above 1800 metres where slopes are steeper, averaging 25-40%. The physiography of James Creek watershed is similar to that of Dennis Creek, except that 64% of the area is above 1800 metres and contains a small headwater lake. Both watersheds have a westerly aspect and include depressions containing small boggy areas.

Soils

Glacial action has resulted in a variety of surficial materials in the study area. Along stream channels below about 1800 metres, loose sandy or gravelly glacio-fluvial materials overlie compact, gravelly sandy loam basal till (GFK). Soils are mainly orthic humo-ferric podzols with occasional dystric brunisols and are rapidly to imperfectly drained, depending on slope position. Upper slopes have relatively shallow loamy sand or sandy loam soils over an intrusive, acidic igneous bedrock (RIA). These soils are well to rapidly drained and consist of lithic podzols or degraded dystric brunisols. Intermediate slopes have gravelly sandy loam or loamy sand soils, formed from weathered till, overlying compact sandy till (GTS). These soils are well to imperfectly drained and are mainly humo-ferric podzols with occasional degraded dystric brunisols. Much of the area below 1800 metres is covered with a layer of volcanic ash several centimeters thick. Table 1 indicates the proportions of the different surficial material-landform types for drainage areas in Dennis and James Creek watersheds.

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1 1 square mile = 2.6 square kilometres (sq km)

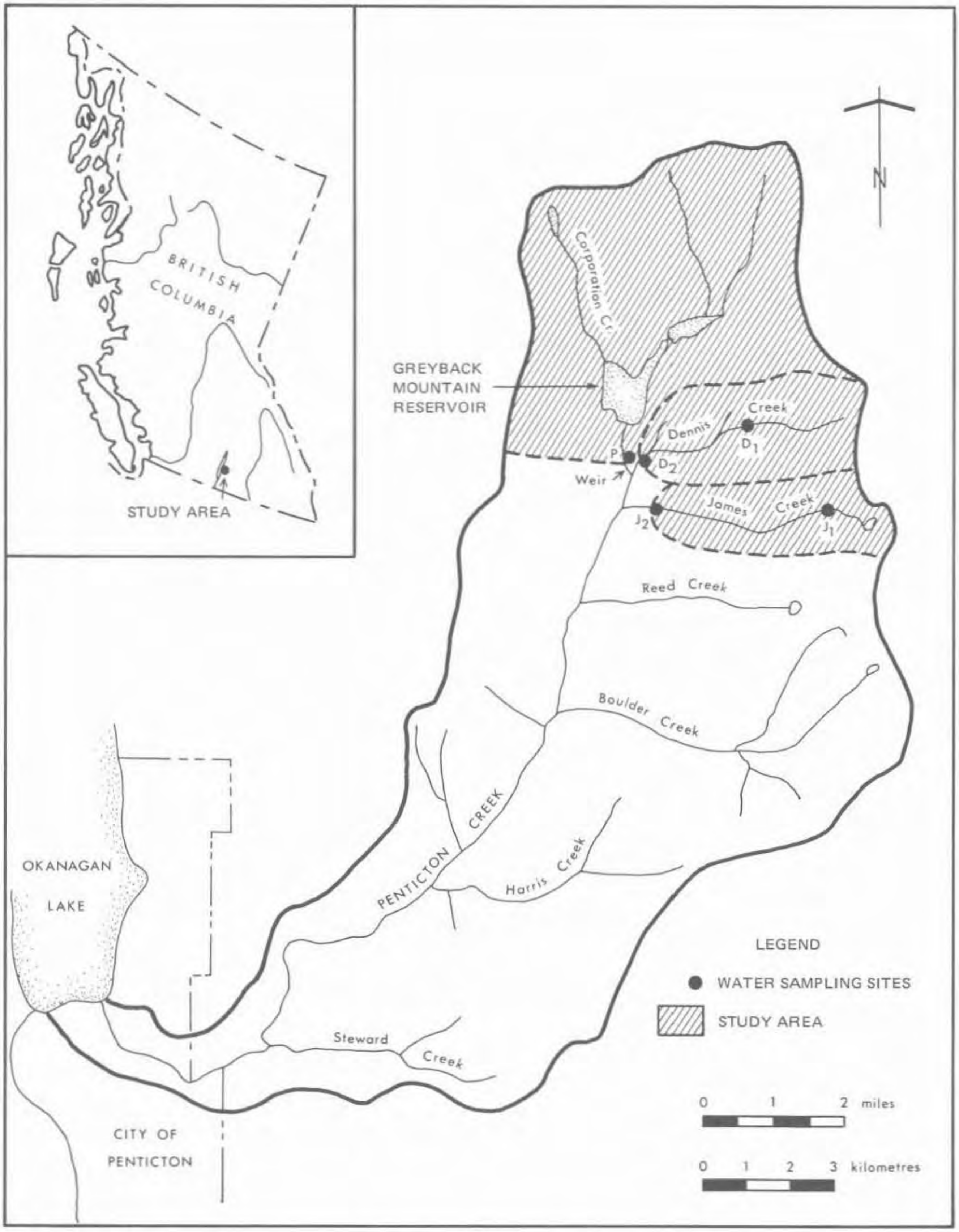


Figure 1. Study area in Penticton Creek watershed.

Principal differences occur with GFK and RIA types; the areas above sites D_1 and J_2 are remarkably similar to each other but different from the lower half or total of Dennis Creek watershed.

Soil samples were collected from four sites in the Dennis Creek watershed (Fig. 2). Soil profile descriptions and results of chemical and particle size analyses of these samples are given in Appendix 1.

Table 1. Percentages of different surficial materials in Dennis and James Creek watersheds. [a]

	Surficial material type		
	GFK	GTS	RIA
Dennis Creek			
Above site D_1	9	41	50
Between sites D_1-D_2	40	50	10
Total watershed	29	47	24
James Creek			
Total watershed	7	43	50

[a] derived from map provided by Soil Survey Division, B.C. Dept. of Agriculture

Vegetation

The study watersheds lie within the Engelmann spruce-subalpine fir zone (12) or the *Abies lasiocarpa* zone (15). The characteristic trees are *Picea engelmanii* (Engelmann spruce) and *Abies lasiocarpa* (subalpine fir). *Pinus contorta* (lodgepole pine) is the most common seral tree and covers large areas of Penticton Creek watershed, as a result of previous fire history. Three general subzones based on understory shrub and herb cover are recognized: below 1680 metres, 1680-2100 metres and 2100-2260 metres. A description of understory vegetation is given in Appendix 2.

The forest cover map for the study area reveals differences in species mix between Dennis Creek watershed and the James and upper Penticton Creek drainage areas. Over 84% of Dennis Creek watershed, before logging, had a cover of mature spruce mixed with lesser amounts of lodgepole pine and fir; the remaining area is alpine forest on the ridge top. In James Creek watershed, the major species is lodgepole pine with smaller amounts of spruce and fir; the percentage area of alpine forest is the same as for Dennis Creek. Lodgepole pine is also the major species in the Upper Penticton Creek watershed.

Precipitation

Mean annual precipitation within the study area exceeds 700 mm[2], over 55% occurring as snow between late October and early April. Table 2 gives mean monthly and annual precipitation for McCulloch (elevation 1250 metres) located about 22 kilometres NE of the study area, plus monthly precipitation for the period October 1972 - November 1973. These data show that previous winter snowfall and precipitation occurring during the study period were below normal for 9 of the 11 months from October 1972 - August 1973, with amounts for the fall of 1973 exceeding the long-term mean. Snow course data for McCulloch also show below average accumulated snowpack for the 1972-73 winter (Table 2). Data from the snow course located on the Dennis Creek watershed near the stream gauge weir on Penticton Creek indicate a higher snowpack than that observed at McCulloch.

Runoff

The reservoir on Penticton Creek is normally closed during winter and spring months to store water for the dry season. For the study period, records indicate that the reservoir gate was first opened June 26, 1973 and closed again about mid-October. Streamflow

[2] 1 inch = 25.4 millimetres (mm)

Table 2. Precipitation data[a]

Month	Total Precipitation McCulloch Actual	Total Precipitation McCulloch Mean	Snow Course[b] McCulloch Actual	Snow Course[b] McCulloch Mean	Snow Course[b] Dennis Creek Actual
	mm				
1972					
October	25.1	49.8	-	-	-
November	18.3	59.9	-	-	-
December	50.0	80.3	-	-	-
1973					
January	32.3	74.2	76.2	124.5	106.7
February	62.2	59.7	109.2	160.0	142.0
March	74.9	50.3	144.8	170.2	175.3
April	20.8	46.5	25.4	73.7	147.3
May	54.4	57.9	-	-	-
June	48.0	69.1	-	-	-
July	3.8	46.7	-	-	-
August	22.6	46.7	-	-	-
September	56.4	48.3	-	-	-
October	97.0	49.8	-	-	-
November	95.3	59.9	-	-	-

a Total precipitation data from published records of Atmospheric Environment Service and snow course data from Province of B.C. Snow Survey Bulletin.

b water equivalent of snowpack at end of month

note: 1 inch = 25.4 millimetres (mm)

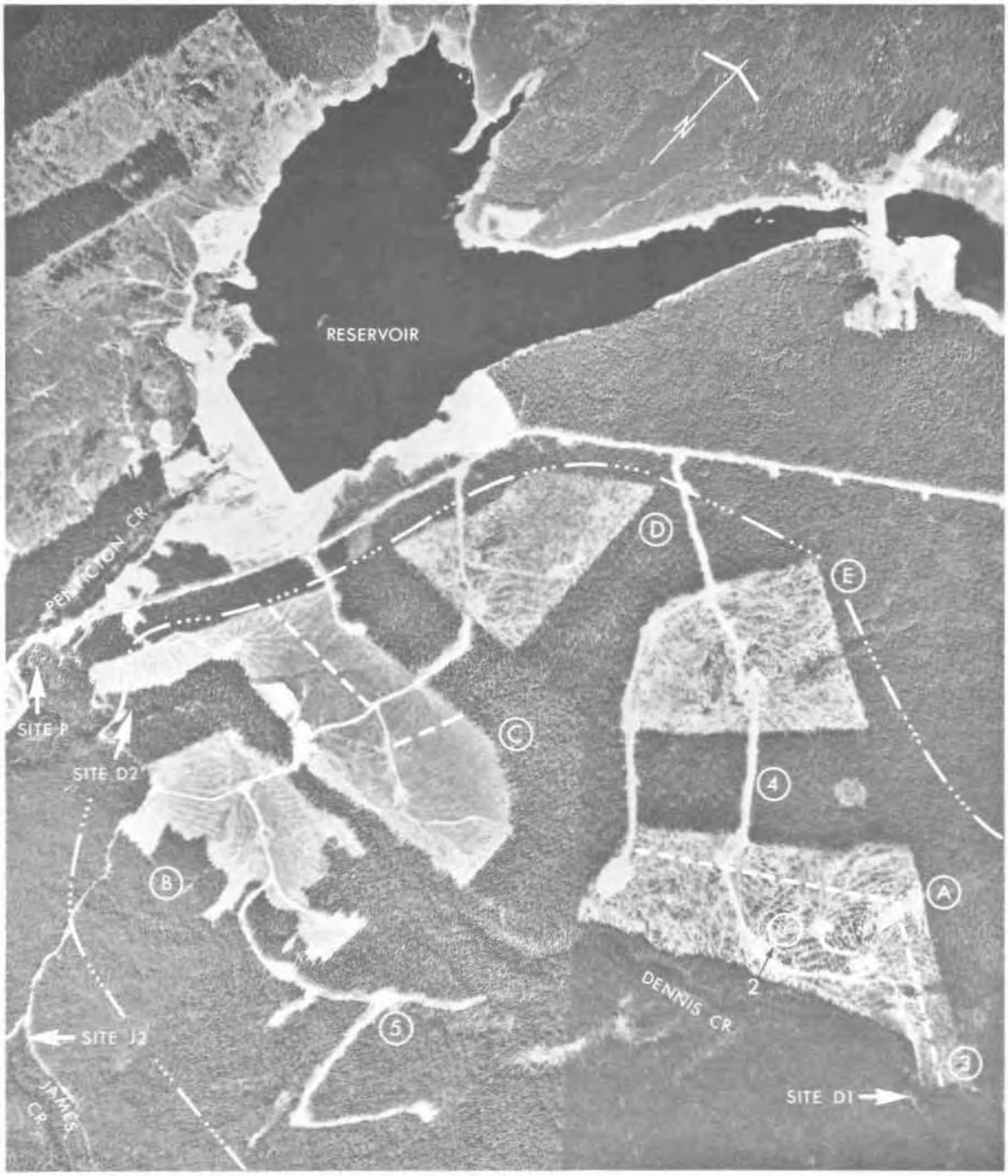
measurements at the Penticton Creek gauging site thus represent natural runoff conditions only when the reservoir is closed and only for the small drainage area between the reservoir dam and the weir. Flow data for 1973 indicate that the bulk of snowmelt runoff from this small area came between April 22 and May 23, the peak occurring from May 5-10.

Most of the snow had disappeared from the logged openings in the Dennis Creek watershed by May 15, although up to about 30 cm of snow remained beneath the adjacent forest canopy on that date. The peak snowmelt runoff in Dennis and James creeks would have occurred before the end of May.

Logging History

Five openings or patch cuts ranging from 22 to 45 hectares[3] were cleared from the lower portion of the Dennis Creek watershed (below 1800 metres' elevation) in 1972 (Fig. 2). Road construction was initiated in February, while most of the felling, yarding and hauling took place in February and March when there was a snowpack of about 1-metre depth. Two sections of clearing A were logged in April and May with some snow still on the ground, although the height of tree stumps suggests that snow depth in

3 1 hectare = approx. 2.5 acres



LEGEND:

SITE D1 ➔	SITE D1 - WATER SAMPLING SITE	– – – –	SOIL DISTURBANCE TRANSECT
(A)	OPENING	——····	WATERSHED BOUNDARY
(2)	SOIL SAMPLE SITE		

Figure 2. Dennis Creek study area.

the eastern corner of the opening must have been quite shallow. A portion of clearing B and two minor sections on the edges of clearing C were logged in August and September. Trees were felled mainly by hand, but also by shears mounted on tracked vehicles in portions of openings A and E, while yarding was done with rubber-tired skidders. During the summer of 1973, all residuals were hand-felled. Also, in September and October 1973, rubber-tired skidders were used in a minor clean-up operation in a portion of opening C.

The total area logged was 155 hectares, which represents about 25% of the drainage area between sites D_1 and D_2 on Dennis Creek immediately above and below the logged areas, respectively.

The upper Penticton Creek drainage above the confluence with Dennis Creek has been disturbed only by creation of the reservoir, the main access road and a 110-hectare clearcut (logged in 1963-64) located at the southwest edge of the reservoir (Fig. 2). In the James Creek watershed, no logging has occurred, but there does exist a well-established access road which parallels the Creek, crossing it at the upper end, with a recent branch road crossing the Creek at the lower end (Fig. 2).

METHODS

Study design

To isolate the effects of logging, water samples were taken at sites above (D_1) and below (D_2) the logged area on Dennis Creek and from an additional control site on James Creek (J_2), which drains an adjacent unlogged watershed (Fig. 2). Sampling sites D_2 and J_2 were located above the access road crossings to avoid road influences. For comparison, water samples were also collected regularly from Penticton Creek (P) upstream from the confluence with Dennis Creek, and on two occasions from upper James Creek (J_1) above the upper road crossing (Fig. 1).

Water samples were collected during the period extending from April 4, 1973, before the onset of the spring melt period, to November 14, 1973, when snow once again covered the ground and ice had reformed on Dennis Creek. Water samples at sites D_1, D_2, J_2 and P were taken weekly from April 4 - July 4 and September 19 - November 14, and every 2 weeks during July-September. Samples at site J_1 were taken on June 13 and August 6.

Chemical analyses

Water samples for chemical analyses were collected in both 1-litre polyethylene and 100-ml glass bottles by lowering the bottles through the depth of the stream. The glass-bottle samples were used for phosphorous determination. Analyses were performed at the Pacific Forest Research Centre (PFRC) chemistry lab in Victoria and by the Water Quality Branch, Department of Environment (D.O.E.) lab in North Vancouver. Water samples were placed in coolers with ice packs and forwarded by bus from Penticton to Vancouver or Victoria the same day they were collected. The samples sent to the PFRC lab in Victoria were initially frozen pending analyses. Analyses by the Water Quality Branch lab in North Vancouver were carried out within a day or two of receipt. These steps were followed to minimize possible chemical changes in the water.

The initial plan called for analyses to be performed at the Pacific Forest Research Centre lab, but it became apparent that this lab was unable to handle the number of samples being collected. Thus, commencing in August, all further samples were sent to the Water Quality Branch lab in North Vancouver for chemical analysis. Samples collected on the following dates were analyzed in Victoria: April 4, 11 (Sites D_1, P only), 18, 21; May 2, 15, 23; June 6. These analyses were completed by the end of August 1973. In November 1973, samples collected on the following dates and kept frozen were sent from Victoria to the Water Quality Branch lab for analyses: April 11 (sites D_2, J_2 only); May 9, 30; June 13, 20, 27; July 4, 18. Water samples for April 4 and May 15 were analyzed by both labs for comparison. In addition, portions of all samples analyzed in Victoria were sent to the North Vancouver lab for reactive silica analysis.

Analyses were carried out for the following variables: total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO_3), total phosphorus (TP), potassium (K), chloride (Cl), calcium (Ca), magnesium (Mg), sodium (Na), alkalinity (Alk), hardness (Hd), electrical conductivity (Con), pH, total organic carbon (TOC), total inorganic carbon (TIC), sulphate (SO_4) and reactive silica (Si). The Water Quality Branch analyzed all variables; the Pacific Forest Research Centre analyzed all except TP, TOC, TIC, SO_4 and Si. The analytical method for nitrate actually measured nitrite plus nitrate. However, since nitrite is usually present in negligible amounts (8), the analytical results can be assumed to approximate closely nitrate concentrations. A list of analytical methods used is given in Appendix 3.

Physical analyses

Separate water samples were collected in 1-litre polyethylene bottles and sent to the Pacific Forest Research Centre for determination of suspended sediment (Sed) and total dissolved solids (DS) concentrations. Measurements of water colour (Col), both unfiltered and filtered, were also taken on these samples as soon as they were received in Victoria. The Water Quality Branch also did colour measurements on unfiltered samples. Analytical methods are listed in Appendix 3.

Statistical analyses

Changes in water quality variable values between selected sample sites were tested for statistical significance, using a t-test for paired differences at the 5% level. Comparisons were made between data for sites D_2-D_1, D_2-J_2 and D_2-P. Data that could not be paired for a specific day were not used in the analyses.

Comparisons of Water Quality Branch and PFRC data for the April 4 and May 15 cross-check samples (see Appendix 4) show differences in concentration levels for some of the variables, due primarily to differences in methods of analysis and possibly to the effects of freezing. To assess the influence of PFRC data, the t-tests were carried out using Water Quality Branch data only, where applicable, and using a combination of data from both agencies. The numbers of samples used in the analyses are indicated in Table 4. For a few of the variables, these numbers differ slightly among pairs of sites because of missing data.

The cross-checks of water sample analysis data show that PFRC analyses gave values that were either the same or slightly higher than those obtained by the Water Quality Branch. For those variables with nearly identical comparative values, the outcome of statistical analyses using combined data should be entirely valid. For parameters where PFRC data are higher, the relative differences between sites remain valid, but the outcome of statistical analyses could be influenced by the use of data samples from slightly different populations. In these cases, results of t-tests based on Water Quality Branch data alone were given the most weight in assessing the significance of any observed changes.

The statistical analyses combine results of chemical and physical analyses from both frozen and unfrozen samples. While it is not known if storage by freezing significantly affected the results, freezing is a commonly used preservative method (6, 24). Since relative comparisons between sites are being made, differences between frozen samples collected before July 18 and unfrozen samples collected after that date should not affect the conclusions. Moreover, the magnitude and general temporal fluctuations of variable values from frozen samples are consistent with data from unfrozen samples

Information on water quality at sites D_1 and D_2 prior to logging is lacking. Because there are some differences in soil (Table 1) and vegetation characteristics between the upper and lower portions of Dennis Creek watershed, it is possible that at least part of any observed differences in water quality between sites D_1 and D_2 are a result of inherent watershed characteristics. It was thus necessary to establish criteria on which inferences as to logging-induced effects could be based. For any given variable, if the measured values at site D_2 are significantly different from those at both sites D_1 and J_2 and the direction of the differences are the same (e.g. both positive or negative), logging was considered to have produced or resulted in a significant portion of the observed change. If the differences are statistically significant between sites D_2-D_1 but are not between sites D_2-J_2 or if the sign of the D_2-J_2 difference differs, a logging effect was considered possible but uncertain. If water quality variable values at site D_2 are greater or less than those at both sites D_1 and J_2 but the differences are not statistically significant, determination of possible logging influence was considered to be inconclusive, even though examination of comparative data for sites J_1-J_2 and/or of time trends for sites D_1 and D_2 might lead one to suspect a logging effect. James Creek data were considered to give a measure of the range in magnitude of water-quality variable values which could be expected from an undisturbed area. Comparative data between sites J_1-J_2 for June 13 and August 6 were also used as an indication of the potential occurrence of downstream changes in water quality variables in an undisturbed watershed.

Field survey of soil disturbance

Field surveys were conducted to assess the nature and extent of soil disturbance and erosion resulting from the harvesting operations. One method of survey employed transects across openings A and C (Fig. 2) with point observations taken at 3-metre intervals for shallow mineral ($<$ 5 cm) and deep mineral ($>$5 cm) soil disturbance. Cause of disturbance was noted, if known, and measurements of ground slope and aspect were also taken at each point. This approach provides estimates of percentage disturbance for each class for the cleared areas. Additional observations and measurements were made where erosion was evident or where exposed soil could potentially contribute sediment to Dennis Creek.

RESULTS AND DISCUSSION

Water quality changes in Dennis Creek

The results, presented below for each variable, are summarized in Table 3 and comparative differences in mean values between site D_2 and sites D_1, J_2 and P are given in Table 4. To illustrate the practical significance of observed water-quality variable values and changes, desirable and maximum acceptable drinking water standards are listed in Table 3, where applicable, The desirable standard is considered to provide water supplies of good and safe quality from health and aesthetic viewpoints. For most variables, the maximum values indicate acceptable limits above which concentrations may become objectionable or potentially harmful to health. The desirable values listed for total Kjeldahl nitrogen and nitrate nitrogen represent lower threshold limits required for potential production of nuisance levels of aquatic plans such as algae. Comparative variations with time for sites D_1 and D_2 are illustrated for several variables in Figures 3 to 11.

Comparisons of June 13 and August 6 data between sites J_1-J_2 and D_1-D_2 are presented in Table 5. The data for James Creek suggest that changes in water quality can and do occur in streams draining undisturbed areas. These data, which represent late spring and mid-summer conditions, provide a gross indication of whether individual variable changes might have occurred in Dennis Creek prior to logging.

Table 3. Summary of stream water quality data[a]

Variable		Site D_1 Min	Site D_1 Mean	Site D_1 Max	Site D_2 Min	Site D_2 Mean	Site D_2 Max	Site J_2 Min	Site J_2 Mean	Site J_2 Max	Site P Min	Site P Mean	Site P Max	Drinking Water Standard Desirable	Drinking Water Standard Max
Total Kjeldahl Nitrogen	1	.095	.166	.346	.090	.189	.351	.061	.157	.320	.100	.308	.448	(0.6)[f]	
	2	.095	.191	.418	.090	.242	.596	.061	.192	.494	.100	.328	.467		
Nitrate-nitrogen	1	.002[b]	.004	.013	.002[b]	.003	.010	.002[b]	.015	.050	.002[b]	.015	.040	(0.3)[f]	10[c]
	2	.002[b]	.010	.050	.002[b]	.028	.368	.002[b]	.022	.129	.002[b]	.029	.124		
Potassium	1	0.2	0.35	0.6	0.3	0.55	1.6	0.2	0.37	0.8	0.3	0.67	1.2		
	2	0.2	0.35	0.6	0.3	0.64	1.9	0.2	0.36	0.8	0.3	0.71	1.7		
Calcium	1	0.8	1.63	2.6	1.0	2.02	3.8	1.2	2.37	4.7	1.9	4.71	13.8	< 75[c]	200[c]
	2	0.8	1.74	3.6	1.0	2.08	3.8	1.2	2.42	4.7	1.9	4.91	13.8		
Magnesium	1	0.1	0.36	0.9	0.1	0.36	0.7	0.1	0.33	0.7	0.1	0.89	3.9	< 50[c]	150[c]
	2	0.1	0.33	0.9	0.1	0.39	0.7	0.1	0.28	0.7	0.1	0.94	3.9		
Sodium	1	0.6	1.15	1.4	1.0	1.54	1.9	1.0	1.33	1.8	1.0	1.61	3.2		
	2	0.6	1.24	2.2	1.0	1.60	2.8	1.0	1.38	2.1	1.0	1.71	3.2		
Chloride	1	0.3	0.48	0.8	0.4	0.85	1.6	0.3	0.50	0.9	0.4	0.61	0.9	< 25[d]	250[c]
	2	0.3	0.70	3.4	0.4	1.13	5.6	0.3	0.66	3.2	0.4	0.72	1.9		
Alkalinity	1	1.9	4.7	8.0	2.0	4.8	8.9	3.0	6.4	11.6	6.2	14.8	49.0	30-500[c]	
	2	1.9	5.1	9.7	2.0	5.1	10.5	3.0	6.6	11.6	6.2	15.6	49.0		
Hardness	1	2.9	5.6	9.5	3.5	6.7	13.0	3.5	7.1	13.0	7.2	15.8	47.1	< 120[e]	180[e]
	2	2.9	5.6	10.1	3.5	6.9	13.0	3.5	7.3	13.0	7.2	16.4	47.1		
Electrical conductivity	1	9.9	14.5	20.4	11.9	17.5	23.6	10.7	17.2	21.9	20.6	31.8	99.1		
	2	9.9	14.7	20.4	11.9	17.9	27.6	10.7	17.2	21.9	20.6	33.1	99.1		
Hydrogen ion (pH)	1	6.0	6.7	7.5	5.9	6.7	7.4	6.2	6.9	7.4	6.5	7.1	7.5	6.5-8.3[c]	
	2	6.0	6.7	7.5	5.6	6.6	7.4	6.2	6.9	7.4	6.5	7.1	7.5		
Total phosphorus	1	.002[b]	.010	.031	.005	.015	.038	.002[b]	.010	.023	.014	.028	.056		
Sulphate	1	< 1.0	—	3.0	< 1.0	—	3.0	< 1.0	—	3.0	< 1.0	—	6.5	250[c]	500[c]
Silica	1	0.9	9.2	13.8	1.0	10.7	17.4	1.1	9.8	14.2	5.2	9.7	14.6		
Total organic carbon	1	3.9	7.1	20.2	5.1	10.6	24.1	3.6	6.9	21.6	5.8	10.1	27.1		
Total inorganic carbon	1	0.5	1.21	6.0	0.5	0.99	2.5	0.6	1.23	2.5	1.2	2.41	11.9		
Dissolved solids	1	11.0	40.9	132.6	18.6	51.8	92.0	13.0	36.9	119.2	23.0	49.1	75.6	< 200[d]	500[d]
Suspended sediment	1	0	0.9	4.3	0	1.5	7.1	0	0.7	4.4	1.3	4.1	8.7	< 25[g]	80[g]
Colour (W.Q. Br.)	1	5	24	50	15	45	85	8	28	75	30	48	85	< 5[c]	15[c]
Colour-unfiltered (PFRC)	1	0	12	30	5	47	130	0	12	40	25	61	105	< 5[c]	15[c]
Colour-filtered (PFRC)	1	0	11	30	5	43	130	0	11	40	15	45	77	< 5[c]	15[c]

[a] Units mg/l except for electrical conductivity (μmho/cm), pH and colour (Pt-Co unit) [b] Minimum detectable concentration

[c] Dept. of National Health and Welfare (4) [d] Ontario Ministry of Environment (21) [e] B.C. Health Branch (1) [f] Walden (26) [g] Canada-B.C. Okanagan Basin Agreement (3)

1 - Water Quality Branch or PFRC data only 2 - Water Quality Branch + PFRC data

( ) - threshold limit for nuisance levels of aquatic plant growth

Table 4. Paired comparisons of mean values of stream water quality variables [a]

Variable		Site D_2	Site D_1	Difference	Site D_2	Site J_2	Difference	Site D_2	Site P	Difference	Number of samples
Total Kjeldahl nitrogen	1	.189	.166	.023	.189	.157	.032	.189	.308	–.119*	20
	2	.242	.191	.051	.242	.192	.050	.242	.328	–.086*	25
Nitrate-nitrogen	1	.003	.004	–.001	.003	.015	–.012	.003	.015	–.012*	21
	2	.028	.010	.018	.028	.022	.006	.028	.029	–.001	26
Potassium	1	0.55	0.35	0.20*	0.55	0.37	0.18*	0.55	0.67	–0.12	21
	2	0.64	0.35	0.29*	0.64	0.36	0.28*	0.64	0.71	–0.07	26
Calcium	1	2.02	1.63	0.39*	2.02	2.37	–0.35	2.02	4.71	–2.69*	19-21
	2	2.08	1.74	0.34	2.08	2.42	–0.34	2.08	4.91	–2.83*	24-26
Magnesium	1	0.36	0.36	0	0.36	0.33	0.03	0.36	0.89	–0.53	12-15
	2	0.39	0.33	0.06	0.39	0.28	0.11	0.39	0.94	–0.55*	17-20
Sodium	1	1.54	1.15	0.39*	1.54	1.33	0.21*	1.54	1.61	–0.07	21
	2	1.60	1.24	0.36*	1.60	1.38	0.22*	1.60	1.71	–0.11	26
Chloride	1	0.85	0.48	0.37*	0.85	0.50	0.35*	0.85	0.61	0.24*	21
	2	1.13	0.70	0.43	1.13	0.66	0.47	1.13	0.72	0.41	26
Alkalinity	1	4.8	4.7	0.1	4.8	6.4	–1.6*	4.8	14.8	–10.0	21
	2	5.1	5.1	0	5.1	6.6	–1.5*	5.1	15.6	–10.5*	26
Hardness	1	6.7	5.6	1.1	6.7	7.1	–0.4	6.7	15.8	–9.1*	19-21
	2	6.9	5.6	1.3	6.9	7.3	–0.4	6.9	16.4	–9.5*	24-26
Electrical conductivity	1	17.5	14.5	3.0*	17.5	17.2	0.3	17.5	31.8	–14.3*	21
	2	17.9	14.7	3.2*	17.9	17.2	0.7	17.9	33.1	–15.2*	26
Hydrogen ion (pH)	1	6.7	6.7	0	6.7	6.9	–0.2*	6.7	7.1	0.4*	21
	2	6.6	6.7	–0.1	6.6	6.9	–0.3*	6.6	7.1	–0.5*	26
Total phosphorus	1	.015	.010	.005	.015	.010	.055	.015	.028	–0.13*	11-14
Silica	1	10.7	9.2	1.5	10.7	9.8	0.9	10.7	9.7	1.0	26
Total organic carbon	1	10.6	7.1	3.5*	10.6	6.9	3.7*	10.6	10.1	0.5	21
Total inorganic carbon	1	0.99	1.21	-0.22	0.99	1.23	-0.24	0.99	2.41	-1.42*	21
Dissolved solids	1	51.8	40.9	10.9	51.8	36.9	14.9*	51.8	49.1	2.7	25-26
Suspended sediment	1	1.5	0.9	0.6*	1.5	0.7	0.8*	1.5	4.1	-2.6*	25-27
Colour (W.Q. Br.)	1	45	24	21*	45	28	17*	45	48	-3	19
Colour-unfiltered (PFRC)	1	47	12	35*	47	12	35*	47	61	–14	26-27
Colour-filtered (PFRC)	1	43	11	32*	43	11	32*	43	45	-2	26-27

[a] Units mg/l except for electrical conductivity (μmho/cm), pH and colour (Pt-Co unit)

* Difference significant at the 5% level

1 - Water Quality Branch or PFRC data only

2 - Water Quality Branch + PFRC data

Table 5. Comparisons of water quality data between sites J_1-J_2 and D_1-D_2[a]

Variable	June 13 Site J_1	June 13 Site J_2	June 13 Diff.	August 6 Site J_1	August 6 Site J_2	August 6 Diff.	June 13 Site D_1	June 13 Site D_2	June 13 Diff.	August 6 Site D_1	August 6 Site D_2	August 6 Diff.
Total Kjeldahl Nitrogen	0.190	0.189	−0.001	0.2	0.1	−0.1	0.171	0.193	0.21	0.1	0.1	0
Nitrate-nitrogen	<.002	<.002	–	0.007	0.026	0.019	.002	.002	–	.005	.004	−.001
Potassium	0.3	0.3	0	0.5	0.3	−0.2	0.3	0.4	0.1	0.3	0.3	0
Calcium	1.2	1.2	0	2.9	2.9	0	0.79	1.0	0.21	1.9	2.0	0.1
Magnesium	0.1	0.1	0	0.2	0.4	0.2	0.3	0.3	0	0.3	0.4	0.1
Sodium	1.2	1.0	−0.2	0.8	1.4	0.6	0.9	1.2	0.3	1.1	1.5	0.4
Chloride	0.3	0.4	0.1	0.4	0.5	0.1	0.35	0.50	0.15	0.6	0.7	0.1
Alkalinity	3.5	3.0	−0.5	6.1	8.6	2.5	1.9	2.0	0.1	4.9	6.7	1.8
Hardness	3.5	3.5	0	7.9	8.7	0.8	3.0	3.5	0.5	6.0	6.8	0.8
Electrical Conductivity	11.0	11.8	0.8	17.9	19.0	1.1	10.2	12.3	2.1	14.1	16.6	2.5
Hydrogen Ion (pH)	6.5	6.6	0.1	6.9	7.0	0.1	6.1	6.2	0.1	6.8	7.0	0.2
Total Phosphorus	0.004	.003	−0.001	0.013	0.011	−0.002	–	–	–	.009	.010	.001
Sulphate	<1.0	<1.0	–	1.9	1.1	−0.7	<1.0	<1.0	–	1.4	1.4	0
Silica	4.0	5.3	1.3	10.9	10.9	0	2.7	3.6	0.9	12.0	14.2	2.2
Total Organic Carbon	8.1	8.6	0.5	5.7	3.8	−1.9	10.8	10.7	−0.1	5.5	5.6	0.2
Total Inorganic Carbon	0.8	0.7	−0.1	3.0	1.4	−1.6	0.5	0.5	0	6.0	2.5	−3.5
Colour-unfiltered (PFRC)	–	8	–	10	15	5	10	12	2	20	30	10

[a] Units mg/l except for electrical conductivity (μmho/cm), pH, and colour (Pt-Co unit)

Total Kjeldahl nitrogen

At site D_2, the mean concentration of total Kjeldahl nitrogen, a measure of total organic nitrogen plus ammonia, was only slightly higher than at sites D_1 and J_2, but was significantly lower than in Penticton Creek (Table 4). PFRC analyses gave slightly higher values than those done by the Water Quality Branch (Appendix 3). However, even overall maximum values were very low, being less than the threshold level of 0.6 mg/l required for production of nuisance algal blooms. Table 5 shows no increase in concentrations in James Creek on June 13 or August 6, while Figure 3 shows that the major difference in Dennis Creek occurred during April and early May. For most of the study period, differences between sites D_1 and D_2 were small and variable. Thus, the effect of logging on total Kjeldahl nitrogen levels, if any, is uncertain. If there was an effect, it was short-lived and very small.

Nitrate-nitrogen

Mean concentrations of nitrate-nitrogen were very low at all sites (Table 3), and several individual values at all sites were below the limit of detection (.002 mg/l). The mean level at site D_2 was lower than those for all other sites when only Water Quality Branch data are considered, but a little higher than those at sites D_1 and J_2 when PFRC data are included (Table 4). On August 6, the concentration at the lower site J_2 on James Creek was higher than at the upper site J_1, indicating that natural increases can occur (Table 5). Concentrations at site D_2 were higher than at site D_1 on only 5 of 27 days. The maximum concentration at site D_2 of 0.368 mg/l (PFRC data) exceeded the lower limit of 0.3 mg/l required for potential development of nuisance algal blooms. However, this value was measured on only 1 day's sample, was twice as high as the next highest value, and is possibly greater than the actual value due to limitations of analytical procedures (assumption based on cross-checks with Water Quality Branch data). All data were well within the drinking water standard of 10 mg/l. Thus, logging appears to have had no significant influence on nitrate concentrations in Dennis Creek.

Potassium

Concentrations of potassium at site D_2 were significantly greater than those at sites D_1 and J_2, but the mean value was still slightly less than that for Penticton Creek and all data were relatively low (Table 4). There was no increase in concentration between upper and lower sites on James Creek on June 13 or August 6 (Table 5). Figure 4 shows that much of the increase in Dennis Creek occurred during spring snowmelt in April and May, while there was very little change during August and September. From these results, it seems reasonable to infer that logging resulted in increased leaching of potassium.

Calcium

The mean concentration of calcium at site D_2 was significantly higher than at site D_1 (Water Quality Branch data only) but still lower than in James or Penticton creeks (Table 4). On June 13 and August 6, there were no changes in calcium concentrations in James Creek, but small increases in Dennis Creek (Table 5). As shown in Figure 5, calcium levels at site D_2 were not continuously higher than at site D_1. The largest differences occurred in May and again in late October-November. Even the maximum value at site D_2 of 3.8 mg/l is considerably lower than the desirable drinking water standard of 75 mg/l. While it is possible that some of the increase in calcium levels in Dennis Creek might be attributable to logging, the evidence is inconclusive and the changes minor and of little practical significance.

Magnesium

Magnesium concentrations changed very little in Dennis Creek. PFRC data indicate a small increase in April and May. Also, using PFRC data, the mean level was slightly higher at

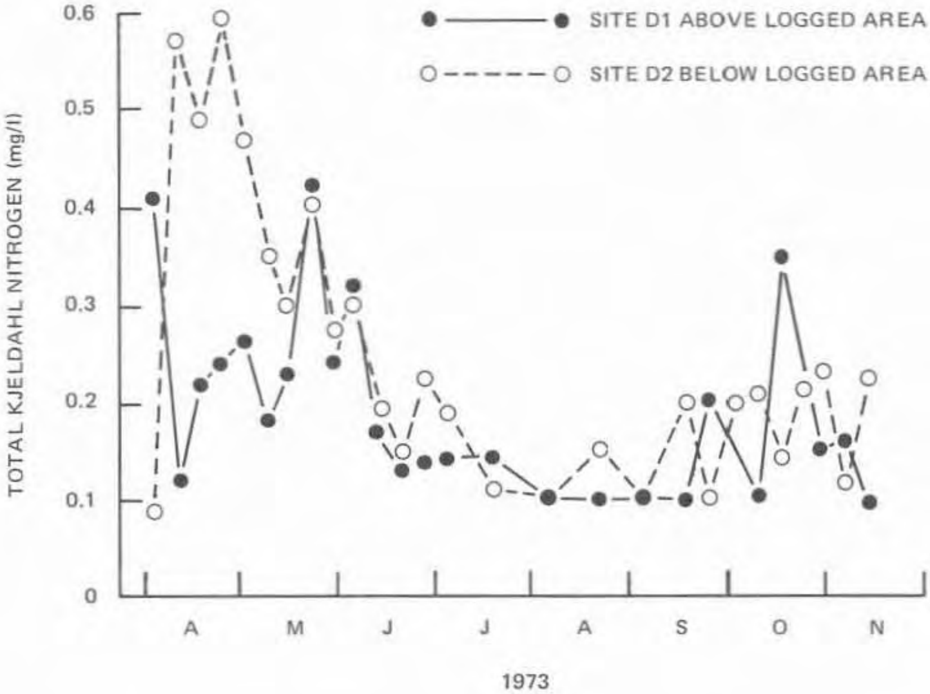


Figure 3. Concentrations of total Kjeldahl Nitrogen in Dennis Creek.

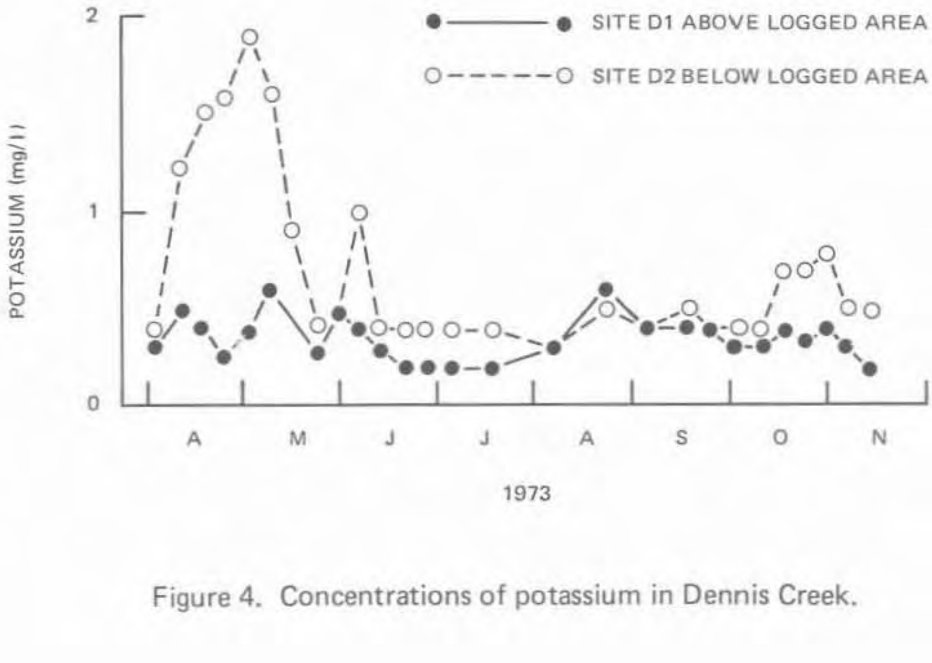


Figure 4. Concentrations of potassium in Dennis Creek.

D_2 than at D_1 or J_2, but definitely lower than in Penticton Creek (Table 4). On August 6, the magnesium concentration was higher at site J_2 than at site J_1, indicating that natural increases might occur (Table 5). All measured values were much lower than the drinking water standard of 50 mg/l. Logging thus had no discernible influence on magnesium levels in Dennis Creek.

Sodium

Sodium concentrations exhibited a small but significant increase between sites D_1 and D_2; the mean concentration at site D_2 was also significantly higher than at site J_2, but slightly lower than in Penticton Creek (Table 4). The PFRC analyses gave slightly higher values than those done by the Water Quality Branch, but the relative differences between sites remained unchanged (Appendix 3). Comparative data between upper and lower sites on James Creek were inconclusive in terms of indicating a natural trend, values at site J_2 being both lower (June 13) and higher (August 6) than at site J_1 (Table 5). However, Figure 6 shows that the increase in sodium concentrations in Dennis Creek extended throughout most of the study period at a fairly constant level. Thus, it is reasonable to infer that logging has resulted in a minor increase in sodium levels in Dennis Creek.

Chloride

Concentrations of chloride were significantly higher at site D_2 than at the other three sites (Table 4). The differences are statistically significant using Water Quality Branch data only. However, natural increases in chloride levels between upper and lower sites on James Creek of 0.1 mg/l were measured for both June 13 and August 6 samples (Table 5). Increases of 0.15 and 0.1 mg/l between sites D_1 and D_2 were recorded for the same dates. Figure 7 shows that chloride levels were higher at D_2 for most of the study period except the middle of April. PFRC analyses tended to give higher values than those done by the Water Quality Branch. However, even the maximum value of 5.6 mg/l at site D_2 is well below the desirable drinking water standard of 25 mg/l. These results suggest that a portion of the change in chloride concentrations in Dennis Creek could have been a result of the effects of logging.

Alkalinity

Alkalinity is defined as the capacity of a solution to neutralize acid (8). For water with a pH less than 8.3, as is the case for study area streams, alkalinity is mainly produced by bicarbonate ions. Data given in this report are for total alkalinity, which also includes any carbonate ions present, and which is expressed in mg/l of calcium carbonate ($CaCO_3$). There was no significant net change in alkalinity in Dennis Creek (Table 4). In fact, values at site D_2 were alternately higher and lower than at site D_1 on different days. Similarly, in James Creek, the alkalinity at site J_2 was higher than at site J_1 on August 6 but lower on June 13 (Table 5). The alkalinity in Dennis Creek was significantly lower than in either James or Penticton creeks and was also below the desirable range for municipal water supplies of 30-500 mg/l $CaCO_3$ (Tables 3, 4).

Hardness

Hardness is associated with effects observed in the use of soap which result from cations forming insoluble compounds with the soap. Most of this effect is due to the presence of calcium and magnesium. Total hardness includes the concentrations of these two ions and is expressed in terms of mg/l of calcium carbonate. Soft water has a hardness range of 0-60 mg/l $CaCO_3$ (8).

Hardness levels increased slightly in Dennis Creek but remained lower than those in both James and Penticton creeks (Table 4). A small increase in James Creek was measured for the August 6 samples indicating that natural increases probably occur (Table 5).

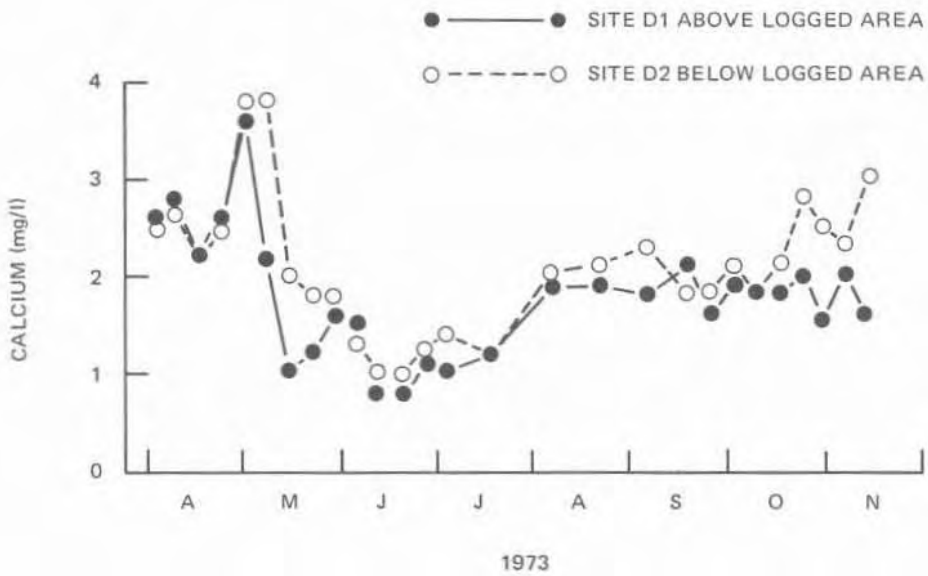


Figure 5. Concentrations of calcium in Dennis Creek.

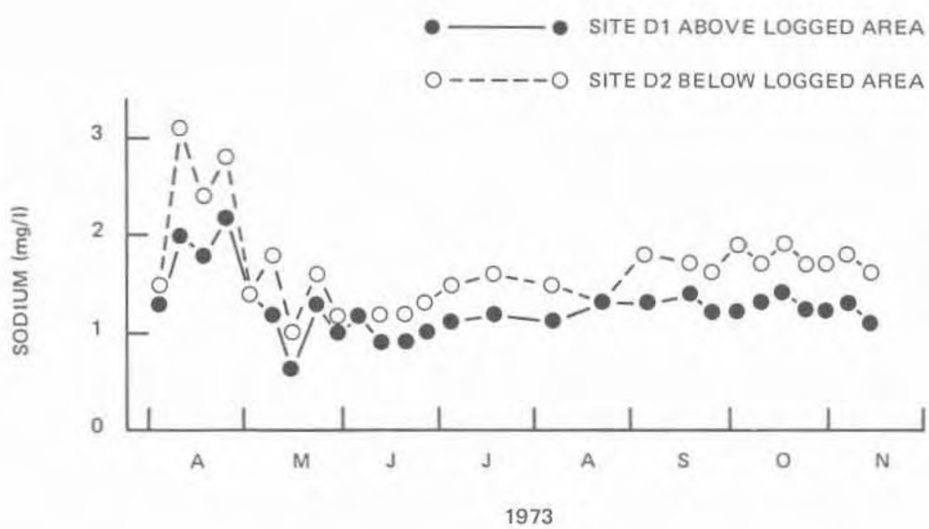


Figure 6. Concentrations of sodium in Dennis Creek.

Hence, changes in hardness which might be attributed to logging effects were likely very small. The hardness in all streams was in the soft range and well below the desirable limit of 120 mg/l $CaCO_3$.

Electrical conductivity

Electrical conductivity, or specific conductance, measures the ability of water to conduct an electric current and is directly related to the total concentration of ions in solution. The unit of measurement is micromhos per centimetre (μ mho/cm) at a standard temperature of 20°C. Electrical conductivity values at site D_2 were significantly higher than those at site D_1, only slightly higher than at site J_2 and significantly lower than in Penticton Creek (Table 4). Levels for June 13 and August 6 samples from James Creek were higher at site J2 than at site J_1, but the increases were lower than those between sites D_1 and D_2 for the same dates (Table 5). Figure 8 shows that the differences between sites D_1 and D_2 were relatively small but consistent during the study period. These results suggest a minor but positive overall increase in ion concentration in Dennis Creek as a result of logging.

Hydrogen ion (pH)

The hydrogen ion concentration or pH, a measure of the acidity of water, remained essentially unchanged in Dennis Creek, where pH values were significantly lower than in James and Penticton creeks (Table 3, 4). For both June 13 and August 6 samples, pH values were slightly higher at sites J_2 and D_2 than at sites J_1 and D_1, respectively (Table 5). The mean pH value in all creeks remained within the desirable range of 6.5-8.3 for drinking water.

Total phosphorus

Total phosphorus includes dissolved phosphates and insoluble phosphorus which is attached to or part of suspended sediment and thus not readily available for aquatic plant or algae growth. Concentrations of total phosphorus at site D_2 were slightly higher than at sites D_1 and J_2 but lower than in Penticton Creek (Table 4), but remained at low levels in all creeks, partly as a result of low suspended sediment loads. Changes in total phosphorus levels in Dennis Creek were too small to conclude that they resulted from logging.

Sulphate

Nearly half of the samples from all sites had sulphate concentrations less than 1 mg/l, the lower limit for the analytical procedure used. Hence, meaningful comparisons of mean values are not possible. Of the remaining samples, no trend was evident for Dennis Creek as sulphate levels at site D_2 were both greater and less than at site D_1. The maximum value of 3.0 mg/l at site D_2 is well below the desirable drinking water standard of 250 mg/l. No conclusions can be drawn as to the effect of logging.

Silica

The mean concentration of reactive silica at site D_2 was slightly higher than those at the other three sites (Table 4). Figure 9 shows that silica concentrations at site D_2 were much the same as at site D1 until July, after which they remained at a higher level. An increase in silica concentration of 1.3 mg/l occurred in James Creek on June 13, which compares with an increase of 0.9 mg/l in Dennis Creek for the same date (Table 4). In contrast, there was no measured increase between sites J_1 and J_2 on August 6, but a change of 2.2 mg/l in Dennis Creek. The results suggest that some of the increase in silica in Dennis Creek might be attributable to logging, although this conclusion cannot be made with any certainty.

Total organic carbon

Total organic carbon concentrations serve as a comprehensive indicator of the presence of

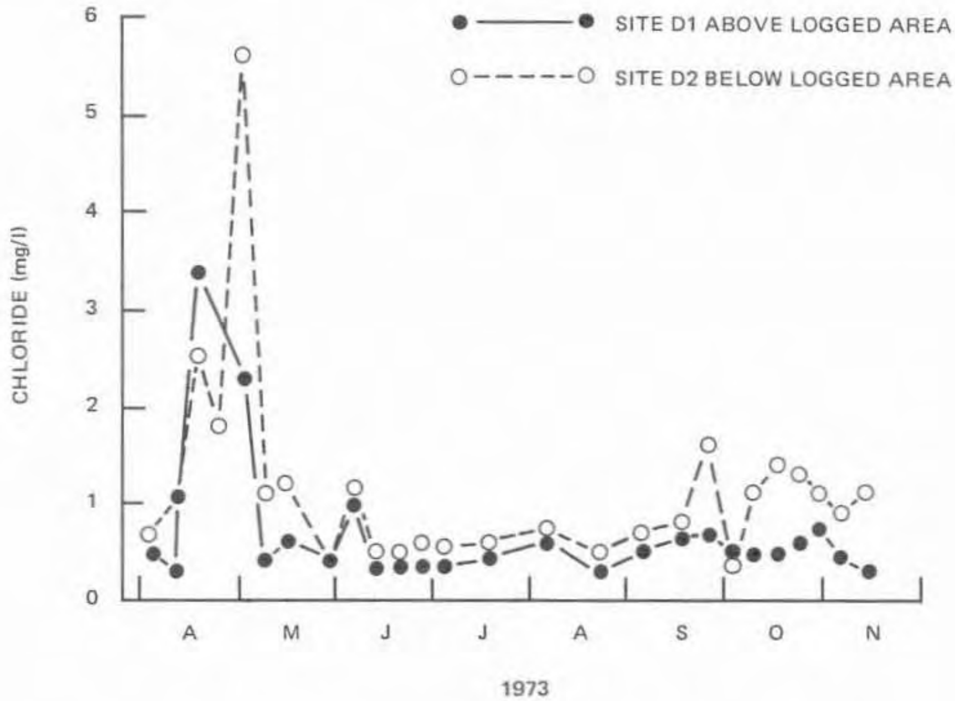


Figure 7. Concentrations of chloride in Dennis Creek.

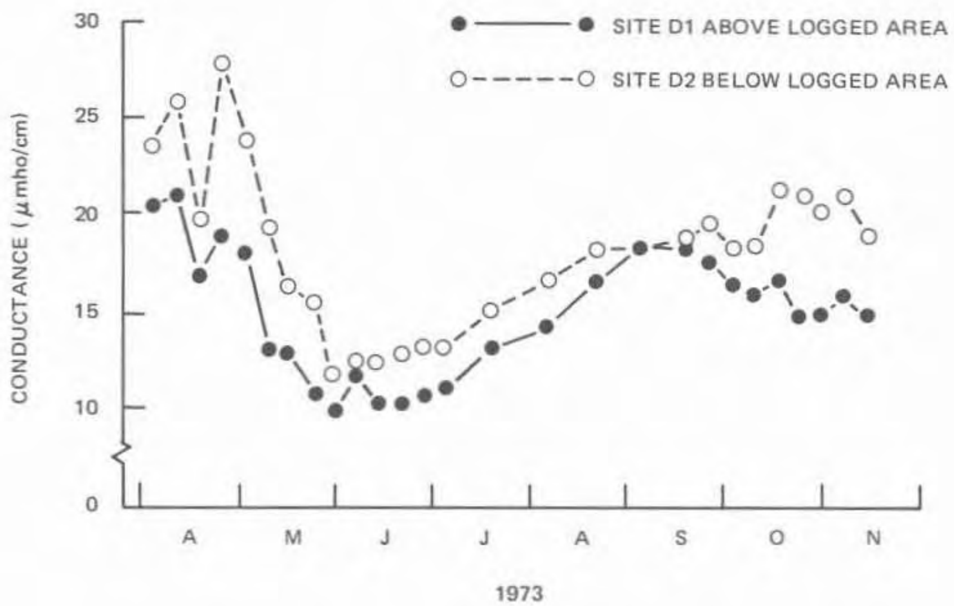


Figure 8. Electrical conductivity values in Dennis Creek.

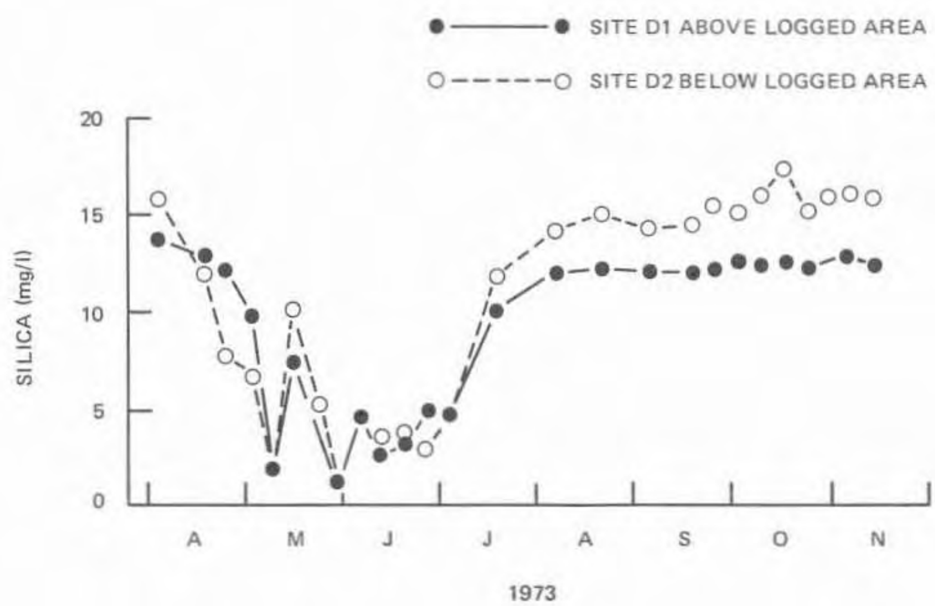


Figure 9. Concentrations of reactive silica in Dennis Creek.

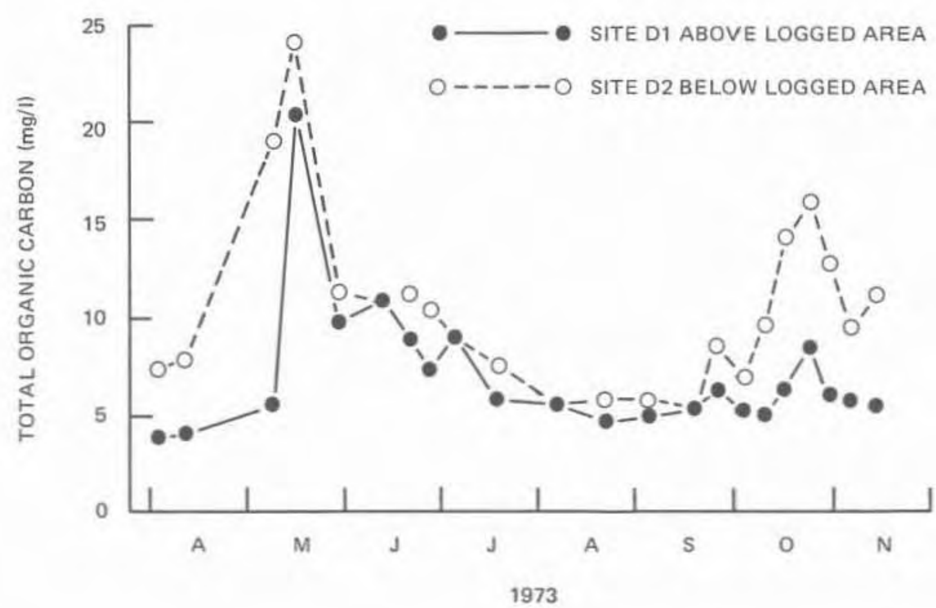


Figure 10. Concentrations of total organic carbon in Dennis Creek.

organic material, both dissolved and suspended, in the water. The mean concentration of total organic carbon at site D_2 was significantly higher than at sites D_1 and J_2 and slightly higher than in Penticton Creek (Table 4). Figure 10 shows that levels at site D_2 were consistently higher than at site D_1, the greatest differences occurring during the spring run-off period (April-May) and in the fall (October-November). No natural trend was evident for James Creek as the value at site J_2 was higher than that at site J_1 on June 13 but lower on August 6 (Table 5). From these results, it is reasonable to infer that much of the increase in total organic carbon in Dennis Creek, at least in the spring and fall, occurred as a result of logging.

Total inorganic carbon

The mean concentration of total inorganic carbon was actually lower at site D_2 than at the other sites (Table 4). In James Creek, total inorganic carbon levels also decreased down-stream, being lower at site J_2 than at site J_1 on June 13 and August 6 (Table 5). The significance of these results is not known, nor is the evidence sufficient to infer any logging-induced influence.

Dissolved solids

The total concentration of dissolved material, which includes the other constituents already discussed, was obtained as the residue on evaporation. The mean concentration of dissolved solids at site D_2 was higher than at the other three sites (Table 4), although maximum values at sites D_1 and J_2 were greater than at site D_2 (Table 3). Figure 11 shows that levels at site D_2 were higher than at site D_1 for all but two samples. It seems probable that at least a portion of this increase might be attributed to the effects of logging.

Suspended sediment

Concentrations of suspended sediment remained at very low levels during the study period; the peak value for Dennis Creek (D_2) was only 7 mg/l (Table 3). Levels at site D_2 were slightly higher than at sites D_1 and J_2 but still lower than in Penticton Creek, and below the desirable drinking water standard of 25 mg/l (Tables 3, 4). To place these results in perspective, snowmelt water running down the main road on April 3, 1973 carried sufficient sediment into Penticton Creek to raise the sediment concentration down-stream from the road to 213 mg/l. Subjective observations of Dennis Creek water taken from May to August of 1972 indicate that occasional inputs of sediment did occur during the first year after logging[4]. However, during 1973, very little sediment entered Dennis Creek from logged areas.

The principal potential sediment sources were located along two small tributaries and at one road crossing. The sediment sources associated with the tributaries were the result of skidding operations across and in the vicinity of the tributary channels. The lack of sediment in Dennis Creek in 1973 can be attributed to several factors. First, and perhaps most important, the buffer strip of trees left along Dennis Creek afforded excellent protection, preventing direct disturbance of the main creek channel and adjacent banks. Second, winter harvesting resulted in minimal soil disturbance over most of the logged area because of the protective snow cover. Third, the relatively gentle slopes in the logged areas tend to minimize the erosive force of water. Additional factors were the below-average snowmelt runoff and the possible removal of readily erodible material during 1972, the first year of logging.

Colour

Colour measurements performed by both the PFRC and the Water Quality Branch are based on arbitrary units using a

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4 Personal communication from Fred Marshall, Northwood Properties.

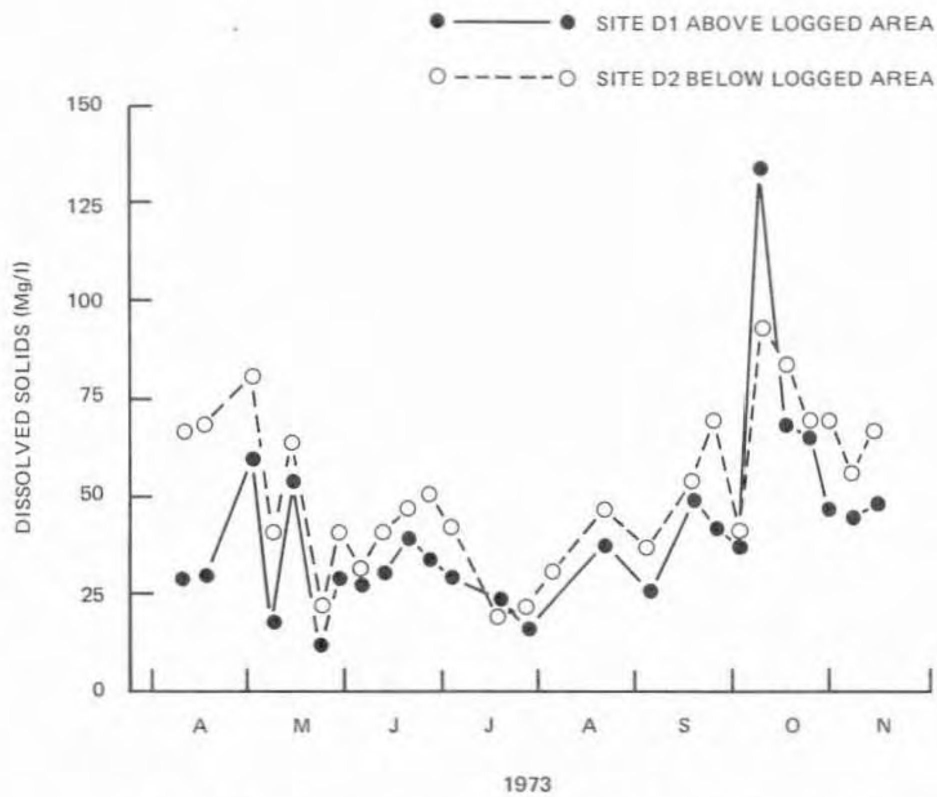

Figure 11. Concentrations of dissolved solids in Dennis Creek.

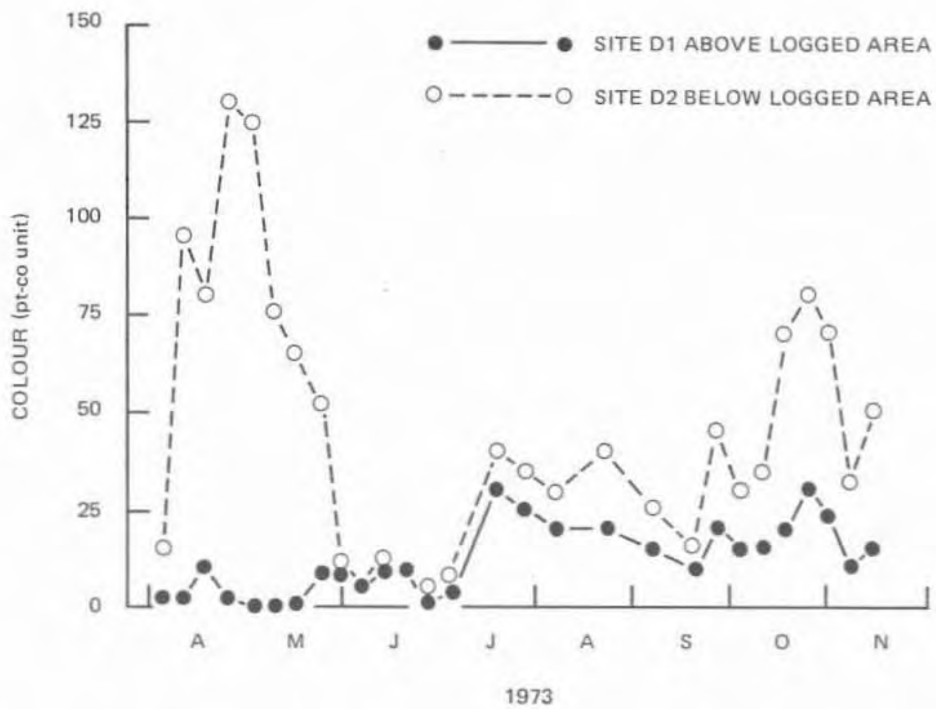

Figure 12. Colour values in Dennis Creek (data from unfiltered samples analyzed at PFRC lab).

platinum-cobalt standard. Although there is some variation between data obtained by the two agencies, the basic results are identical. For all three colour measurements, the mean values at site D_2 were significantly higher than at sites D_1 or J_2, but lower than in Penticton Creek (Table 4). Reservoir storage may have influenced colour in Penticton Creek, as noted in the next section. A small colour increase in James Creek on August 6 (Table 5) suggests that some of the increase in Dennis Creek might have occurred in the absence of logging (Table 5). Figure 12 shows that the colour at site D_2 was consistently higher than at site D_1, except during June, and that the greatest increases occurred during the spring snowmelt period April-May and in the fall during October-November. Logging thus appears to have resulted in a significant increase in the colour of Dennis Creek water, particularly during these two periods.

Water is essentially clear when the colour value is less than the drinking water standard of 15, but becomes noticeably coloured when colour units exceed 20-40. For PFRC data, colour values of unfiltered samples exceeded 15 at site D2 on 20 of 28 (71%) sampling days also exceeded 15 on 8 of 27 (30%) sampling days at site D_1 and 7 of 27 (26%) at site J_2. For Water Quality Branch data mean colour values of unfiltered samples were higher, exceeding 15 at site D_2 in 18 of 19 (93%) samples but also exceeding 15 in 12 of 19 (63%) samples from site D_1 and 11 of 19 (58%) from site J_2. Colour values were greater than 15 in all unfiltered Penticton Creek samples for both PFRC and Water Quality Branch data. Colour values for the filtered samples from Dennis and James creeks were only marginally smaller than those for the unfiltered samples, indicating that very little of the colour was caused by suspended particulate material in these two streams. The PFRC data also show that suspended matter was a more important contributor to colour in Penticton Creek than in the two tributaries.

In Ontario, the maximum permissible colour limit is 75 (21). For PFRC data, this value was exceeded on only 5 of 28 (18%) sampling days at site D_2, not at all at sites D_1 and J_2, and 8 of 28 (29%) samples from site P.

The change in stream water colour was primarily due to an increase in dissolved organic material (8). Removal of the forest cover modifies the soil microclimate, resulting in an increased rate of organic matter breakdown due to warmer soil temperatures and greater micro-organism activity. The net result is an increase in the amount of organic compounds available for leaching from the soil mantle into the streams. This conclusion is supported by observed concentrations of total organic carbon, a comprehensive indicator of organic material, which also showed a significant increase in Dennis Creek. Temporal variations of organic carbon approximately paralleled those of colour, maximum increases occurring in the spring and fall. In addition to leaching, increased amounts of coloured water may move directly over the ground surface from bogs to stream channels during periods of high precipitation or snowmelt rates as a result of skid road or other soil disturbance.

Water quality in Penticton Creek

The data from Dennis Creek have also been compared with measurements from Penticton Creek. Despite the influence of logging, mean concentrations in Dennis Creek below the logged area (site D_2) remained lower than those in Penticton Creek (above the confluence with Dennis Creek) for 16 of the 20 variables, being higher only for chloride, silica, total organic carbon and dissolved solids. The water chemistry in Penticton Creek is likely modified by being stored in the reservoir located a short distance upstream from the sampling site P (Fig. 2). Water colouring, for example, is probably enhanced during storage by prolonged contact with decaying organic matter. Water quality in Penticton Creek may also have been influenced by extensive soil disturbance associated with dam and reservoir construction, particularly downstream from the dam, and by a 9-year-old logged clearcut located to the west of the creek (Fig. 2). During another study, high colour values were also measured in Penticton Creek near its downstream end in a period prior to logging in the watershed (3).

Comparisons with other studies

To help place Dennis Creek water quality changes in perspective, it is useful to compare results of the present study with those from studies in other areas. Table 6 summarizes the characteristics of a number of study areas reported in the literature for British Columbia (5), the northwestern United States (2, 6, 7, 24, 25) and eastern North America (9, 14, 20, 23) for contrast. All studies listed in Table 6 involved streams draining total watershed areas except that by Snyder, et al. (24) in which stream water quality was measured above and below three individual logged openings. The relative changes in water quality noted in these other studies are indicated in Table 7, which also includes Dennis Creek results for comparison.

An examination of Table 7 reveals some variations in relative water quality changes among the study areas cited. Such variations could be due to a number of causes, such as differences in ecosystem characteristics, climate, extent and nature of land treatment or timing of measurements in relation to occurrence of logging or burning. In general, the range and magnitude of concentrations or values of most variables measured in the studies indicated in Table 7 were similar to those observed in the Dennis Creek study area. Also, for these study areas, including Dennis Creek, the amount of change in most variables after harvesting was small. One major exception occurred in New Hampshire, where substantial increases in nitrate (NO_3) levels, including maximum values exceeding 10 mg/l, have been reported (9, 14, 23). These excessive changes are in stark contrast to those in the present study and others reported in the literature and indicate important differences in soil, vegetation and climate, as well as post-logging treatment in the study reported by Likens, et al. (14).

Some studies indicate that changes in concentrations of some water chemistry variables are greater following slash burning than after clearcutting alone. For example, larger increases have been found for calcium (Ca), potassium (K) and magnesium (Mg) (6), alkalinity (Alk) (2, 6, 24) and nitrate-(NO3) (2, 6). There is also evidence from other studies to indicate that maximum changes in some stream water variables tend to occur during the second year following logging and/or burning: for example, nitrate (NO3) (6, 7, 9, 23, 25), magnesium (Mg) and potassium (K) (9, 25), calcium (Ca) (9, 23, 25), electrical conductivity (Con) (9, 23), sodium (Na) and pH (25). Thus, it seems possible that changes observed during the study period could have been near their maximum levels for many of the variables examined.

Duration of water quality changes

Logging-induced changes in water quality should also be viewed from the perspective of duration in space and time. In general, increased concentrations of water chemistry constituents can be expected to diminish downstream from the logged area as a result of dilution by drainage from undisturbed areas. Thus, the minor changes in Dennis Creek water would be quickly masked by flow in the larger Penticton Creek. With time, modified water-quality variable values will tend to return to pre-logging levels at a rate dependent on the rate and type of revegetation, soil, physiographic and climatic factors. For some variables, maximum concentrations have tended to occur in other areas within the first 2 years after logging and/or burning as noted above. In Oregon, changes in some variables have lasted from a few months (2) up to several years (6). The potential duration of changes in water quality in Okanagan streams is not

Table 6. Characteristics of other study areas reported in the literature

Reference	Location	Soil Texture	Soil Parent Material	Tree species[a]
5	Coastal B.C.	sandy loam	granitic till	F, H, C, D
2	Oregon	gravelly loam	sandstone	F,D
6	Oregon	loam	volcanic	F, H
7	Oregon	loam	glacial deposit	F, H, C, D
24	Idaho	silt loam	ash/till	F, Pw
25	Washington	fine	volcanic	Py, F, Ba
20	Ontario	sandy loam	glacial outwash	Pj, Sb, Bi, Pop
9	New Hampshire	sandy loam	glacial till	Be, Bi, M
14	New Hampshire	sandy loam	glacial till	Be, Bi, M
23	New Hampshire	sandy loam	glacial till	Be, Bi, M
DC[b]	Okanagan, B.C.	sandy loam	ash/(till and outwash)	Se, Ba, Pl

[a] Ba - subalpine fir; Be - beech; Bi - birch, C - cedar; D - alder; F - Douglas-fir; H - western hemlock; M - maple; Pj - jack pine; Pl - lodgepole pine; Pop - poplar; Pw - white pine; Py - ponderosa pine; Sb - black spruce; Se - Engelmann spruce

[b] Dennis Creek

Table 7. Relative changes in water quality following treatment in other study areas in comparison with Dennis Creek results

Reference	Treatment	% Area Treated	Water Quality Variable[a] NO_3	K	Ca	Mg	Na	Cl	Alk	Con	pH	TP	SO_4	Si	TOC	Col	DS
5	clearcut	20	I	I	I	I	I	I	NC	I	D		I	I			
	clearcut	60	I	I	NC	NC	NC	NC	D	I	NC		NC	NC			
2	patch cut	29	NC	NC													
	clearcut & burn	87	I	I													
6	clearcut	100	I	I	I	I	I		I		NC						I
	clearcut & burn	100	I	I	I	I	I		I		NC						I
7	clearcut & burn	25	I														
24	clearcut & burn	—	D,I	NC,I	I	I	I,D,NC	I,D,NC	I	I	D,I		I,D				
25	wild fire	100	I	NC	I	NC	I		I	I	NC						
20	clearcut	85-100	D	I	D	D	D	I	D	I	D	I	I		I	I	
9	strip cut	33	I	I	I	I	I	I		I	NC		D				
14	clearcut & herbicide	100	I	I	I	I	I	I					D	I			
23	clearcut	75+	I	I	I	I	I	I		I			D				
DC[b]	patch cut	25	NC	I	I[c]	NC	I	I	NC	I	NC	NC	NC	I[c]	I	I	I

[a] I = Increase D = decrease NC = no change

[b] Dennis Creek

[c] Increase not definitely attributable to logging effects

known.

Soil disturbance and erosion

The transect survey data for clearcut C indicate that 92% of the logged area remained undisturbed, 7% had deep and 1% shallow mineral soil disturbance. Felling and yarding over snow thus left most of the ground surface virtually undisturbed. Almost all of the soil disturbance in this opening was associated with the main haul roads, landings, and with skidding operations along a portion of the tributary creek channel which passes through the clearing.

Transect survey data indicated a greater amount of soil exposure in clearcut A, 68% being undisturbed, 18% deep and 14% shallow mineral soil disturbance. Disturbed areas were fairly evenly distributed among different land slope classes. Most of the soil disturbance was associated with haul roads, landings and skid roads. The latter accounted for most of the increase in soil exposure over that in clearcut C because skidding in clearcut A took place over a much shallower snowpack. Skidding operations also disturbed the soil in and adjacent to the tributary creek channel in opening A.

Soil disturbance is mainly detrimental to water quality when it results in erosion leading to stream sedimentation. Evidence of erosion which would have resulted in some sediment inputs to Dennis Creek were noted in three locations: namely, adjacent to the tributary creeks in openings A and C and at the haul road crossing of Dennis Creek between openings B and C, the latter being a very minor sediment source. There was also some downslope movement of soil, mostly fine sands, below several culvert outlets at haul road intersections. At these points, a short path had been bull-dozed away from the road to ensure water flow from the culverts onto the forest floor. Water draining down the ditches leading to the culverts picked up sand and soil along the ditches themselves, from drainage across road surfaces and from exposed soil in the bull-dozed paths. This material was transported across the forest floor for distances up to 75 metres on 6-10% slopes and up to 30 metres on 2-3% slopes. In no case did this transported soil appear to reach a surface stream channel. Movement of soil was only partially impeded by forest debris or slash on the ground. A leveling off of the slope was observed to be more effective in stopping soil movement.

Management considerations

The surface soils in the lower portion of Dennis Creek watershed, the volcanic ash and fine sands, are easily erodible materials. However, to become a source of stream sediment, exposed soil requires a fairly direct connection with a stream channel. In logging operations, much can be done to avoid creating conditions conducive to erosion and stream siltation. The buffer strip along Dennis Creek is a good example. Protection of smaller, definable tributaries is also important. Where buffer strips are not feasible, special attention should be given during the yarding operation to minimize disturbance in the vicinity of the tributary channel. Common sense should dictate measures to be taken for specific sites. For winter operations, creek channels should be flagged to ensure that their locations are clearly marked. Machine operators should also be adequately briefed on the value and necessity of stream protection, particularly for smaller tributaries which may not seem too important.

The smaller tributary streams should also be considered in locating haul roads and landings and thus in designing cutting units. If a sufficient volume and velocity of running water is available, such as from a roadside ditch, soil or sediment can be moved a considerable distance overland as already noted. Consequently, for the soil types encountered in the study area, culvert location and distance from stream channel should be taken into account in planning logging operations. If a stream channel is nearby, bulldozed paths below culvert outlets should be avoided or kept narrow, level and screened with loose slash.

CONCLUSIONS

Logging in the Dennis Creek watershed does appear to have resulted in measureable but generally minor changes in stream water quality, as detected during the second year after harvesting. Specifically, concentrations or values of the following variables were found to have increased as a result of logging: namely, colour, total organic carbon, potassium, sodium, chloride, electrical conductivity and dissolved solids. In addition, levels of calcium, hardness and silica also experienced minor increases which could reasonably be attributed to logging effects but for which results were inconclusive. The variables for which no logging influence could be discerned were total Kjeldahl nitrogen, nitrate, total phosphorus, magnesium, alkalinity, pH, sulphate and total inorganic carbon. Based on control data for James and Penticton creeks and from reports on both harvesting and slash burning effects for other areas in North America, the water quality changes observed were generally within the natural range of variation for the study area (upper Penticton Creek watershed) and comparable or lower in magnitude to those found elsewhere.

The quality of water in Dennis Creek was not impaired for drinking, although the colour of Dennis Creek below the logged area did exceed the desirable standard for drinking water for a portion of the study period. This increased colour would not alter the quality of water from a health viewpoint but would alter its aesthetic appearance. However, this change in Dennis Creek water would be masked by dilution in Penticton Creek, to which it is a tributary and which had a slightly higher mean colour value. Neither was Dennis Creek enriched with nutrients which would stimulate excessive aquatic plant growth. The primary plant nutrients, nitrogen and phosphorus, remained at very low levels.

The present study has monitored, over a relatively short time span, one type (ground skidding, winter operation) and extent (25% patch cut) of land treatment under one set of vegetative, physiographic and climatic conditions. The results represent one point in a spectrum of possibilities. It seems probable that logging effects on water quality would increase with increasing percentage of watershed area cutover, assuming that source areas contributing to change are affected. However, measurements in other areas have shown that changes in water chemistry due to harvesting alone remain relatively small even for totally clearcut watersheds. Two exceptions would appear to be colour, reported in only one other logging-effect study cited (20), and sediment. Other studies have shown that larger changes in some water quality variables might be anticipated following broadcast slash burning than from harvesting alone. Even then, observed changes due to fire have been small relative to drinking water standards for most chemical constituents. However, the potential is greater for significant changes in nutrient concentrations needed to promote growth of aquatic plants.

In conclusion, further investigation is needed to define the potential magnitude and duration of changes in the following water quality parameters in Okanagan Basin streams due to forest harvesting plus slash burning: namely nitrogen, phosphorus, colour, and sediment. Measurements should be taken in watersheds with a relatively high proportion of the drainage area cut and burned to record the maximum probable effects. Changes that are likely to occur in other chemical constituents monitored in the present study should not significantly alter the quality of stream water for drinking or most other uses. The problem of sediment in stream water can be avoided for the most part, using existing knowledge,by prudent forest management practices from the planning stage to field operations. In this regard, further information and research on site-specific soil erosion hazard and soil-water interactions would be helpful.

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APPENDIX I

Description of soil profile physical and chemical properties

Soil Profile Description

Horizon	Depth (cm)	Particle size (%) Sand	Silt	Clay	Texture	Colour (moist)
Site no. 2	Parent material: Aeolian/granitic till Drainage: moderately well Slope: 20% Aspect: 160°					
L-F	5-0	–	–	–	–	–
Ae	0-5	60	36	4	Sandy loam	10YR 3/2
Bf1	5-13	62	34	4	Sandy loam	7.5YR 3/2
Bf2	13-25	65	31	4	Sandy loam	10YR 3/4
II BC	25-64	72	24	4	Sandy loam	10YR 4/2
II CB	64-107	75	22	3	Loamy sand	10YR 6/1
II C	107+	–	–	–	–	10YR 6/1
Site no. 3	Parent material: Aeolian/granitic till Drainage: imperfect Slope: 12% Aspect: 260°					
L-F-H	6-0	–	–	–	–	–
Ah	0-6	–	–	–	–	5YR 2/2
Ahe-Aeh	6-17	56	36	8	Sandy loam	5YR 2/2
AB	17-28	68	24	8	Sandy loam	5YR 2/3
Bhf1	28-43	77	15	8	Loamy sand	5YR 3/3
Bhf2	43+	80	13	7	Loamy sand	5YR 3/3
Site no. 4	Parent material: Aeolian/glacio-fluvial sands Drainage: well Slope: 15% Aspect: 255°					
L-F	5-0	–	–	–	–	–
Ae-Ah	0-10	69	25	6	Sandy loam	10YR 4/2
Bm1-Bf	10-17	70	24	6	Sandy loam	7.5YR 4/4
Bm2	17-36	74	22	4	Loamy sand	7.5YR 5/6
II BC	36-102	94	4	2	Sand	10YR 6/4
II CB	102+	94	3	3	Sand	10YR 7/4
Site no. 5	Parent material: Aeolian/granitic till Drainage: moderately well Slope: 12% Aspect: 295°					
L-F-H	6-0	–	–	–	–	–
Ae	0-10	45	50	5	Sandy loam	–
AB	10-15	52	42	6	Sandy loam	–
Bhf	15-33	54	40	6	Sandy loam	–
II Bfh	33-58	61	33	6	Sandy loam	–
II Bf	58-86	75	21	4	Loamy sand	–
II C	86+	–	–	–	–	–

Soil Chemical Properties

Horizon	Depth (cm)	pH ($CaCl_2$)	TKN (%)	Org.C (%)	Exch. Cations (me/100 g)					Oxalate (%)		Avail. P (ppm)
					Ca	Mg	K	Na	C.E.C.	Fe	Al	
Site No. 2			Orthic Humo-Ferric Podzol				Parent Material: Aeolian/granitic till					
L-F	5.0	–	1.12	44.17	6.26	3.13	2.07	0.16	–	–	-	–
Ae	0-5	3.90	0.11	3.69	0.17	0.08	0.14	0.03	20.66	0.49	0.57	39.6
Bf1	5-13	4.40	0.07	1.88	0.07	0.02	0.07	0.04	14.20	0.52	0.77	30.8
Bf2	13-25	4.70	0.05	1.22	0.07	0.02	0.07	0.05	16.17	0.52	0.77	27.0
II BC	25-64	5.25	0.18	0.18	0.08	0.01	0.08	0.04	4.41	0.31	0.25	43.4
II CB	64-107	6.00	0.01	0.00	0.15	0.00	0.03	0.06	2.74	0.29	0.14	51.1
Site No. 3			Orthic Dystric Brunisol				Parent Material: Aeolian/granitic till					
L-F-H	6-0	–	1.20	41.86	16.77	6.68	2.40	0.17	–	–	–	–
Ah	0-6	4.05	0.94	21.70	1.21	0.38	0.17	0.10	46.12	1.35	0.94	4.6
Ahe-Aeh	6-17	4.20	0.12	2.66	0.45	0.11	0.10	0.06	18.48	0.47	0.30	4.9
AB	17-28	4.25	0.06	0.99	0.42	0.10	0.06	0.06	14.39	0.76	0.35	3.2
Bhf1	28-43	4.25	0.05	1.06	0.49	0.10	0.05	0.04	14.92	1.08	0.31	2.1
Bhf2	43+	4.30	0.05	1.06	0.47	0.09	0.05	0.05	13.90	1.09	0.39	2.1
Site No. 4			Orthic Humo-Ferric Podzol				Parent Material: Aeolian/glacio-fluvial sands					
L-F	5-0	–	1.00	43.01	0.21	3.34	1.42	0.11	–	–	–	–
Ae	0-10	4.00	0.09	3.27	0.32	0.11	0.13	0.02	13.84	0.41	0.57	59.2
Bm1-Bf	10-17	4.65	0.04	0.93	0.15	0.03	0.06	0.03	12.27	0.47	0.90	49.4
Bm2	17-36	4.85	0.03	0.61	0.34	0.03	0.05	0.03	9.20	0.38	0.74	48.3
II BC	36-102	5.50	0.00	0.08	0.62	0.07	0.07	0.03	3.28	0.19	0.11	35.7
II CB	102+	5.55	0.01	0.04	0.67	0.05	0.04	0.09	3.10	0.20	0.10	26.7
Site No. 5			Orthic Humo-Ferric Podzol				Parent Material: Aeolian/granitic till					
L-F-H	6-0	–	1.11	44.44	15.42	6.57	2.14	0.14	–	–	–	–
Ae	0-10	3.75	0.11	3.17	0.88	0.27	0.12	0.05	15.82	0.10	0.13	22.4
AB	10-15	4.30	0.07	1.59	0.20	0.06	0.09	0.03	15.64	0.37	0.65	14.0
Bhf	15-33	4.50	0.08	2.07	0.21	0.06	0.10	0.03	20.89	1.10	1.50	4.9
II Bfh	33-58	4.50	0.03	0.74	0.17	0.03	0.06	0.02	10.28	0.71	0.41	6.3
II Bf	58-86	4.60	0.01	0.30	0.15	0.02	0.04	0.03	4.22	0.37	0.17	4.2

APPENDIX 2

Description of vegetation[a]

The characteristic trees in the study watersheds (*Abies lasiocarpa* zone) are *Abies lasiocarpa* (subalpine fir) and *Picea engelmanii* (Engelmann spruce). *Pinus controta* (lodgepole pine) is the most common seral tree and to a lesser extent *Pseudotsuga menziesii* (Douglas-fir) and *Larix occidentalis* (Western larch) occur.

One habitat type and two phases are recognized.

Abies lasiocarpa - Vaccinium scoparium habitat type - Calamagrostis rubescens phase:

This phase occurs on lower and drier slopes of the zone below 1680 metres in elevation. It is characterized by *Picea engelmannii* and to a lesser extent *Abies lasiocarpa,* with the seral species *Pinus contorta* dominating many sites. *Pseudotsuga menziesii* and *Larix occidentalis* may occur as seral species.

The shrub layer is characterized by *Vaccinium scoparium* (grouseberry), *Vaccinium membranaceum* (big whortleberry), *Pachistima myrsinites* (false box), *Shepherdia canadensis* (soopolallie), *Spiraea betulifolia* (spirea) and *Ledum glandulosum* (Labrador tea).

The characteristic herb is *Calamagrostis rubescens* (pinegrass). Other herbs include *Carex concinnoides* (carex species), *Arnica cordifolia* (heart-leaf arnica), *Lupinus latifolius* (lupine), *Fragaria* spp. (wild strawberry), *Linnaea borealis* (twin flower), and *Pyrola secunda* (pyrola).

Abies lasiocarpa - Vaccinium scoparium habitat type:

This habitat type occurs at middle elevations in the zone from about 1680 to 2100 metres in elevation. It is characterized by *Abies lasiocarpa* and *Picea engelmannii. Pinus contorta* is the most important seral tree.

Shrubs include *Vaccinium scoparium, Vaccinium membranaceum, Lonicera involucrata* (black twinberry), *Lonicera utahensis* (red twinberry), *Ledum glandulosum,* and *Rhododendron albiflorum* (white rhododendron).

In the herbcover grasses are poorly represented. Herbs include *Arnica latifolia* (arnica), *Arnica cordifolia, Lupinus latifolius, Rubus pedatus* (trailing rubus), *Pedicularis bracteosa* (wood betony), *Fragaria* spp., and *Pyrola secunda.*

Seepage areas have an increased shrub cover of *Rhododendron albiflorum, Ledum glandulosum, Lonicera involucrata,* and *Ribes lacustre* (swamp gooseberry). The herbs *Valeriana sitchensis* (mountain valerian), *Veratrum virde* (Indian hellebore), *Caltha leptosepala* (white marsh marigold), *Senecio triangularis* (giant ragwort). *Trollius laxus* (globe flower), *Viola orbiculata* (round-leaf violet), *Tiarella unifoliata* (foam flower), *Listera cordata,* and *Habenaria saccata* (orchid) also commonly occur.

Abies lasiocarpa-Vaccinium scoparium habitat type--Phyllodoce empetriformis phase:

This phase occurs on the higher slopes of the zone from about 2100 to 2260 feet in elevation. It is characterized by *Picea engelmannii and Abies lasiocarpa. Pinus contorta* may also occur as a seral species. Trees tend to be somewhat wider apart and stunted (includes the Krummholz formation).

The shrub layer includes *Vaccinium scoparium, Phyllodoce empetriformis* (red heather), and lesser amounts of *Phyllodoce glanduliflora* (yellow heather). The herb layer includes *Arnica latifolius, Lupinus latifolia, Valeriana sitchensis* and *Pedicularis bracteosa.*

In wetter area *Veronica wormskjoldii, Trollius laxus, Senecio triangularis, Erigeron peregrinus, Poa juncifolia* and *Carex* spp. occur.

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[a] Information provided by R.A. Hawes

APPENDIX 3

Analytical methods

Variable		Method	Reference
TKN	WQ	digestion and titration	11
	PFRC	digestion and titration	16
NO_3-N	WQ	automated cadmium reduction	11
	PFRC	manual cadmium reduction	13
K	WQ	automated, flame photometric	11
	PFRC	atomic absorption	17
Ca	WQ	atomic absorption	11
	PFRC	atomic absorption	17
Mg	WQ	atomic absorption	11
	PFRC	atomic absorption	17
Na	WQ	automated, flame photometric	11
	PFRC	atomic absorption	17
Cl	WQ	automated, thiocyanate	11
	PFRC	manual, thiocyanate	18
Alk	WQ	titration with standard acid	11
	PFRC	titration with standard acid	18
Hd	WQ	titration with EDTA	11
	PFRC	by calculation from Ca and Mg	
Con	WQ	conductivity meter	
	PFRC	conductivity meter	16
pH	WQ	titration with standard alkali	11
	PFRC	electrometer	16
TP	WQ	manual digestion, with sulphuric acid and potassium persulphate followed by automated stannous chloride	11
	PFRC	manual digestion, followed by manual $SnCl_2$ reduction of molybdate complex in n-butanol	22
S	WQ	titration with barium chloride	11
Silica	WQ	automated ANSA	11
TOC	WQ	carbon analyzer	11
TIC	WQ	carbon analyzer	11
DS	PFRC	evaporation, gravimetric	
Sed	PFRC	filtered, gravimetric	
Colour	WQ	visual comparison (Hellige Aqua Tester)	11
	PFRC	Hach Chemical Company colorimeter	

APPENDIX 4

Results of comparative water quality analyses performed by Water Quality Branch, D.O.E., and PFRC labs for April 4 and May 15 samples

Variable		Unit	April 4, 1973				May 15, 1973			
			D_1	D_2	J_2	P	D_2	D_2	J_2	P
TKN	WQ	mg/l	.410	.090	.080	.100	.230	.300	.320	.440
	PFRC		.456	.250	.093	.285	.377	.455	.494	.461
NO_3	WQ	mg/l	.010	.010	.050	.040	.010	.010	.050	.010
	PFRC		.010	.010	.070	.030	.050	.188	.129	.124
K	WQ	mg/l	.30	.40	.30	.90	.50	.90	.70	1.10
	PFRC		.29	.55	.40	.92	.63	1.10	.53	.83
Ca	WQ	mg/l	2.6	2.5	3.0	10.5	1.0	2.0	2.3	3.1
	PFRC		3.2	2.8	3.4	12.7	2.2	2.4	3.8	4.8
Mg	WQ	mg/l	0.2	0.6	0.5	3.9	–	–	–	–
	PFRC		0.5	0.6	0.6	3.3	–	–	–	–
Na	WQ	mg/l	1.3	1.5	1.3	3.2	0.6	1.0	1.0	1.4
	PFRC		8.7	3.3	3.2	5.5	1.0	1.4	1.4	2.1
Cl	WQ	mg/1	.50	.70	.40	.90	.60	1.20	.70	.90
	PFRC		.35	.97	.16	.41	1.15	2.15	2.71	1.82
Alk	WQ	mg/l	7.9	8.9	8.9	49.0	3.0	2.0	4.0	8.0
	PFRC		9.3	9.5	10.5	47.3	2.7	2.1	5.8	7.2
Con	WQ	mho/cm	20.4	23.6	21.5	99.1	12.9	16.2	16.1	23.7
	PFRC		19.0	18.1	18.3	78.6	12.4	18.6	17.5	23.9
pH	WQ		6.7	6.7	7.0	7.3	6.0	5.9	6.3	6.5
	PFRC		6.5	6.4	6.6	7.5	6.0	5.9	6.6	6.6

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