CLEARCUTTING AND BURNING SLASH ALTER QUALITY OF STREAM WATER IN NORTHERN IDAHO

Gordon G. Snyder, Harold F. Haupt, and George H. Belt, Jr.

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EXPERIMENT STATION
Ogden, Utah 84401

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ABSTRACT

Three cutting units of varying size, soil, and aspect located along streams in the Priest River Experimental Forest in northern Idaho were chosen for evaluation of changes in water quality caused by clearcutting and subsequent burning of slash. Water sampling stations were established on each creek--upstream, downstream, and on the site of clearcut-burned areas. Except for on-site stations, buffer strips of natural vegetation were left along channels to minimize the effects of treatment. Physical and nutrient comparisons between the upstream and downstream stations showed slight increases in electrical conductivity, bicarbonate, sulfate, calcium, and magnesium. Similar comparisons between upstream and the on-site stations revealed significant increases in pH, electrical conductivity, turbidity, suspended solids, bicarbonate, sulfate, potassium, calcium, and magnesium. Nutrients that did not indicate increases for buffer strip comparisons were chloride and sodium. In general, larger increases were observed at the on-site stations, except for one station with a different drainage pattern.

INTRODUCTION

U.S. Senate Subcommittee Hearings (1971) on management of the public land focused on clearcutting of timber and subsequent burning of slash. Two major concerns were the long-term depletion of nutrients from the harvested sites and the resultant changes in stream and lake water quality. Tarrant (1971) addressing the committee pointed out that few studies of nutrient depletion have been made; and that most of these were case histories. Though useful, the resultant information has not provided a good base for extrapolation of variables from one ecosystem to another.

Natural rates of nutrient depletion from forested areas are believed to be relatively low. Likens and others (1967) at Hubbard Creek Experimental Forest in New Hampshire found small, but consistent, amounts of major nutrients leaving undisturbed ecosystems. Low natural rates of nutrient loss were also implied in a study of Montana streams (Weisel and Newell 1970). Similarly Skau and others (1971) reported nutrient export was insignificant in Nevada's Truckee River and other tributary streams draining forested lands.

Studies of such forest practices as roadbuilding, clearcutting, slash burning, and herbicide spraying have provided insight into the types of activities that affect nutrient cycles of ecosystems. Roadbuilding has been monitored since 1962 on the H. J. Andrews Experimental Forest (Rothacher and others 1967) and on the Alsea basin in Oregon (Marston 1967). Both studies suggest that road construction increased nutrient losses immediately after construction, but that total loss was small. Packer (1965) concluded from sedimentation studies in northern Idaho and western Montana that roads which were either poorly drained or too close to streams were a primary cause of water quality deterioration in forests. Fredriksen (1971) reported that cation loss increased to 3.0 times following timber harvest and slash burning in Oregon. Three years after logging, calcium and magnesium concentrations had declined from the high reached the second year after logging to a point approaching prelogging conditions. In forests of the Oregon Coast Range, complete forest removal followed by slash burning temporarily, but significantly, altered the pattern of nutrient loss (Brown and others 1973). Under the soil and revegetation conditions observed in their study, such changes did not degrade water quality with respect to nutrient levels nor did they significantly reduce the productivity of forest soils. Partial clearcutting or patch-cutting under such conditions produced no significant change in water quality.

Cole and Gessel (1963, 1968) examined nutrient movement through a forest soil before and after timber harvest. Even after highly soluble salts (urea and ammonium sulfate, both at 200 lb/acre) were added to the forest floor following cutting, only slight amounts of phosphorus, potassium, and calcium were removed beyond the watering depth. This finding demonstrated the effectiveness of the soil system to absorb elements.

After clearcutting on the Hubbard Brook Experimental Forest (Likens and others 1970), all trees and woody vegetation felled were left in place. The area was treated with herbicides for three successive summers to insure that major vegetation would not be present. During the first year after treatment, streamf low export of all ions tested, except ammonium, sulfate, and bicarbonate, was from 2 to 53 times greater on the deforested watershed. The large nutrient losses were attributed mainly to alteration of the nitrogen cycle by clearcutting and herbicide application. Two years after herbicide use was stopped, nitrate losses had decreased to the level of several other cutover forest areas nearby. The Hubbard Brook study provides information as to the highest nutrient losses that might be expected if vegetative regrowth is denied.

Summarizing results of earlier studies, Tarrant (1971) concluded:

> ...at least for a short period, removal of vegetation from a forest by any means, results in greater nutrient losses from the ecosystem than if the forest had been left undisturbed. The loss is generally small in comparison to the nutrient supply available from all sources at that site. The rate of loss declines 1 or 2 years after treatment. In considering nutrient loss, it must be understood that even with undisturbed forest cover some nutrients constantly leave the site in streamwater....

CEDAR-HEMLOCK-GRAND FIR ECOSYSTEM

The impact of timber harvesting on the quality of stream water has not been studied in the cedar-hemlock-grand fir ecosystem of the northern Rocky Mountains. As early as 1970, plot results obtained in an eastern extension of the ecosystem, and later reported by DeByle and Packer (1972), indicated a flush of nutrients transported by overland flow and sediment moving down the surface of burned, denuded clearcuts. When compared with unlogged check plots, clearcut plots produced increased amounts of total phosphorus, potassium, calcium, magnesium, and sodium for a period of 3 years after burning. However, in their plot study, measurement of the impact of nutrient-laden material upon stream water was not a consideration.

The present paper describes a stream quality study conducted on the Priest River Experimental Forest in northern Idaho. Physical and chemical components were monitored on three clearcut-burned units. Each unit and its surrounding area represented different drainage patterns. All three patterns are common in the ecosystem. Each unit was isolated from the main channel by a buffer strip of unlogged timber.

The objective was threefold: to evaluate changes in the physical and chemical quality of stream water on and off the clearcut-burned units; to characterize nutrient losses from different drainage patterns; and to determine the effectiveness of buffer strips in controlling sediment and nutrient losses. This study extended for 21 months, from the fall of 1970 through the summer of 1972.

METHODS

Study Sites

General Description

The Priest River Experimental Forest is a 2,577-ha tract in the Idaho Panhandle National Forests north of Priest River, Idaho. Mountainous terrain, with elevations ranging from 671 to 1,798 m, makes up 85 percent of the area. Benton Creek, Canyon Creek, and Ida Creek are the major drainages. The climate is predominantly maritime; 89 cm of precipitation, mostly snow, falls between October and June. Summers are warm and dry. Gross precipitation (a mixture of rain or snow and dry fallout) is collected at Headquarters meteorological station.

Soils of the mountain slopes are underlain by Precambrian metamorphic rock. Predominantly silt loam, the soils were derived from glacial till and are capped by a thick layer of volcanic ash. Soils of the lower benches are associated with silt, clay, and sand in varves and strata. Those on the stream terraces and bottom lands are associated with stratified sand and gravel substrata.

The Experimental Forest is entirely forested except for south-slope "balds," rock outcrops, and some clearcut plots. Major tree species of the ecosystem are western white pine *(Pinus monticola* Dougl.), western redcedar *(Thuja plicata* Donn), Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco), and western larch *(Larix occidentalis* Nutt.). Other forest species present are ponderosa pine *(Pinus ponderosa* Laws.), lodgepole pine *(Pinus contorta* Dougl. var. *murrayana* (Grev. & Balf.) Engelm.), western hemlock *(Tsuga heterophylla* (Raf.) Sarg.), grand fir *(Abies grandis* (Dougl.) Lindl.), subalpine fir *(Abies lasiocarpa* (Hook.) Nutt.), and Engelmann spruce *(Picea engelmannii* Parry).

Benton Creek Site

The 44-ha Benton Creek site has a topography ranging in elevation from 914 to 1,219 m. The Jughandle silt loam soil is deep and well drained, and some rock outcrops occur. South and west aspects support mainly 100-year-old Douglas-fir. Remaining areas support 140-year-old white pine.

This site was clearcut in 1969 and broadcast burned in 1970. The boundary of the clearcut is about 61 m from Benton Creek, leaving a buffer strip of natural tree vegetation. During harvesting, there was no jammer skidding of logs across the creek.

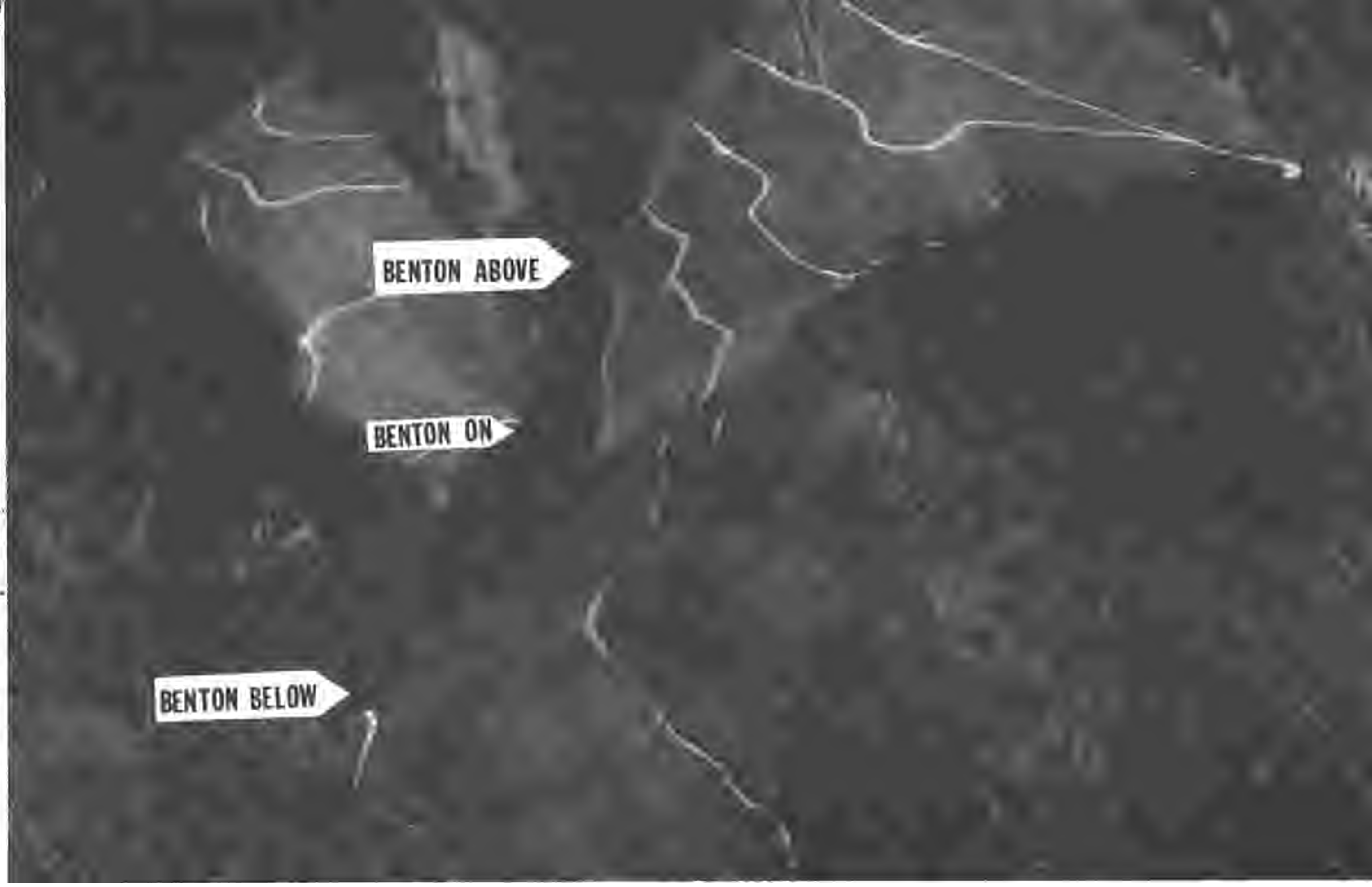


Figure 1.--Benton Creek clearcut and water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

The Benton Creek clearcut and water-quality sampling stations are shown in figure 1. The control station designated "BENTON ABOVE" is upstream from the Benton Creek clearcut at the Benton Creek stream-gaging weir. The off-site station called "BENTON BELOW" is downstream from the clearcut area. The final sampling site, "BENTON ON," is on the lower edge of the southern aspect of the clearcut. A large portion of the south-facing section of the Benton Creek clearcut drains to this point without benefit of a buffer strip. However, this ephemeral drainage flows only during periods of rapid snowmelt or heavy rainfall.

Water samples were first collected September 28, 1970, from BENTON ABOVE and BENTON BELOW. Subsequent samples were obtained weekly and after each storm until heavy snows started. Sampling was resumed as snowmelt began. Samples were also collected during brief winter periods of snowmelt, when there was flow at the on-site station.

Ida Creek Site

The Ida Creek site consists of approximately 2.6 ha at the headwaters of Ida Creek. Elevation is nearly uniform, 745 m, and topography is level. The soil is a Cabinet silty clay loam. Timber types are larch, Douglas-fir, and white pine. Tractor logging of this site was completed by August 1970, and the remaining slash was windrowed and burned in September 1970. The boundary of the clearcut 61 m above Ida Creek provides an area of undisturbed vegetation to function as a buffer strip.

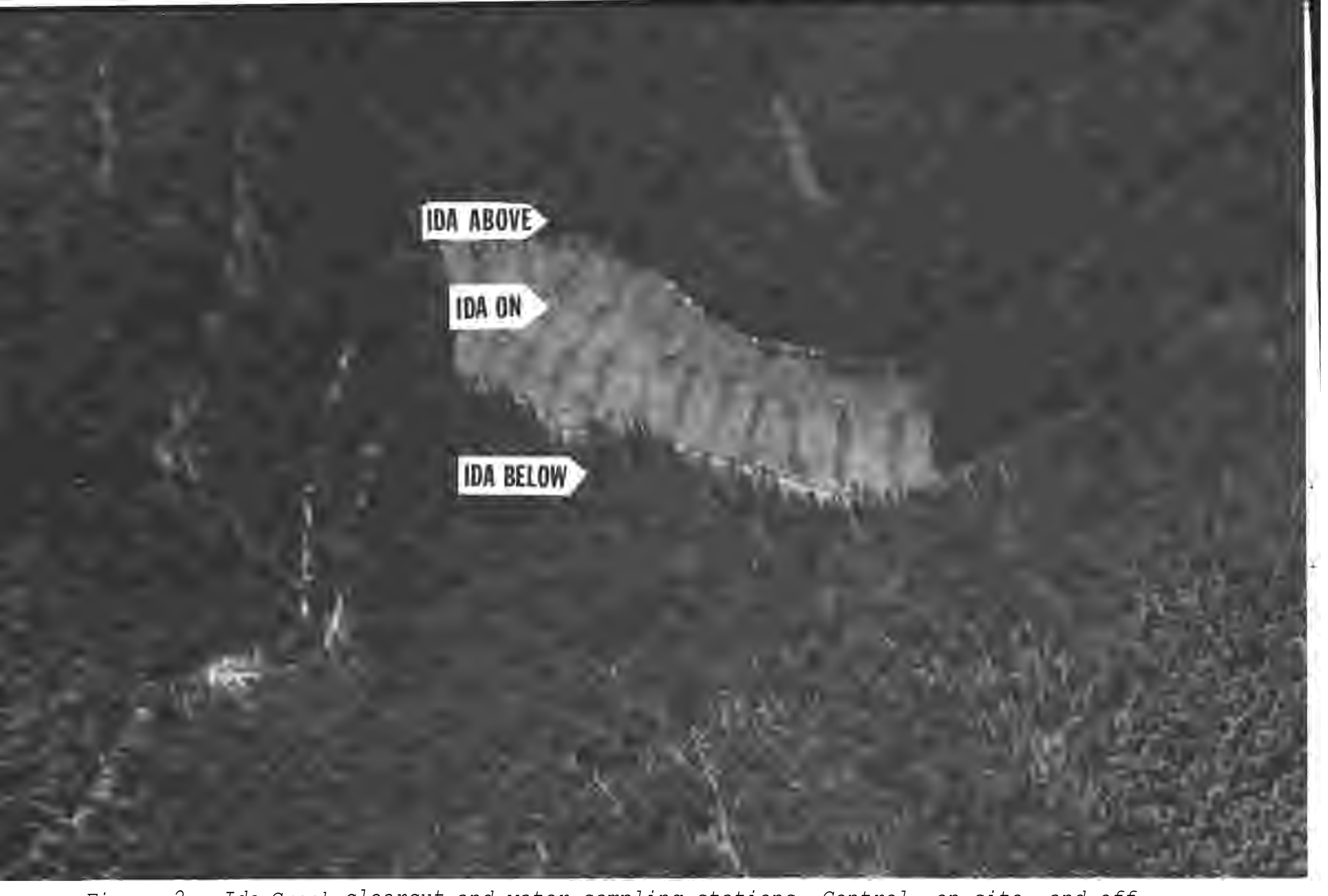


Figure 2.--Ida Creek clearcut and water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

The Ida Creek clearcut and sampling stations are shown in figure 2. From the stations labeled "IDA ABOVE" to "IDA ON," a low-volume flow from a spring crosses the clearcut without a buffer strip. After IDA ON, the surface flow spreads out, seeps underground, reemerges as the main channel of Ida Creek below the buffer strip and upstream from the off-site station designated "IDA BELOW." Interruption of surface flow from IDA ON to IDA BELOW caused atypical changes in water quality that will be discussed. Water sampling began in October 1970 at all stations. Subsequent samples were taken weekly until snow covered the stations. Sampling was resumed during the snowmelt season.

Canyon Creek Site

The Canyon Creek site, between 762-792 m in elevation, covers approximately 26 ha, of which 23 ha were clearcut and 3 ha partially cut. Three soils occur, Saltese loam, Jughandle silt loam, and Bonner silt loam. The site contained mixed stands more than 100 years old of white pine, cedar, larch, Douglas-fir, spruce, and lodgepole pine. The area was clearcut and burned the fall of 1970. The clearcut is separated from Canyon Creek proper by a buffer strip of about 30 m.

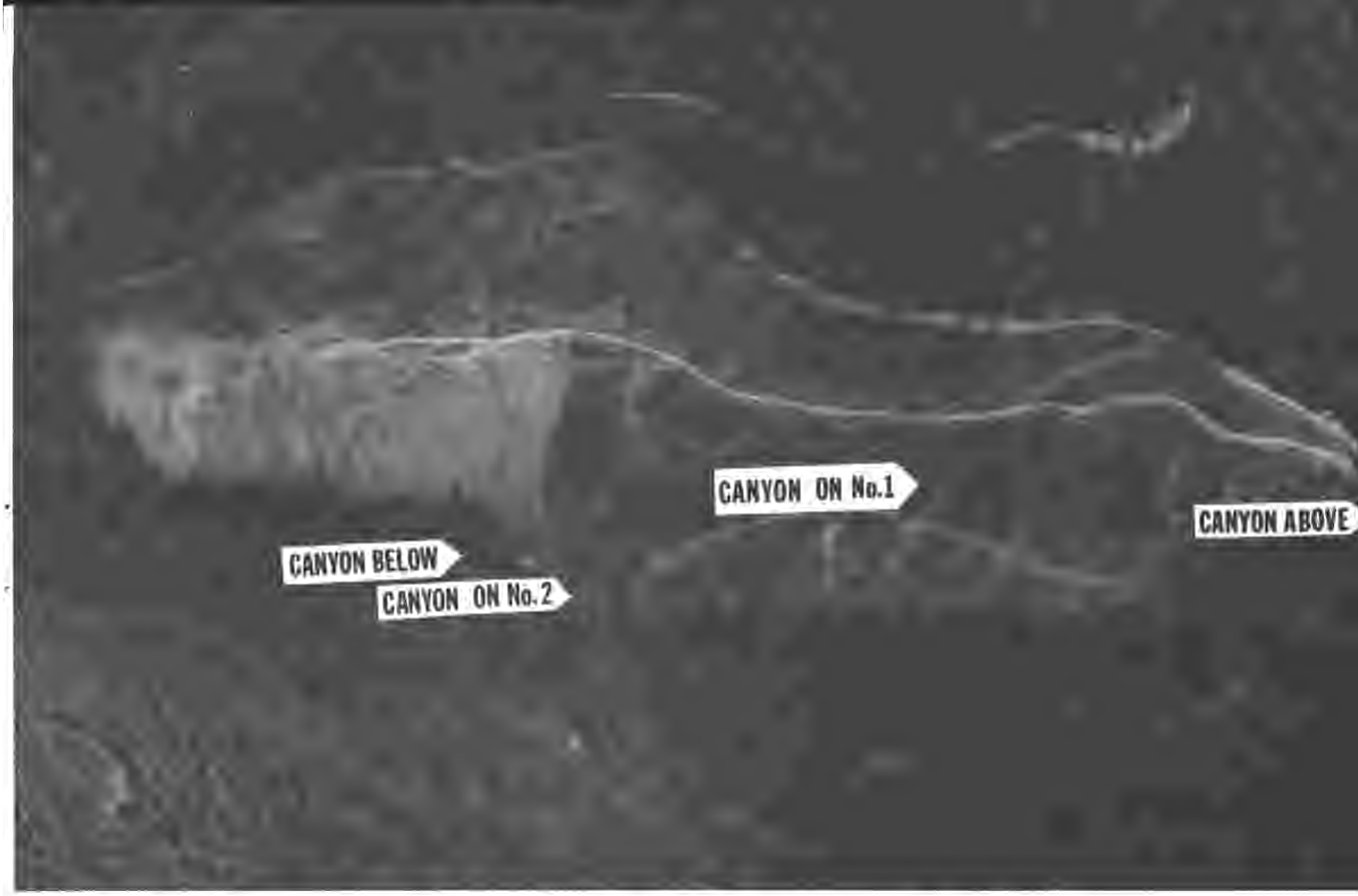


Figure 3.--Canyon Creek clearcut and water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON No. 1" and ON No. 2," and "BELOW."

Canyon Creek clearcut and water-quality sampling stations are shown in figure 3. Control and off-site stations respectively designated "CANYON ABOVE" and "CANYON BELOW" are on Canyon Creek upstream and downstream from the clearcut area. Both stations are separated from the clearcut by the buffer strip. The station named "CANYON ON #1" is near a small spring that emerges in the east central portion of the clearcut. The low-volume flow from the spring crosses the clearcut in a well-defined channel without a buffer strip. The flow enters the buffer strip at the station labeled "CANYON ON #2." The first Canyon Creek water samples were collected from all stations in June 1971. CANYON ON #1 was sampled from the time of snowmelt (March) until the low-flow period of summer (July). CANYON ABOVE, CANYON ON #2, and CANYON BELOW were sampled weekly, except during periods of deep snow cover.

SAMPLE COLLECTION AND ANALYSES

Samples were collected in polyethylene bottles from the free-flowing portion of the streams. Streamwater temperature was measured in *situ.* Because of dilute ionic concentrations and low biological productivity of the streams under study, no preservatives were added to the samples. After collection, samples were frozen until sample analyses were made in the University of Idaho laboratory. Because pH and bicarbonate are very susceptible to changes between time of collection and laboratory analysis, and, particularly, after the sample has been thawed and opened, these tests were performed first on each sample.

Hydrogen ion concentration (pH) and bicarbonate concentration (HCO_3) were determined on a Coleman (model 38) pH meter (Brown and others 1970). In nearly all samples the pH was less than 8.3, eliminating the need to test for carbonate (CO_3).

Electrical conductivity was measured by a conductivity bridge (Brown and others 1970) and correlated for temperature at the time of analysis.

Turbidity of a well-shaken sample was measured by a Hellige Turbidimeter. Filtration for determining filterable solids was done using a 0.45-micron millipore filtration disk (Brown and others 1970). The concentration of ions sorbed on filtrable solids was not determined in this study.

Anions were analyzed as follows: chlorides by the Mohr method (Brown and others 1970); nitrates by an Orion, nitrate-specific ion-electrode with a detection limit near 0.6 mg/ℓ; and sulfates by a turbidimetric method (American Public Health Association, Inc. 1971) utilizing a Spectronic 70 (420 nm) and 50 mm cells. Sodium, potassium, calcium, magnesium, the cations, were determined by atomic absorption spectrophotometer (American Public Health Association, Inc. 1971).

Dissolved oxygen was measured in the field and found to be saturated in all stream samples. This dissolved oxygen level was to be expected due to the free-flowing turbulent nature of these shallow creeks. Tannins and lignins were checked on initial samples and the concentrations were below detection limits (American Public Health Association, Inc. 1971). These tests were excluded from the routine analyses for these reasons.

STATISTICAL METHOD

Two statistical analyses were performed on the data. First, all data for each sampling station were processed by computer with means, variances, and standard errors calculated for each parameter. Second, changes in water quality between selected stations were tested for significance by using a t test for paired differences ($\alpha = 0.05$). When data could not be paired by specific day, they were not used; this resulted in a test of differences based on fewer degrees of freedom. These differences will be referred to as paired data, or paired comparisons.

Because of the short reach between ABOVE and BELOW stations, we assumed that prior to land treatment stream quality was essentially the same at both stations. Thus, if significant increases were detected at the BELOW-site station, the contribution originated on the clearcut-burned area. Statistical tests were based on the hypothesis similar to

electrical conductivity of BENTON ABOVE = electrical conductivity of BENTON BELOW.

Paired comparisons were also tested between ABOVE- and ON-site stations to determine the amount of change in quality of stream water flowing directly off the clearcut-burned area.

Similar procedures were used to evaluate differences between ABOVE stations and precipitation samples.

RESULTS

General Chemistry

Results of this study are organized by chemical groups rather than by location. Comparison of station data in tables 1 and 2 indicates that the three sites are slightly different in respect to some measured water-quality parameters. The "stiff-type" diagrams in figure 4 show average concentrations of ions for each site, illustrating this point. The general shape of the diagrams suggests chemical similarities, but the variation in size indicates concentration differences.

In terms of chemical response, the Benton Creek and Canyon Creek sites reacted similarly and predictably. ON-site stations generally had higher concentrations than ABOVE- or BELOW-site stations. The Ida Creek site was an exception; IDA BELOW usually had the highest ionic concentration.

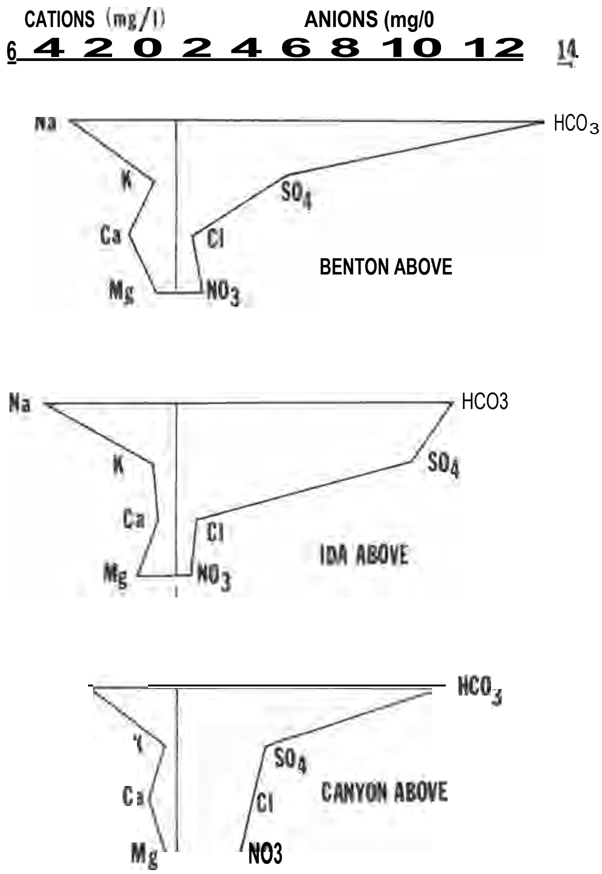


Figure 4.--Average ionic concentrations for the Benton, Ida, and Canyon Creek control (ABOVE) water sampling sites.

Table 1.--S[illegible] *sampling* [illegible] four [illegible]-[illegible] *parameters*

STATION/ Parameters	pH	Electrical conductivity	Turbidity (SiO_2)	Filterable solids
		µmhos/cm	Mg/ℓ	- - - -
BENTON ABOVE				
Number of samples	78	76	66	73
Mean	7.8	43	0.9	4.6
Variance	0.28	170.	0.49	65.3
Standard error	0.06	1.50	0.09	0.95
BENTON ON				
Number of samples	16	16	16	15
Mean	8.3	140	8.2	6.5
Variance	0.24	3780.	148.	3235.
Standard error	0.12	15.4	3.04	14.7
BENTON BELOW				
Number of samples	76	76	67	74
Mean	7.9	49	1.0	4.7
Variance	0.24	99.8	0.72	54.7
Standard error	0.06	1.15	0.10	0.86
IDA ABOVE				
Number of samples	53	54	46	58
Mean	7.4	58	1.1	9.0
Variance	0.19	171.	0.60	245.
Standard error	0.06	1.78	0.11	2.06
IDA ON				
Number of samples	53	53	44	53
Mean	7.3	62	4.9	35.7
Variance	0.15	277.	57.1	8792.
Standard error	0.05	2.29	1.14	12.9
IDA BELOW				
Number of samples	56	56	56	55
Mean	7.2	83	3.5	12.6
Variance	0.31	740.	740.	174.
Standard error	0.07	3.64	3.64	1.78
CANYON ABOVE				
Number of samples	37	37	28	37
Mean	7.7	31	0.6	2.7
Variance	0.27	53.2	0.19	3.03
Standard error	0.09	1.20	0.08	0.29
CANYON ON #1				
Number of samples	24	24	15	24
Mean	6.8	40	1.7	16.4
Variance	0.32	31.0	1.34	953.
Standard error	0.12	1.14	0.29	6.30
CANYON ON #2				
Number of samples	37	37	28	36
Mean	7.3	60	1.6	8.5
Variance	0.16	502.	0.38	28.4
Standard error	0.07	3.68	0.12	0.89
CANYON BELOW				
Number of samples	37	37	28	37
Mean	7.5	34	0.8	3.9
Variance	0.19	81.2	0.38	36.1
Standard error	0.07	1.48	0.12	0.99
PRECIPITATION				
Number of samples	20	20	18	20
Mean	6.8	24	8.9	21.8
Variance	0.09	240.	42.2	215.
Standard error	0.07	3.47	1.53	3.28

Table 2.--Statistical *data from each sampling station for* chemical *concentrations in water samples*

STATIONS/ Measurements	Bicarbonate ($CaCO_3$)	Sulfate	Chloride	Nitrate[1/]	Sodium	Potassium	Magnesium	Calcium
	-----	-----	-----	Mg/l	-----	-----	-----	-----
BENTON ABOVE								
Number of samples	78	73	72	66	75	74	75	75
Mean	13.1	3.6	0.7	0.9	3.7	0.7	0.6	1.5
Variance	7.41	2.31	0.03	2.55	0.34	0.07	0.06	0.26
Standard error	0.31	0.18	0.02	0.20	0.07	0.03	0.03	0.06
BENTON ON								
Number of samples	16	15	15	16	16	16	16	16
Mean	51.4	12.8	0.8	7.9	4.1	1.0	4.8	3.2
Variance	503.	25.3	0.08	49.6	0.26	0.14	8.46	7.88
Standard error	1.30	1.30	0.07	1.76	0.13	0.09	0.73	0.70
BENTON BELOW								
Number of samples	76	72	75	69	76	76	76	76
Mean	14.2	3.9	0.6	0.8	3.6	0.7	0.7	1.6
Variance	7.31	2.69	0.04	0.67	0.33	0.03	0.04	0.37
Standard error	0.31	0.19	0.02	0.10	0.07	0.02	0.02	0.07
IDA ABOVE								
Number of samples	53	57	57	50	60	60	60	60
Mean	9.8	8.5	0.7	0.6	4.6	0.9	1.4	0.8
Variance	2.02	6.64	0.09	0.41	0.72	0.14	0.26	0.12
Standard error	0.20	0.34	0.04	0.09	0.11	0.05	0.07	0.05
IDA ON								
Number of samples	53	55	47	44	54	54	54	54
Mean	11.5	10.3	0.8	0.8	4.8	1.7	1.6	0.9
Variance	16.7	16.9	0.13	0.77	0.08	2.40	0.54	0.39
Standard error	0.56	0.56	0.05	0.13	0.14	0.21	0.10	0.09
IDA BELOW								
Number of samples	56	57	55	47	57	57	57	57
Mean	21.6	8.2	0.7	0.7	4.6	1.0	2.3	2.2
Variance	64.6	34.5	0.16	0.65	0.85	0.16	0.95	1.62
Standard error	1.07	0.78	0.06	0.12	0.12	0.05	0.13	0.17
CANYON ABOVE								
Number of samples	37	36	36	29	37	37	37	37
Mean	7.7	3.1	0.7	0.4	3.1	0.5	0.4	1.0
Variance	0.27	3.00	0.05	0.35	0.94	0.01	0.02	0.07
Standard error	0.09	0.29	0.04	0.11	0.16	0.02	0.02	0.02
CANYON ON #1								
Number of samples	24	24	22	21	24	24	24	24
Mean	10.8	4.5	0.7	0.4	3.4	0.6	0.5	1.4
Variance	2.31	2.17	0.03	0.65	0.24	0.06	0.02	0.13
Standard error	0.31	0.30	0.04	0.18	0.10	0.05	0.03	0.07
CANYON #2								
Number of samples	37	37	34	28	37	37	37	37
Mean	14.2	4.3	0.8	0.4	4.0	0.8	1.1	2.3
Variance	31.3	2.45	1.38	0.54	0.25	0.21	0.21	0.51
Standard error	0.92	0.26	0.20	0.14	0.08	0.08	0.08	0.12
CANYON BELOW								
Number of samples	37	37	37	28	37	37	37	37
Mean	10.1	3.3	0.6	0.2	3.2	0.5	0.5	1.2
Variance	4.83	2.85	0.07	0.06	0.68	0.04	0.04	0.35
Standard error	0.36	0.28	0.04	0.05	0.14	0.03	0.03	0.10
PRECIPITATION								
Number of samples	20	19	20	14	17	17	14	17
Mean	6.8	2.4	Trace	0.4	1.1	0.8	0.1	0.4
Variance	0.09	0.87	Trace	0.04	1.20	2.07	0.01	0.03
Standard error	0.07	0.21	Trace	0.05	0.27	0.35	0.02	0.04

[1/] These data are subject to question due to minimum detection of 0.6 mg/l for the method of analysis used.

Stream Water Parameters

Hydrogen Ion Concentrate (pH)

Alkaline waters characterize streams of the Intermountain Northwest (Streebin and others 1970). This was generally the case in this study, although on all sites, the pH values varied throughout the year. The range of mean pH values never dropped below 6.8 (table 1). However, the pH values may be slightly lower because the samples were frozen before analysis. Benton and Canyon Creek sites show a significant difference in pH within the cut and burned areas, but no changes are evident between ABOVE and BELOW stations (table 3). Ida Creek showed a drop in pH between IDA ABOVE and IDA BELOW that could have resulted from a lack of surface flow from IDA ON to IDA BELOW. The t tests also show a significant difference between all the ABOVE stations and the precipitation (table 4). The pH of the precipitation becomes alkaline by contact with the soils in the watersheds.

Table 3.--P[illegible] data of [illegible] of [illegible], S[illegible] 1970 [illegible] J[illegible] 1972

Station	pH	Electrical conductivity	Turbidity (SiO2)	Filterable solids	HCO3 (CaCO3)	SO4	Cl	[illegible] 1/	Na	K	Mg	Ca
		µmhos/cm			Mg/ℓ							
BENTON ABOVE	7.9	45	1.2	4.6	13.3	4.8	0.6	0.8	3.7	0.7	0.6	1.6
vs. BENTON ON	8.3*	134*	8.2 2/	6.4*	51.4*	12.6*	0.7	7.6*	4.1	1.0*	4.9*	3.2*
BENTON ABOVE	7.8	43	1.0	4.4	13.2	3.6	0.7	0.9	3.7	0.7	0.6	1.5
vs. BENTON BELOW	7.9	47*	1.0	4.7	14.3*	4.0*	0.6	0.8	3.7	0.7	0.7*	1.6*
IDA ABOVE	7.4	58	1.1	7.1	9.8	8.8	0.7	0.6	4.7	0.9	1.4	0.7
vs. IDA ON	7.3	62	4.9*	36.8*	11.4*	10.3*	0.8	0.7	4.8	1.7*	1.6*	0.9*
IDA ABOVE	7.4	58	1.1	7.6	9.7	8.5	0.7	0.6	4.7	0.9	1.4	0.7
vs. IDA BELOW	7.2*	84*	3.3*	12.0	22.3*	8.0	0.8	0.7	4.6	1.0	2.4*	2.2*
CANYON ABOVE	7.7	27	0.6	2.6	8.5	3.1	0.7	0.3	2.7	0.4	0.5	0.9
vs. CANYON ON #1	6.9*	40*	1.7*	16.3*	10.9*	4.4*	0.7	0.8*	3.4*	0.6*	0.3*	1.4*
CANYON ON #1	6.8	40	1.7	10.7	10.9	4.4	0.7	1.0	3.4	0.6	0.5	1.4
vs. CANYON ON #2	7.3*	47*	1.4	7.6	14.2*	4.4	0.6*	0.4*	3.8*	0.6	0.9	2.1*
CANYON ABOVE	7.7	31	0.6	2.7	9.4	3.1	0.6	0.3	3.1	0.5	0.4	1.0
vs. CANYON BELOW	7.6	34*	0.8	3.8	10.1	3.4*	0.6	0.2	3.2	0.5	0.5	1.2*

*Significant at the 5% level of probability.
1/ These data are subject to question due to minimum detection of 0.6 mg/ℓ for the analysis used.
2/ Not significant because of unusually high variance for BENTON ON.

Table 4.--Comparison [illegible] of [illegible] of [illegible] S[illegible] 1970 [illegible] June 1972

Station	pH	Electrical conductivity	Turbidity (SiO_2)	Filterable solids	HCO3 ($CaCO_3$)	SO_4	Cl	[illegible] 1/	Na	K	Mg	Ca
		µmhos/cm			Mg/ℓ							
Precipitation at Head-quarters	6.8	24	8.9	21.8	6.8	2.4	--2/	0.4	1.1	0.8	0.1	0.4
BENTON ABOVE	7.8*	43*	0.9*	4.6*	13.1*	3.6*	0.7	0.9*	3.7*	0.7	0.6*	1.5*
IDA ABOVE	7.4*	58*	1.1*	9.0*	9.8*	8.5*	0.7	0.6	4.6*	0.9	1.4*	0.8*
CANYON ABOVE	7.7*	31	0.6*	2.7*	7.7*	3.1	0.6	0.3	3.1*	0.5	0.4*	1.0*

*Significantly different from precipitation samples at > 0.05 level.
1/ These data are subject to question due to minimum detection of 0.6 mg/ℓ for the method of analysis used.
2/ No statistical comparison.

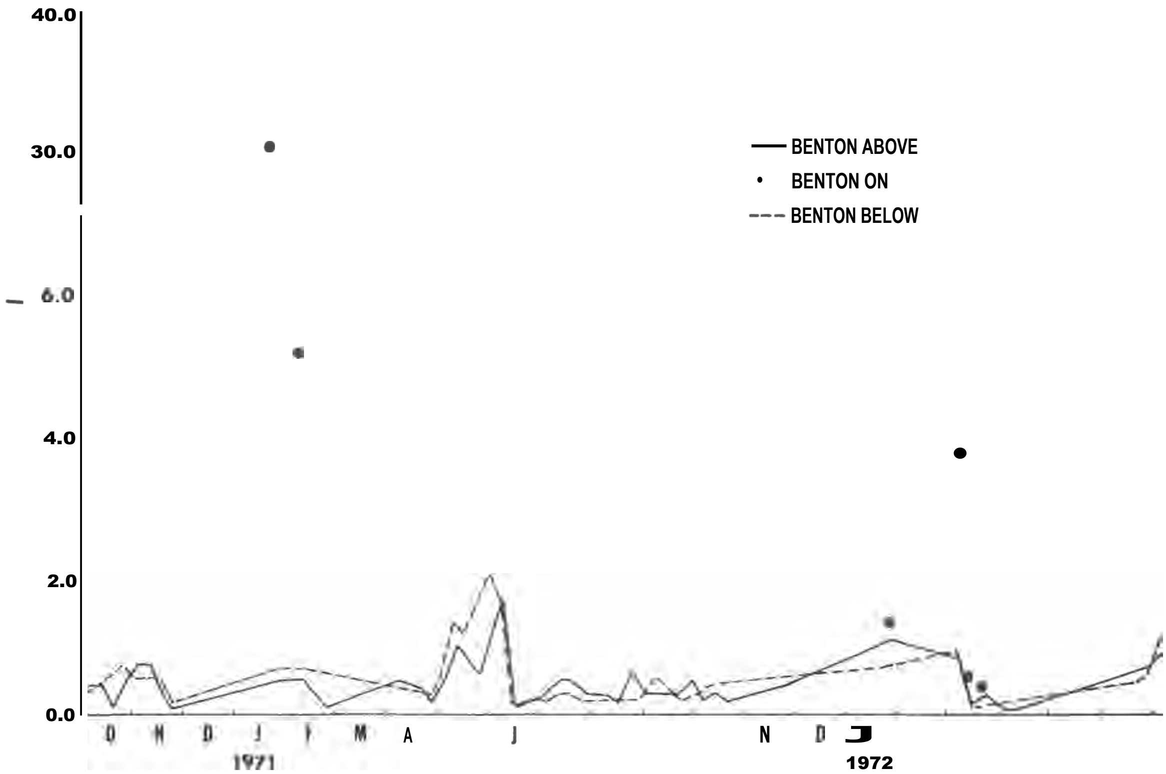


Figure 5.--Weekly *average turbidity values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."*

Turbidity

Turbidity is the optical property of water that causes light to be scattered and absorbed rather than transmitted. Generally, water from study creeks was quite clear; the ABOVE stations' turbidity values ranged around 1 mg/Z silicon dioxide (Si02) or less. BELOW stations, except IDA BELOW, were not significantly different from ABOVE stations. Statistics in table 3 support the conclusion that increases in turbidity at the ON stations are associated with the clearcut-burned treatment. Turbidity fluctuations for Benton Creek and Ida Creek sites are shown in figures 5 and 6, respectively. The Canyon Creek site (not shown) was similar to the Benton Creek site. The BENTON ABOVE and BENTON BELOW stations show slight increases, but BENTON ON turbidities are almost nine times greater than BENTON ABOVE turbidity values. Data for the Ida Creek site also show an increase, but the decrease in turbidity of the Ida Creek values to previous levels within 6 months is notable.

Filterable Solids

Measurement of filterable solids verifies loss of particulate matter from a watershed (table 3). Concentrations for all the ABOVE and BELOW stations are nonsignificant, whereas ON-site stations show a significant increase. This increase is probably associated with soil disturbance caused by logging and by lack of soil protection after

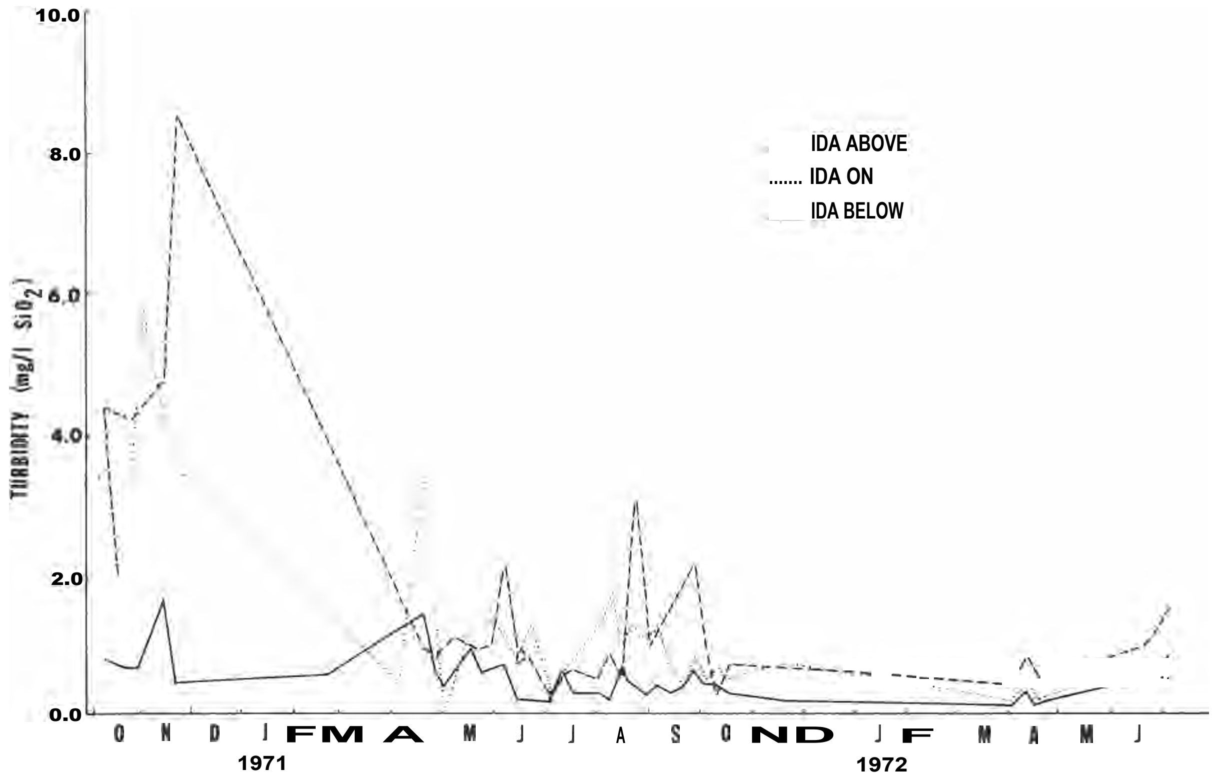


Figure 6.--Weekly *average turbidity values for the Ida Creek water sampling stations Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."*

burning of litter and slash. ON-station increases relative to ABOVE stations were 14, 4, and 6 times greater for Benton, Ida, and Canyon Creeks, respectively.

Of special interest is the high rate of incoming solids detected in the precipitation (table 4). This input to the system is several times greater than natural losses in the stream water.

Electrical Conductivity

Electrical conductivity represents the amount of electrical current a sample of water will conduct. Because conductance is proportional to the concentration of dissolved ions, this test indexes the total concentration of ions present in a sample. Mean electrical conductivity for the ABOVE stations ranges from 27 to 58 pmhos/cm (table 3). Graphs in figures 7, 8, and 9 show natural variation within season. The highest values occurred during periods of low streamflow, except for BENTON ON. These graphs also show greater variability for the ON-site stations. For instance, the average electrical conductivity for the BENTON ON station was three times the average for the BENTON ABOVE station, but the variance increased 40 times. This trend can also be seen for the Ida and Canyon Creek sites, but not to the same degree. Larger variance in the BENTON ON samples is probably due to the limited period of flow which occurs only during rapid snowmelt and heavy rainfall. Significant changes in electrical conductivity are indicated between all the ABOVE and BELOW stations.

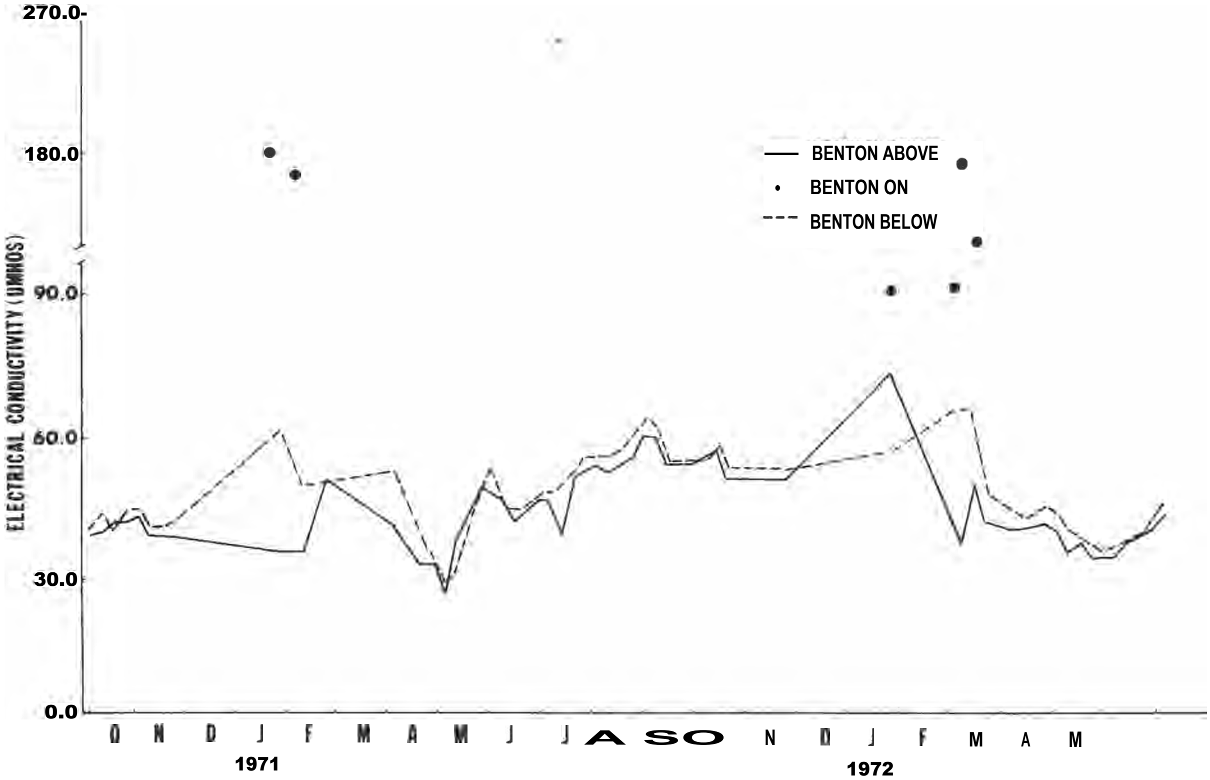


Figure 7.--Weekly average electrical conductivity values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

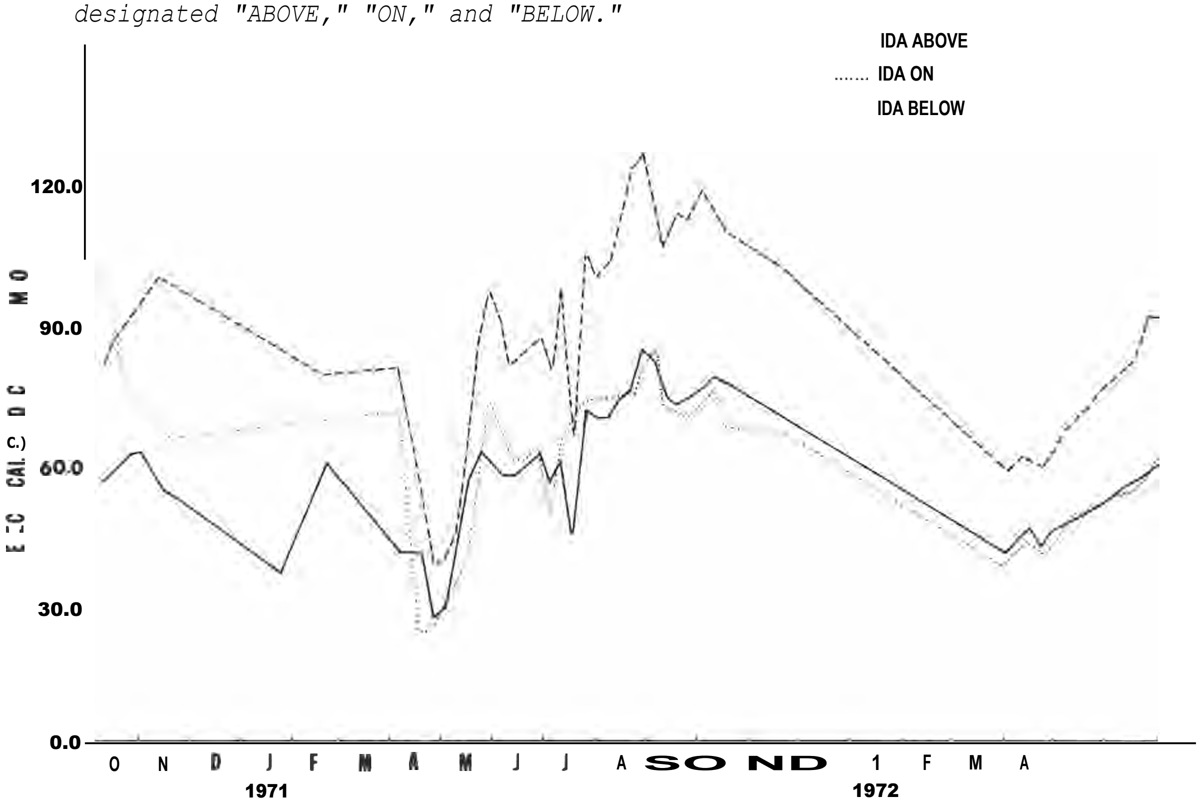


Figure 8.--Weekly average electrical conductivity values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

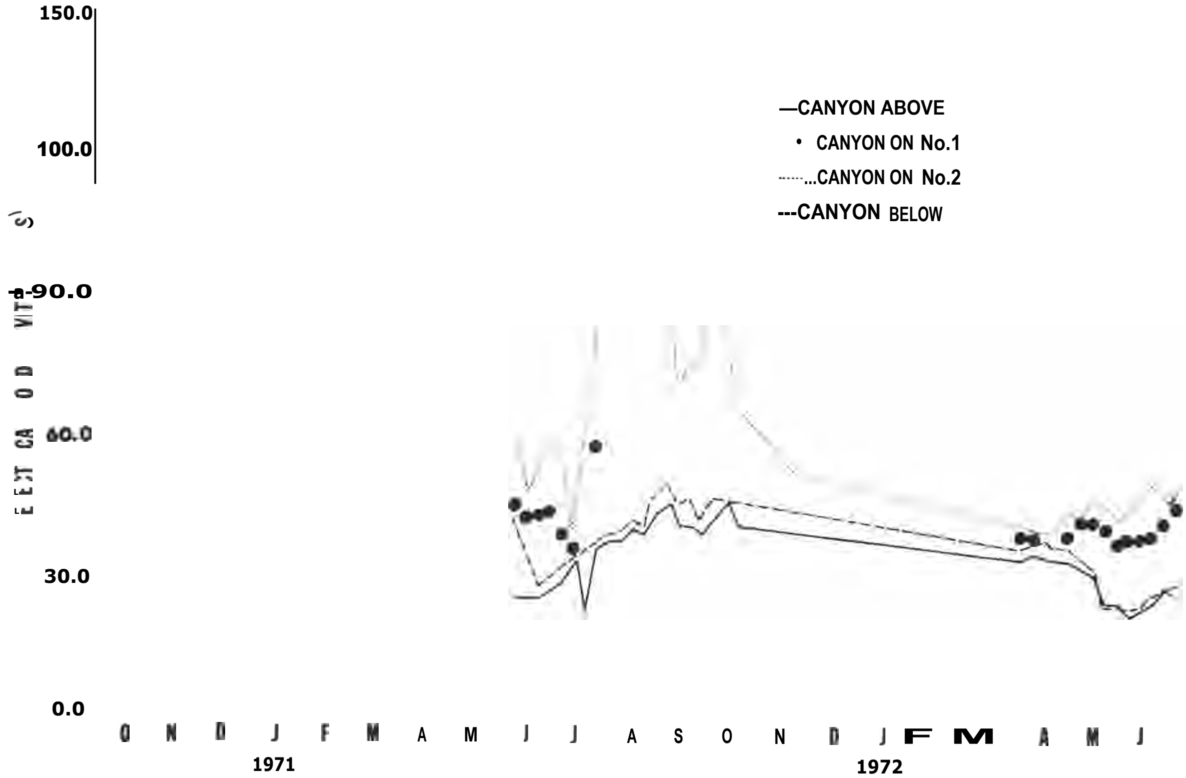


Figure 9.--Weekly average electrical conductivity values for the Canyon Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON No. 1" and "ON No. 2," and "BELOW."

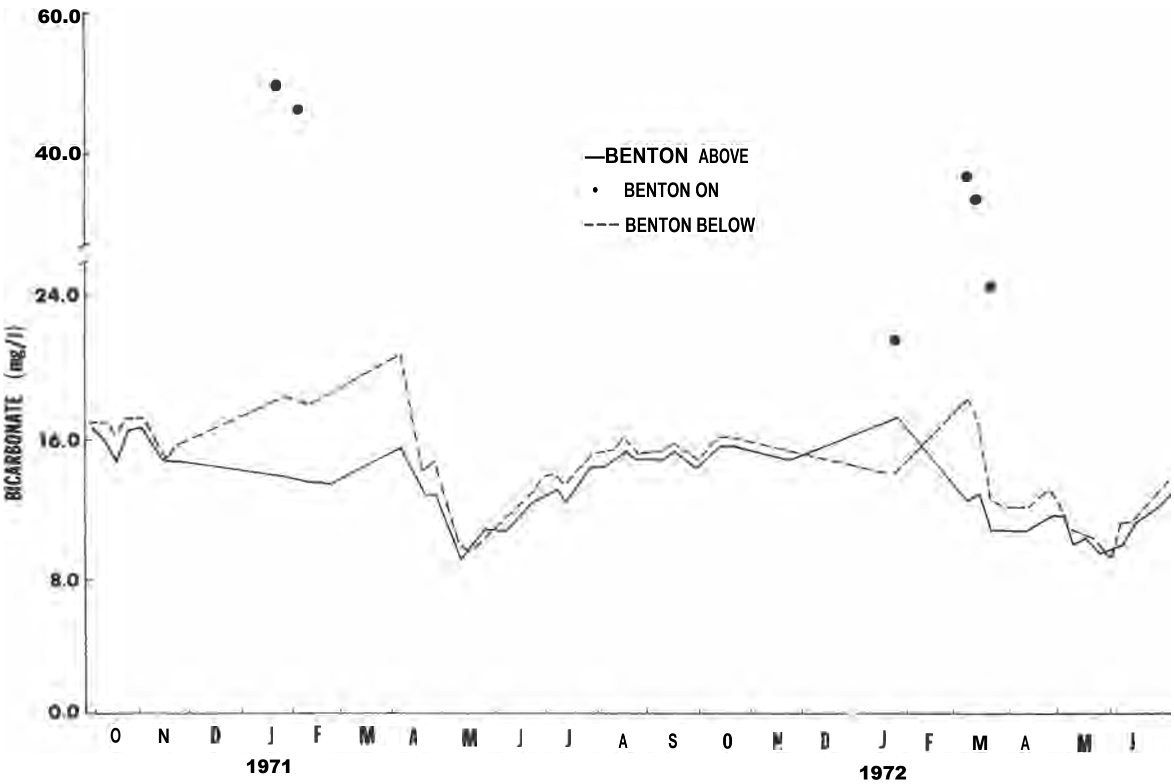
Bicarbonate (HCO_3)

Bicarbonate was the most abundant anion in the three basins under study. Mean bicarbonate concentrations in table 3 for BENTON ABOVE and BENTON BELOW are about 13 and 14 mg/ℓ, respectively, but the concentration for BENTON ON is 51 mg/ℓ--an increase of almost four times (fig. 10). CANYON ON #1 also evidences an increase in mean bicarbonate over the CANYON ABOVE station, but the increase was only from 8 to 11 mg/ℓ (fig. 11). The IDA ON and BELOW stations also showed increases over the ABOVE station value of 10 mg/ℓ (fig. 12). But, as was characteristic for the Ida site, the BELOW station was the highest with a value of 22 mg/ℓ, about twice the value of the ABOVE station. The striking result is the increased variance in bicarbonate concentrations for the stations. Variances for the BENTON ON and CANYON ON stations increased 68 and 116 times, respectively, over the ABOVE values. T tests also show all BELOW-station increases to be significant.

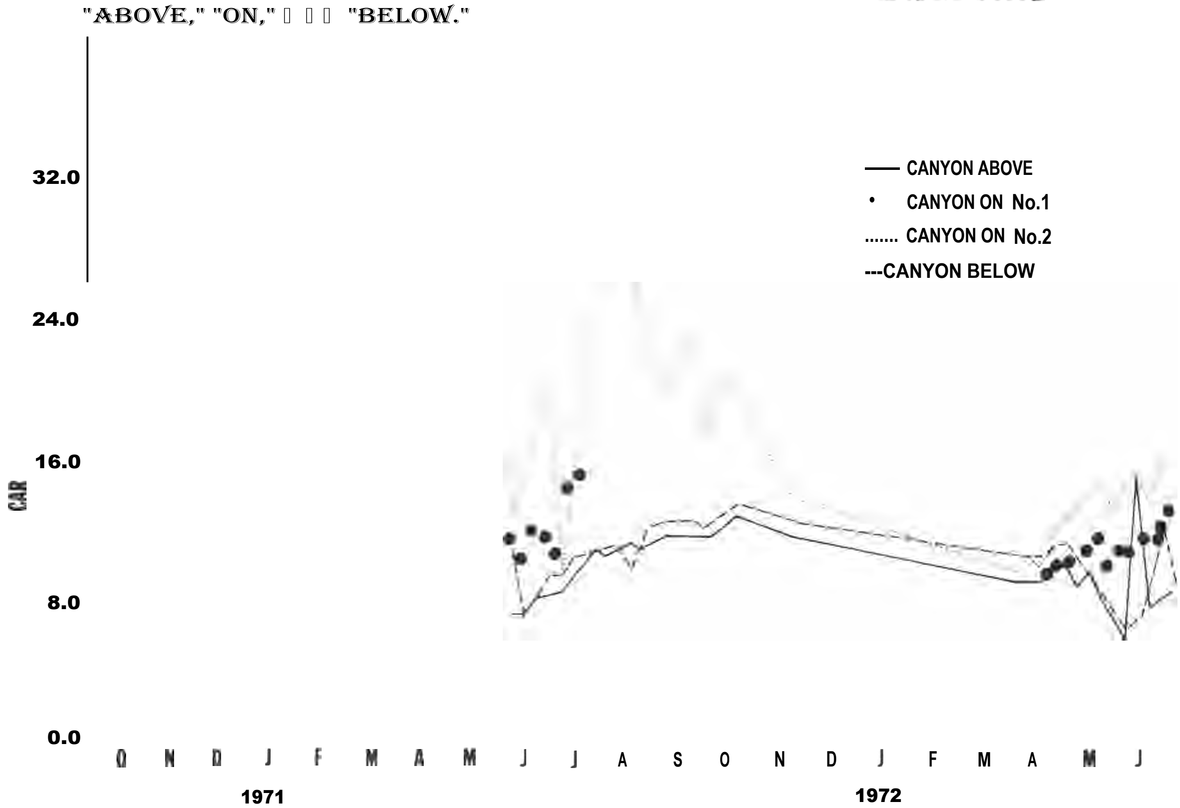
The bicarbonate concentration of the precipitation shown in table 4 is significantly less than the baseline bicarbonates of the three ABOVE stations.

Sulfate (SO_4)

Next to bicarbonate, sulfate proved to be the second most abundant anion in the stream water. The BENTON ON-site station averaged higher sulfate concentrations than the BENTON ABOVE station. The mean concentration increased about four times from ABOVE to BELOW table 3), but the variance increased more than 10 times (table 2).



F[illegible] 10.--Weekly [illegible] the B[illegible] C[illegible] sampling [illegible]. C[illegible], [illegible]-[illegible], [illegible]-[illegible] respectively [illegible] "ABOVE," "ON," [illegible] "BELOW."



F[illegible] 11.--W[illegible] values [illegible] C[illegible] C[illegible]. C[illegible], [illegible]-[illegible], [illegible]-[illegible] "ABOVE," "ON N[illegible]. 1" [illegible] "ON N[illegible]. 2, [illegible] "BELOW."

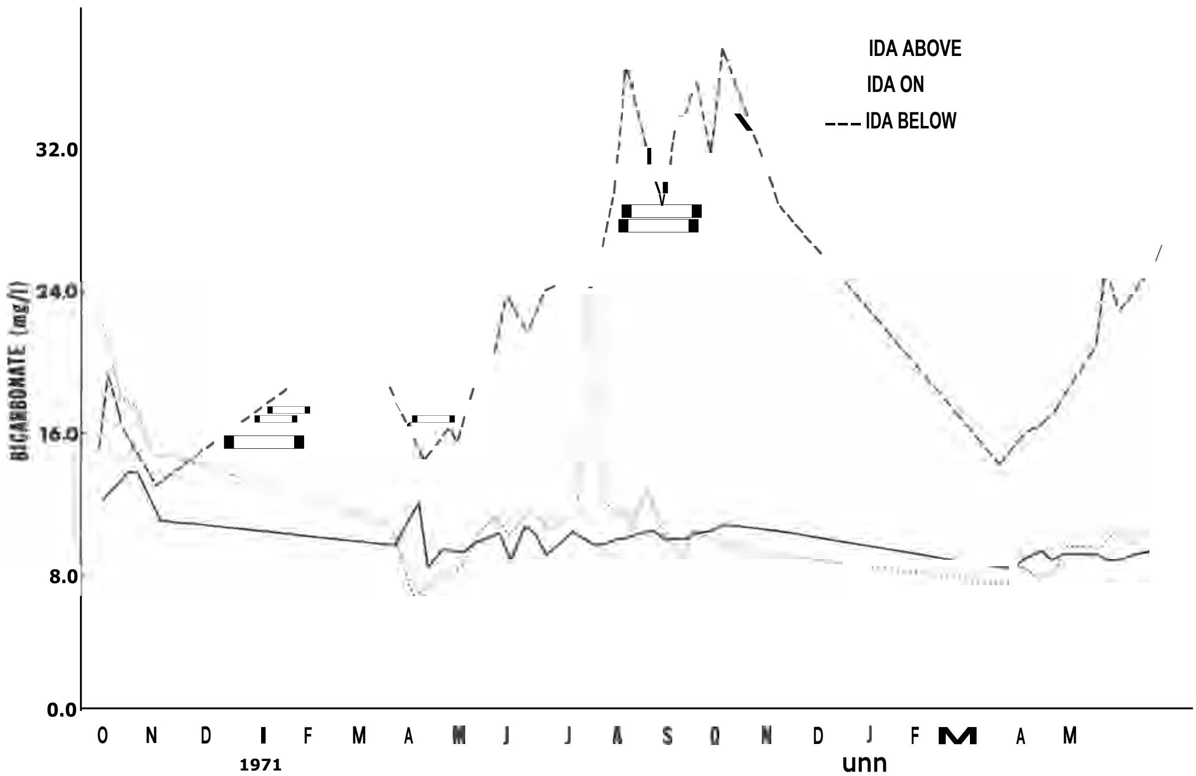


Figure 12.--Weekly average bicarbonate values for the Ida Creek water sampling stations. Control, on–site, and off–site stations are respectively designated "ABOVE," "ON," and "BELOW."

Mean sulfate concentrations for the CANYON ON-site stations were 3 to 4 mg/ℓ approximately, but the variance dropped slightly, the opposite response from the normal for ON-site stations. The average for IDA ON station shows a slight increase over IDA ABOVE. This increase was not of the same magnitude as that of the other nutrients. IDA BELOW was not significantly different from IDA ABOVE (table 3). The variances showed the usual increase from IDA ABOVE to IDA BELOW, again indicating that the normal range of concentrations of sulfate ions was altered by the clearcut-burned treatment.

Ida Creek sites have a much larger variation and a greater range of sulfate ion concentrations than the Benton Creek site, because of the headwater location of the Ida Creek site (fig. 13 and 14). The Canyon Creek site curves are not shown, but were very similar to those for Benton Creek in figure 13.

Sulfate concentrations in the precipitation averaged over 2 mg/ℓ, roughly 1 to 6 mg/ℓ less than the ABOVE sites (table 4). This concentration was significantly lower than that at the ABOVE stations of Benton and Ida Creeks. CANYON ABOVE station, however, did not show significant differences.

Chloride (Cl^-)

Chloride concentrations did not change with land treatment. The mean concentration for all stations ran less than 1 mg/Z, which is close to the detection limit.

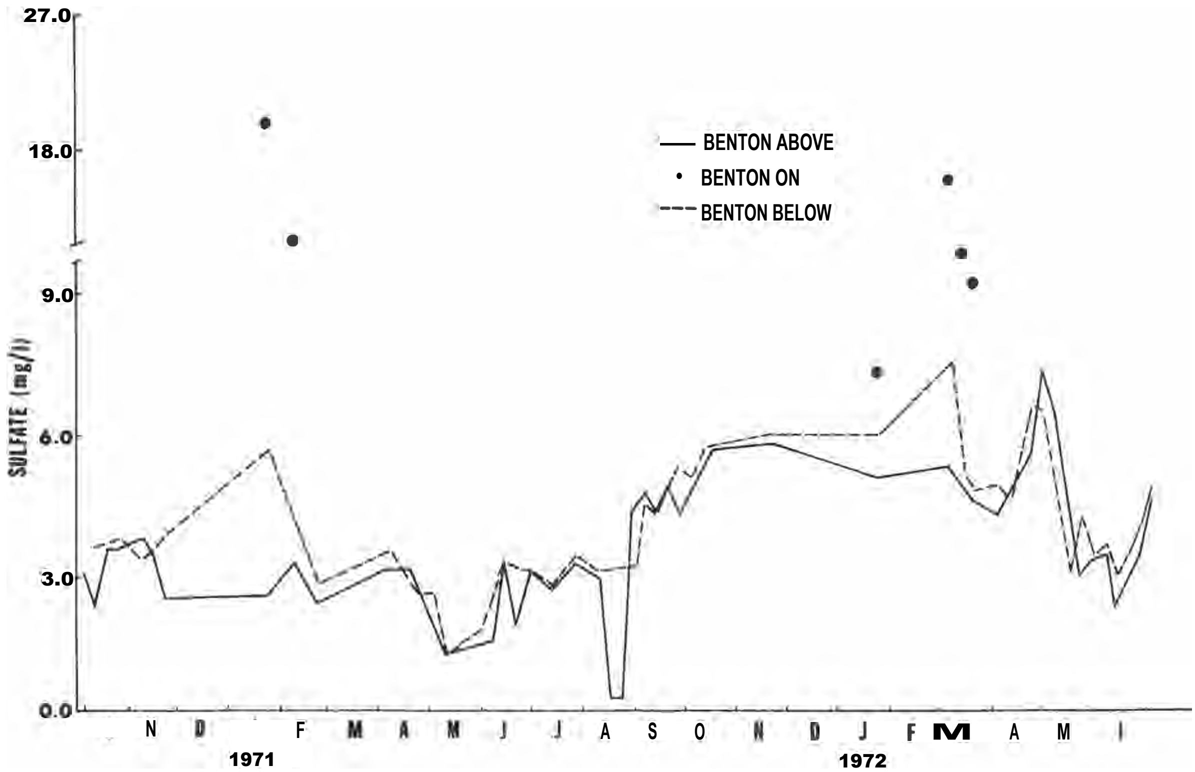


Figure 13.--Weekly average sulfate values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

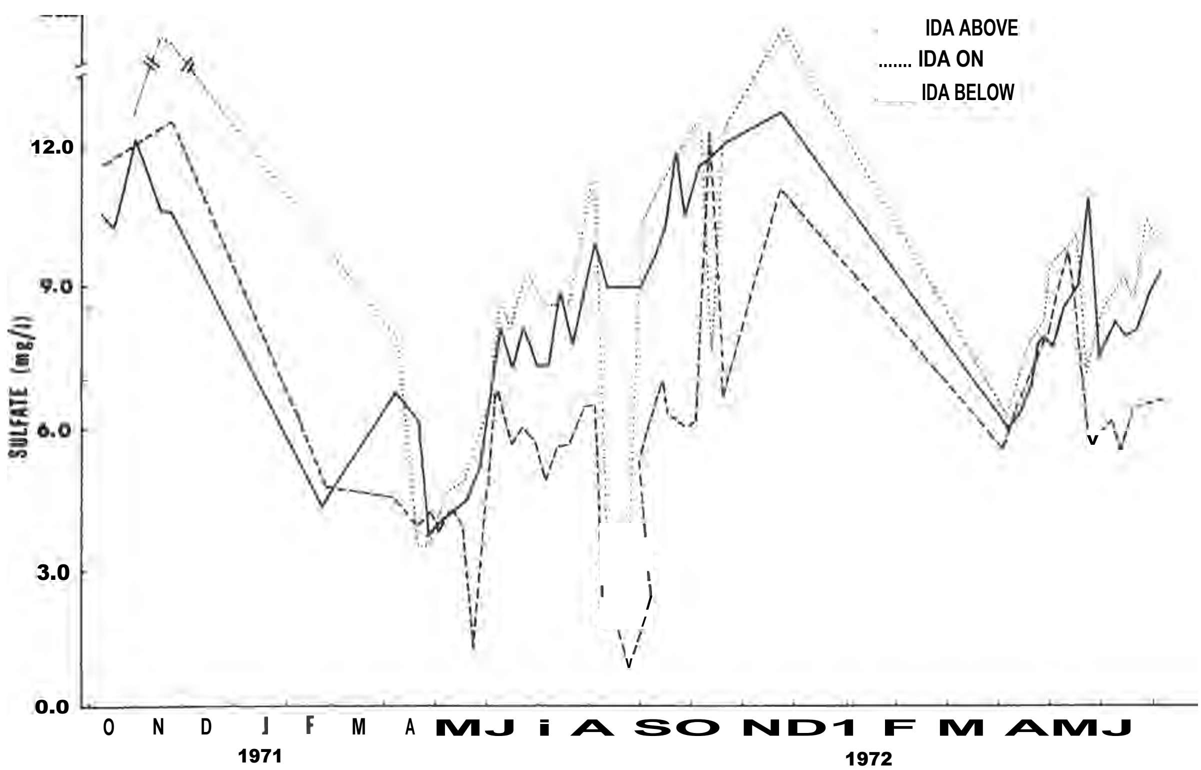


Figure 14.--Weekly average sulfate values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

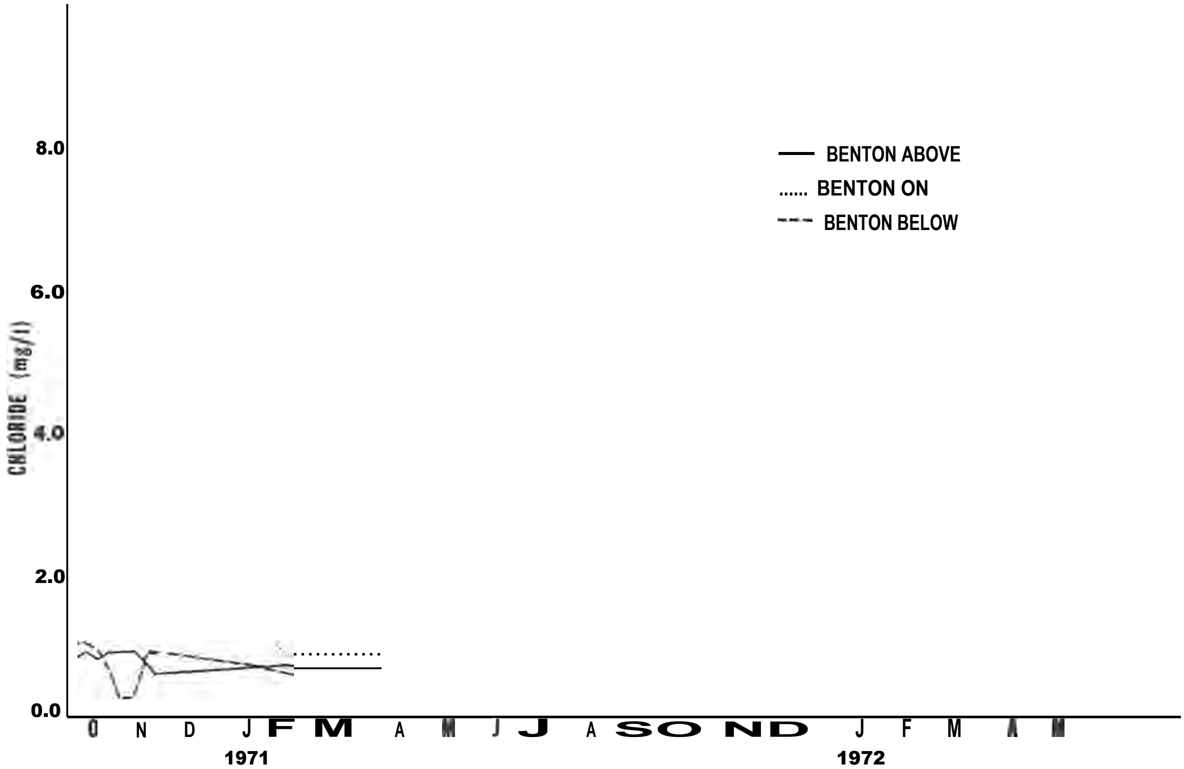


Figure 15. --Weekly average chloride values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

The Benton Creek site (fig. 15) typifies data observed for the other sites. Apparently, clearcutting or burning did not influence the concentration of chlorides. Only trace amounts of chloride were found in the precipitation samples.

Nitrate (NO_3^-)

Nitrate ion concentrations (table 3) averaged less than 1 p/m, except for the BENTON ON-site station. This station averaged 8 mg/ℓ, about eight times the BENTON ABOVE value. Peak concentrations of nitrate for the Benton and Ida Creek sites occurred during periods of rapid snowmelt. Although some peak concentrations of the BELOW stations were two or three times higher than the ABOVE stations, none of the paired comparisons were significant. If logging and burning caused a release of nitrate ions, the amount of nitrate loss was indeed small. Also, except for BENTON, nitrate ion concentrations for the ABOVE stations were not significantly different from such concentrations in precipitation. The reader should be cautioned that all nitrate values are higher than normally expected due to the minimum detection limits (0.6 mg/ℓ) of the nitrate electrode used for analysis.

Sodium (Na^+)

Sodium concentrations changed very little with land treatment (fig. 16, 17, and 18). Mean concentrations for the Benton Creek and Ida Creek sites changed less than 0.5 mg/e between the ABOVE and ON stations. The only significant change occurred on Canyon Creek (table 3) between the CANYON ABOVE and CANYON #1 stations. Average sodium concentration due to treatment increased less than 1 mg/ℓ, a nonsignificant increase at CANYON BELOW. Sodium concentration in the precipitation was found to be significantly less than the concentration at the three ABOVE stations.

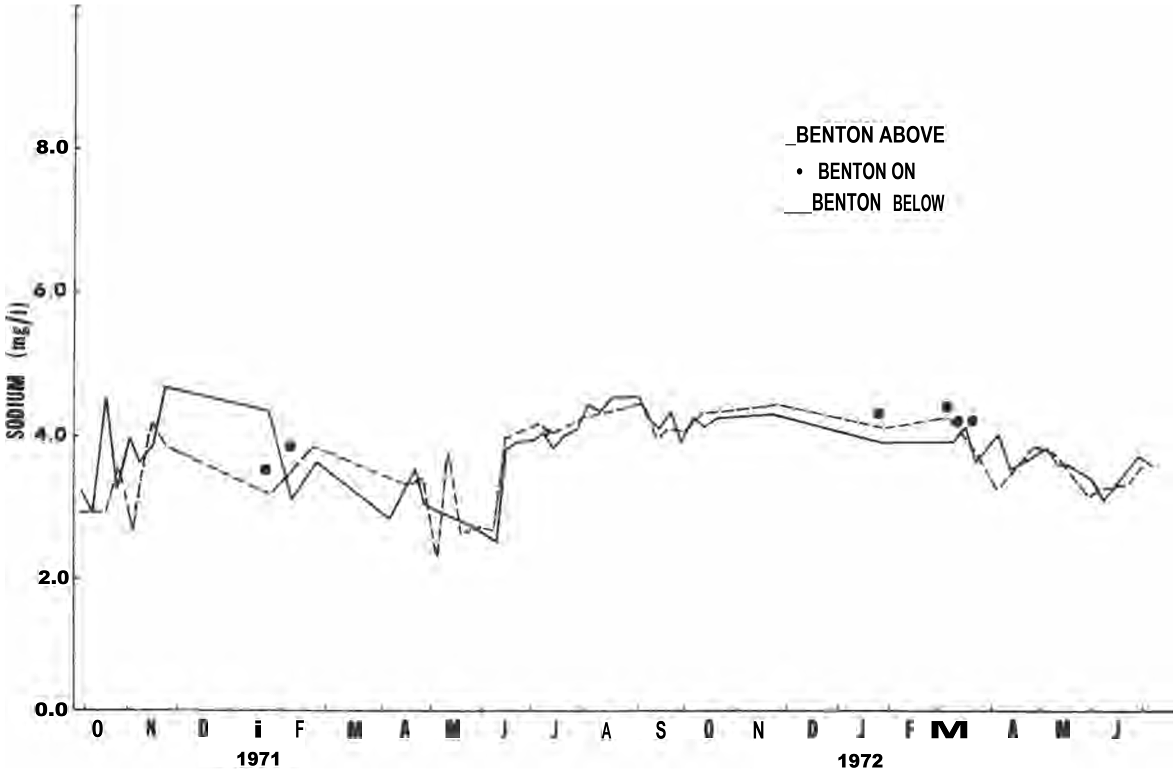


Figure 16. --Weekly average sodium values for the Benton Creek water sampling sites. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

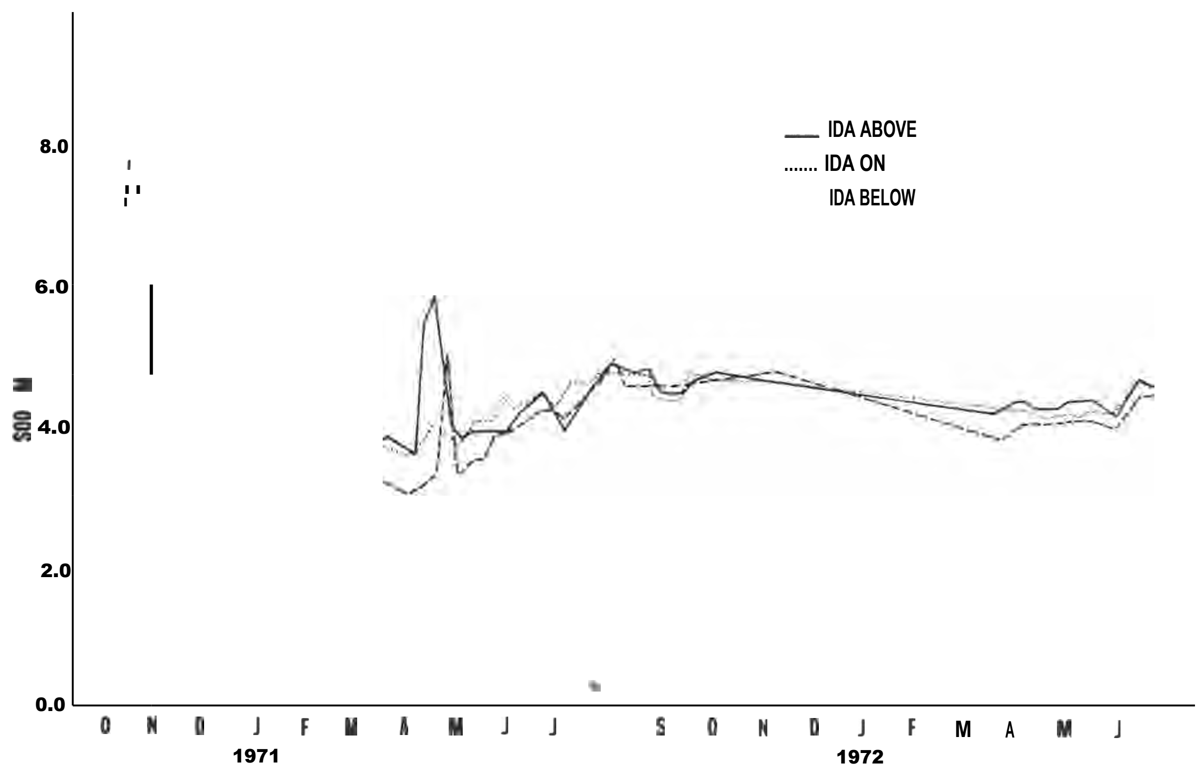


Figure 17. - -Weekly average sodium values for the Ida Creek water sampling sites. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

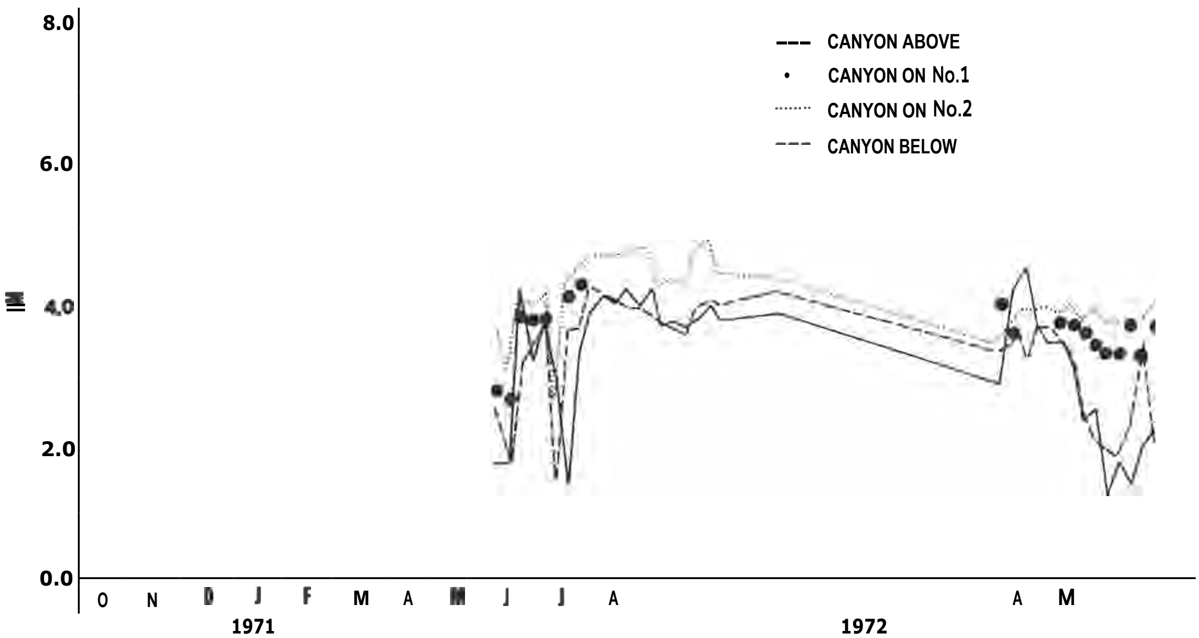


Figure 18. --Weekly average sodium values for the Canyon Creek water sampling sites. Control, on—site, and off—site stations are respectively designated "ABOVE," "ON," (No. 1 and No. 2), and "BELOW."

Potassium (K^+)

Potassium increased significantly with land treatment on all three sites between ABOVE and ON stations. However, no significant change occurred between the ABOVE and BELOW stations. Canyon Creek response was similar to that for Benton Creek (fig. 19). On the Ida Creek site, potassium concentration at the ON station rapidly decreased to a normal level (fig. 20). Highest values were observed immediately after logging and burning at the time of fall precipitation, but within 1 year, the concentration had returned to a normal level.

Comparison of potassium concentrations between ABOVE stations and precipitation catch showed no significant difference.

Magnesium (Mg)

Magnesium concentrations for the ABOVE and BELOW stations from Benton and Canyon Creek sites have similar averages, less than 1 mg/ℓ, and a variance no greater than 0.06 (fig. 21 and 22). This small variance suggests a low dependence of magnesium concentration on seasonal flows. The Ida Creek site, however, shows more pronounced cyclic variation (fig. 23); average magnesium concentrations and variances increased from the ABOVE to BELOW stations. The variances at the Ida Creek stations were 4 to 40 times the variances of the Benton Creek or Canyon Creek sites.

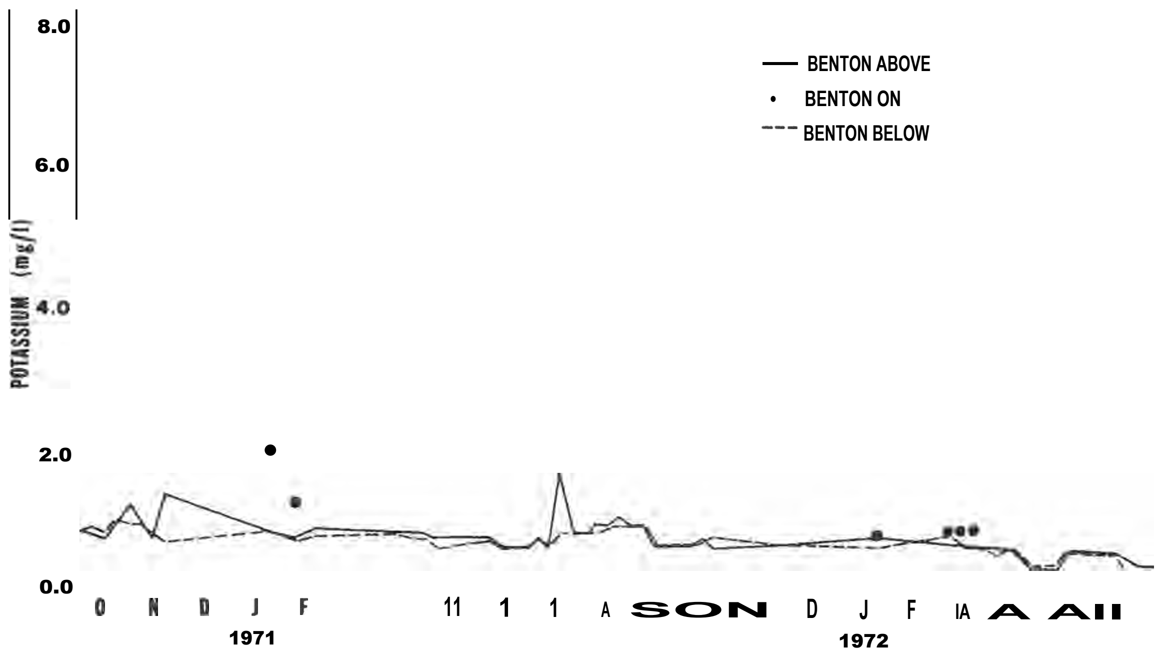


Figure 19. --Weekly average potassium values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

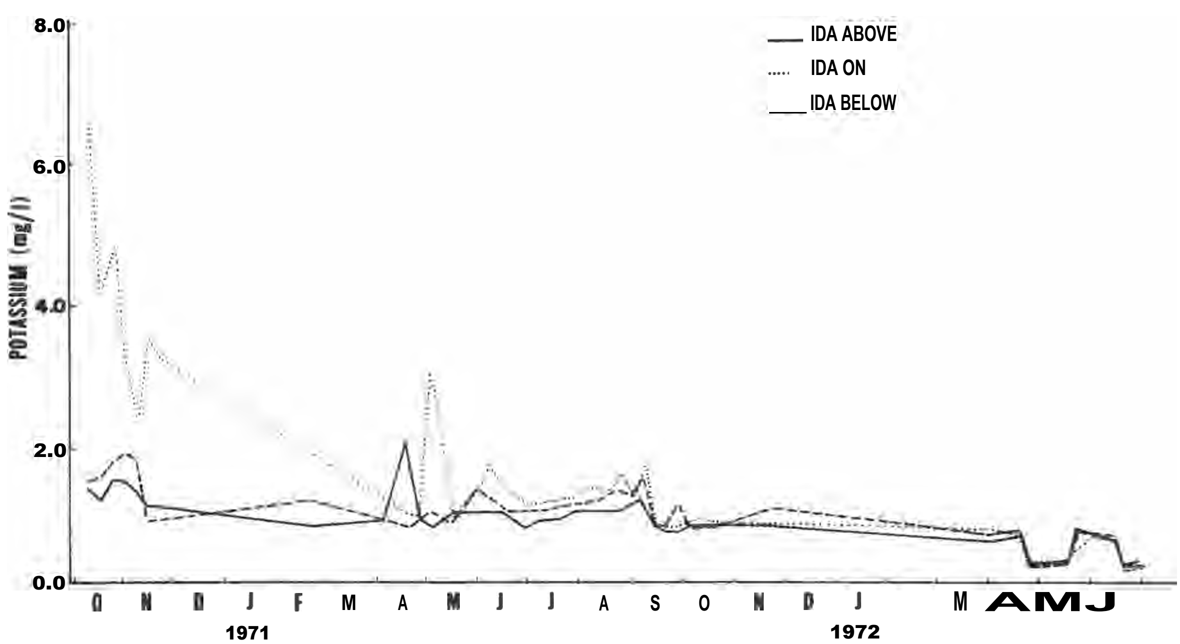
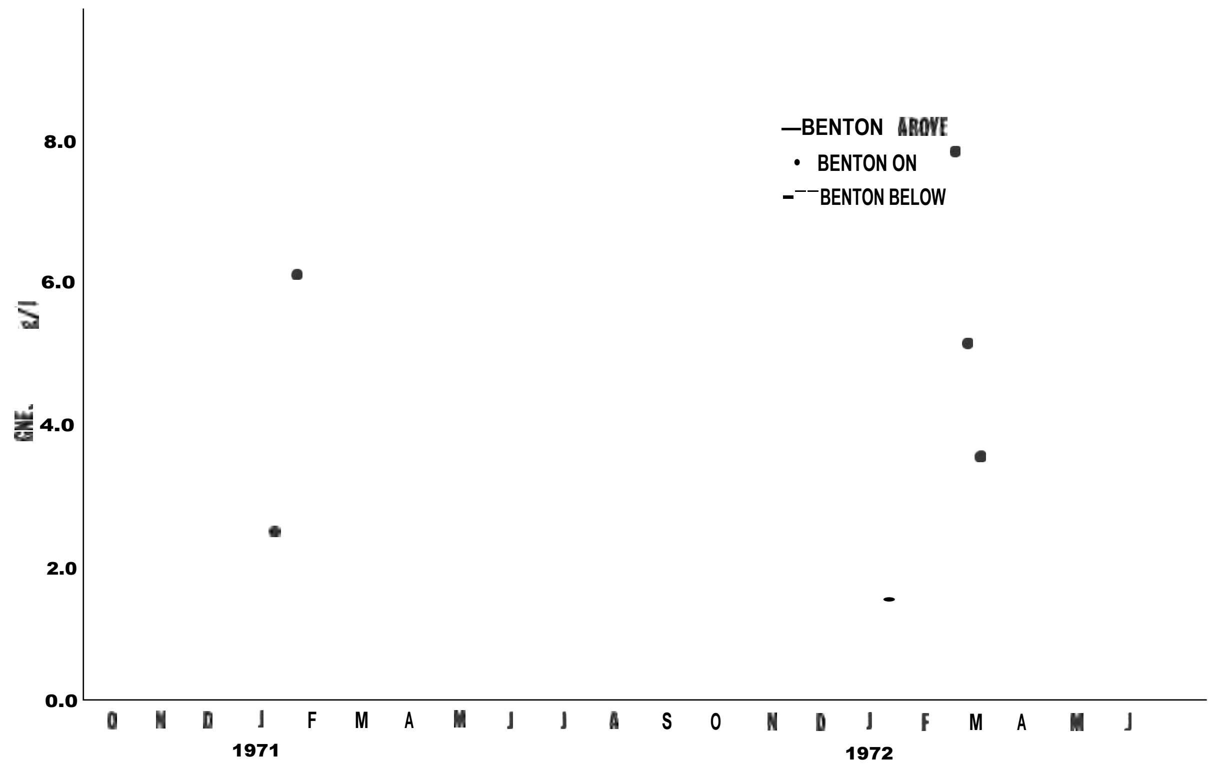
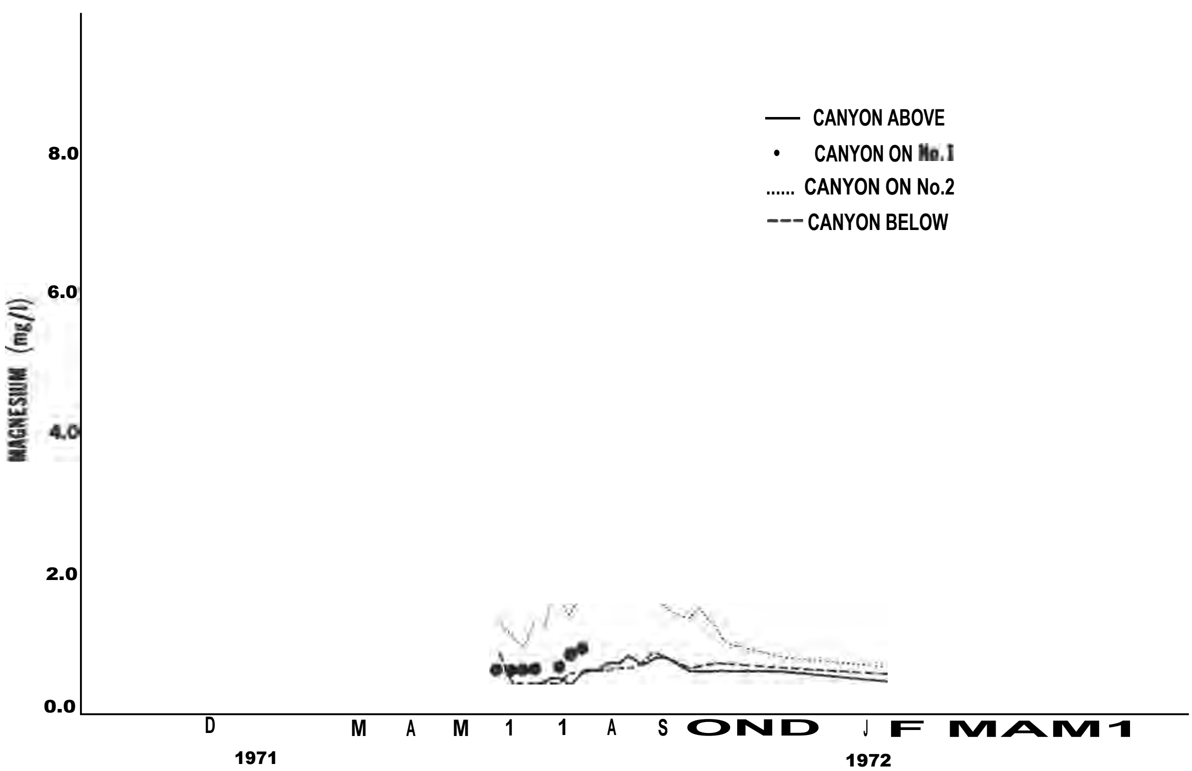


Figure 20. ----Weekly average potassium values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."



F 21.--W B C -
. C , - , -
"ABOVE," "ON," "BELOW."



F 22.--W *Canyon* C -
. C , - , -
"ABOVE," "ON" (N . 1 N . 2), "BELOW."

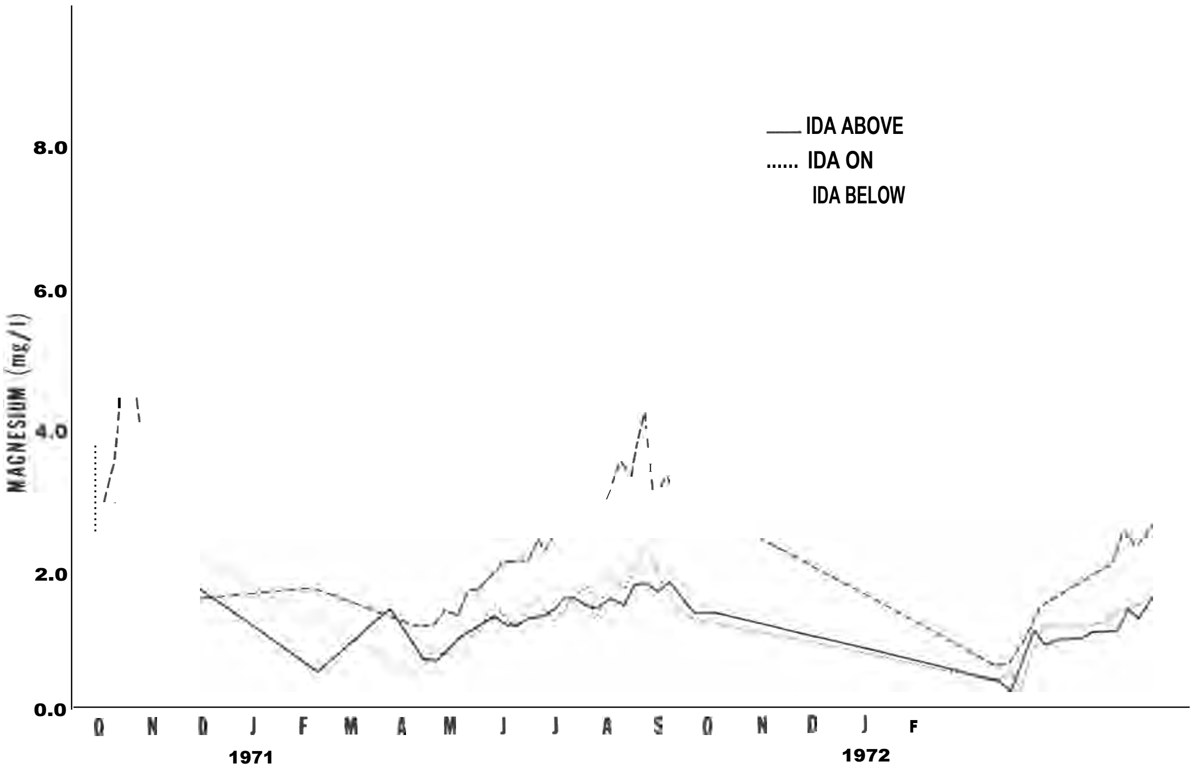


Figure 23.--Weekly *average magnesium values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."*

Magnesium concentrations increased significantly for the ABOVE- and ON-site stations at all three sites. A significant difference exists between the ABOVE and BELOW stations of all sites except Canyon Creek. Magnesium concentration in the precipitation was significantly less than that for the three ABOVE stations.

Calcium (Ca^{++})

Mean calcium concentrations ranged from 1 to 2 mg/ℓ for the ABOVE stations (table 3). Concentrations at the ON-site stations for Benton and Canyon Creeks were twice the ABOVE-site concentrations, but the IDA ON-site concentration was only slightly higher than the IDA ABOVE calcium concentration.

Calcium concentrations show some dependence upon seasonal flows (fig. 24, 25, and 26). However, during low-flow periods, concentrations do not increase as might be expected from previous nutrient results. Instead, calcium values increased during periods of snowmelt and high flow. The concentration differences between the ABOVE and BELOW stations for the high-flow period are most apparent for the Benton and Ida Creek sites. During high flow, the BELOW stations had significantly higher calcium concentrations than did the ABOVE stations. It is difficult to generalize the dependence of calcium on seasonal flow, but it is apparent that calcium can be lost from the clearcut-burned area during periods of high runoff. As with most of the other measured cations, the calcium content of the precipitation was significantly less than that of stream water at ABOVE stations.

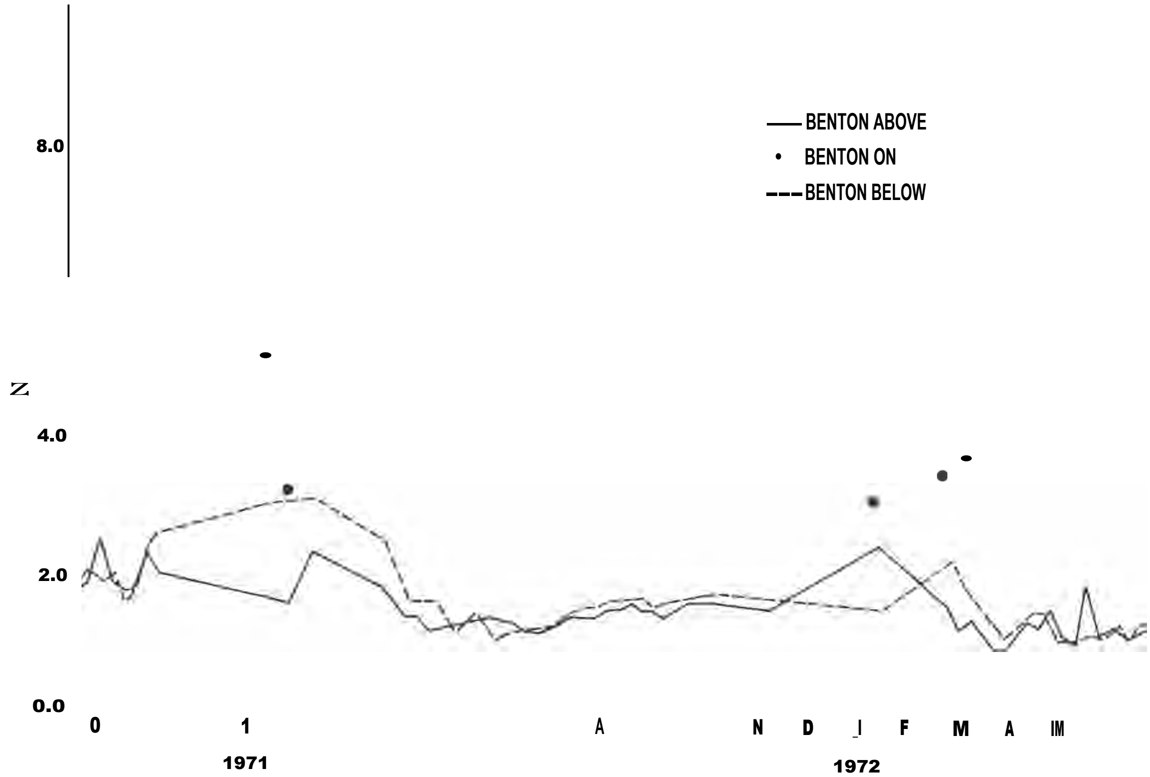


Figure 24.--Weekly *average calcium values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."*

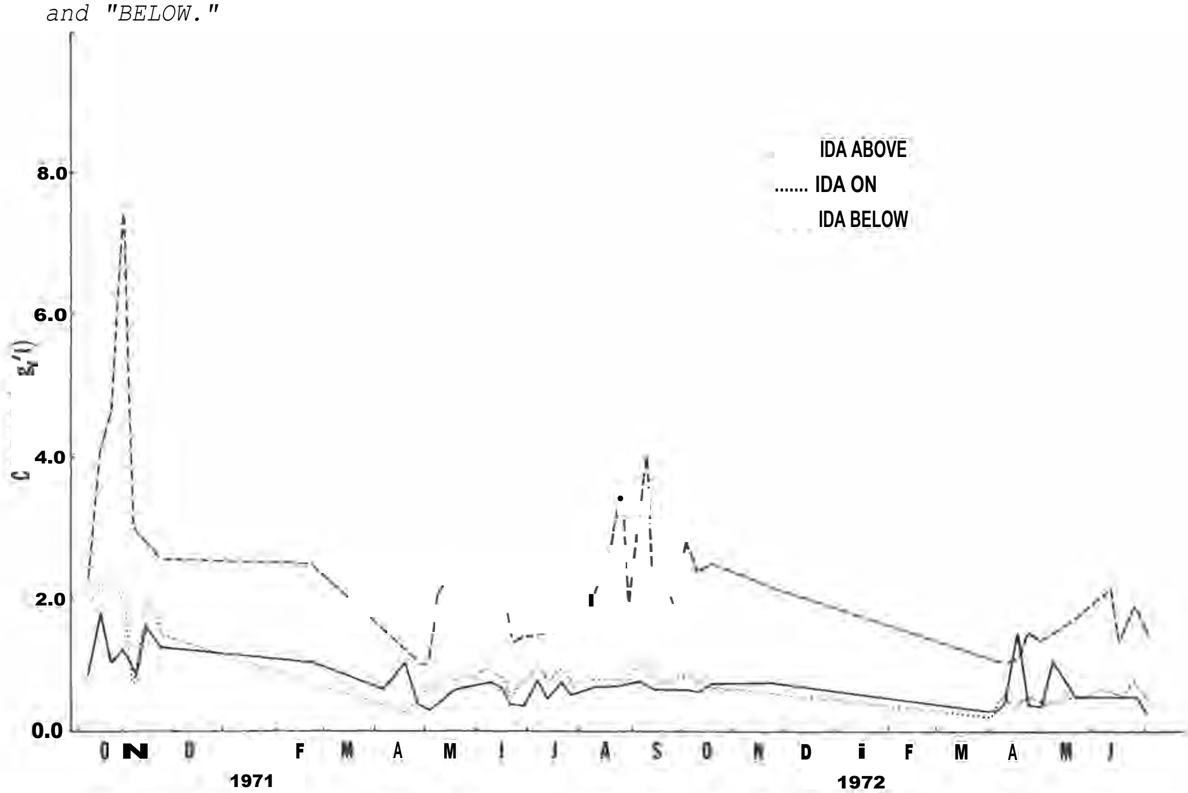


Figure 25.--Weekly *average calcium values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."*

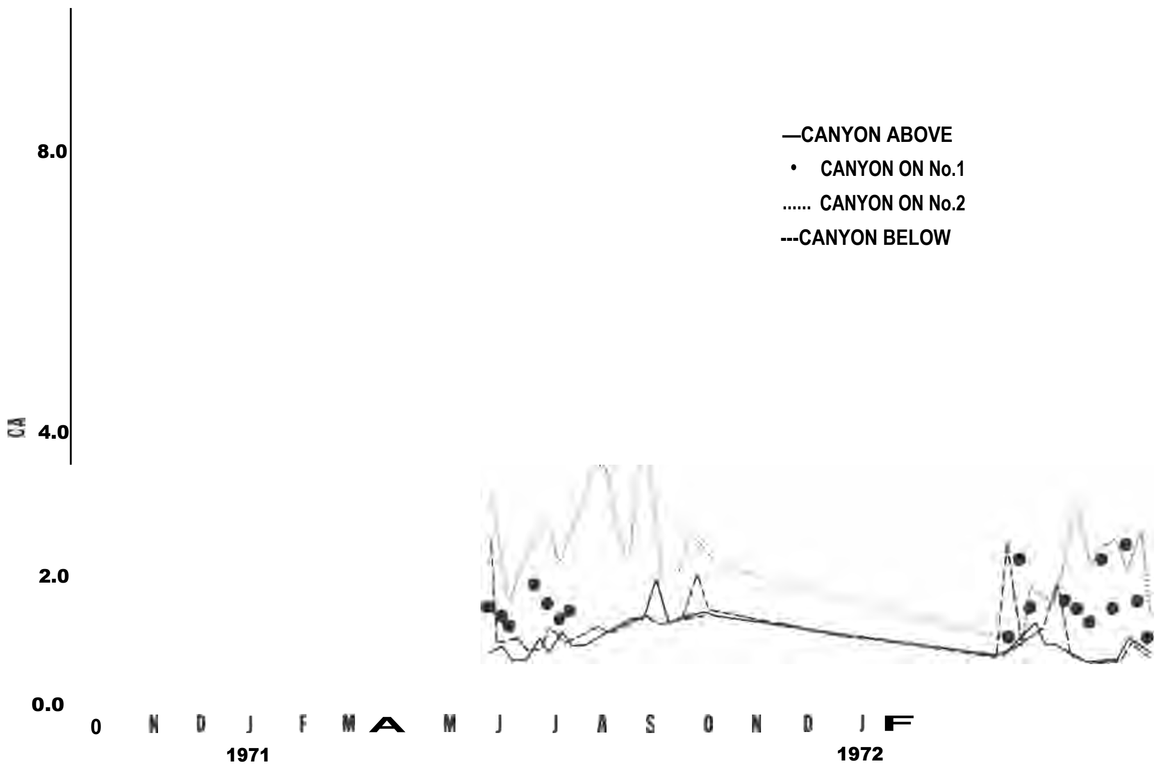


Figure 26.--Weekly average calcium values for the Canyon Creek stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

GENERAL DISCUSSION AND CONCLUSIONS

In the cedar-hemlock-grand fir ecosystem clearcutting of units of varying size (2.6 to 44 ha) and subsequent disposal of slash by prescribed burning resulted in on-site stream water quality changes. But off-site changes were of less intensity. Two of three clearcut units responded in this manner; a third unit gave different results. The physical and chemical components discussed represent the mean concentration per unit volume of discharge (or precipitation input) over a timespan of 21 months following land treatment.

Precipitation-Particulate Matter Input

Nitrate and potassium were the only nutrients in gross precipitation that equaled concentrations of these nutrients in the stream water at the ABOVE-site (control) stations. Incoming filterable solids (primarily atmospheric dust) exceeded by two to eight times the natural losses of filterable solids from undisturbed lands to stream water. All other precipitation nutrients were at lower concentrations than those in the stream water; only trace quantities of chloride could be detected in any precipitation sample.

On-Site Changes

Using the paired-station technique, comparisons of the physical and chemical parameters between most of the ABOVE-site (control) and ON-site (treated) stations indicated mean increases in pH, electrical conductivity, turbidity, filterable solids, bicarbonate, nitrate, sulfate, potassium, calcium, and magnesium. These ON-station increases also displayed large variances, ranging up to 116 times those calculated for the ABOVE-site stations.

With the exception of sodium, changes in cation concentrations between ABOVE and ON stations were lower than those reported by Tiedemann (1974) in his study of the effects of wildfire on water quality in central Washington. On the other hand, increases in cation concentration approximated those reported by Fredriksen (1971) in his evaluation of the effects of logging and slash burning on natural water quality in western Oregon.

Sulfate and bicarbonate were of particular interest because of the well-publicized studies by Likens and others (1970) conducted in the Northeast. They reported that the clearcutting of a small watershed, followed by treatment with herbicide, did not cause any increase in sulfate or bicarbonate concentrations in stream water. Our study at Priest River does not show this trend. We found that at all ON-site stations these anions increased in concentration after clearcutting and burning; the largest increase of any anion tested at Priest River was bicarbonate. These changes in bicarbonate concentration were of the same magnitude as reported by Fredriksen (1971).

Off-Site Changes

Comparisons between ABOVE-site (control) and BELOW-site (off-site) stations showed changes in fewer parameters, some barely significant. The parameters that did increase in concentration at most of the BELOW or downstream stations were bicarbonate, sulfate, calcium, magnesium, and electrical conductivity.

Benton and Canyon Creek ABOVE- and BELOW-site differences were generally less than ABOVE- and ON-site differences. At Ida Creek, increases were greater between ABOVE- and BELOW-sites. The local drainage pattern appears to play a dominant role in the reversal of nutrient concentration at the off-site stations. Although the steep slopes of the Benton clearcut-burn are dissected by first- and second-order channels, the surface runoff was ephemeral. Snowmelt runoff quickly collected in channels and transported a rich concentration of nutrients in solution. However, the overall volume of the side tributary was minimal compared with the volume in the main channel; hence, the process of dilution caused only slight increases in four nutrients.

A similar end point was reached at Canyon Creek, although the side tributary was perennial in constancy and produced a greater overall volume than at Benton Creek. We observed a significant increase in nutrient concentration after water emerged from the spring (ON #1 station) and flowed through a moderately incised channel to ON #2 station. Again, highly enriched and low in overall volume, the side tributary caused little impact on the main channel because of dilution. Small increases were detected in three chemical components.

Ida Creek has a markedly different drainage pattern. The logged area, located at the headwaters, lies downslope from a large spring and upslope from the point in Ida Creek of year-around surface flow. Water from the spring flows through the ABOVE-site station and onto the clearcut-burn to the ON-site station where it submerges, moves as subsurface flow, and reemerges to provide the bulk of the Ida Creek flow.

Uptake of nutrients increased progressively as the water moved on the surface to the ON-site station and, especially, as it percolated through the lower half of the clearcut-burn. Apparently, large quantities of leachate moved laterally from the nutrient-enriched surface layers. Unique to the Ida Creek site were the higher mean readings for certain nutrients at the off-site station because of the absence of a large volume of stream water. Thus a process of concentration rather than dilution prevailed.

Seasonal Trends and Runoff

Bicarbonate, sulfate, magnesium, and electrical conductivity increased between the ABOVE- and BELOW-site stations and displayed dependence upon seasonal runoff. Concentrations were lowest during high spring flows and highest during low flows. Tiedemann (1974) attributed similar trends to the dilution effect since lowest concentrations coincided with peak snowmelt runoff. Of the constant off-site parameters remaining (turbidity, suspended solids, pH, chloride, nitrate, sodium, and potassium), sodium was the only ion that displayed dependence upon seasonal runoff patterns.

Stream Ecology

The impacts of dissolved nutrients on the downstream ecology are generally unknown. However, such aquatic organisms as algae, which may contribute to eutrophication, thrive and grow if essential nutrients are available. Greeson (1969) lists the minimum concentrations of many essential nutrients for the growth and reproduction of algae. Minimum requirements for most of these nutrients are at trace levels. Many, if not all, of these ions are constituents of soils and could be added to natural waters through leaching. Without exception, nutrients found at the ABOVE-site stations in Benton Creek, Canyon Creek, and Ida Creek exceeded the minimal requirements of algae (table 5).

From the standpoint of hazard to humans, increased concentrations did not exceed U.S. Public Health Service (1962) standards for drinking water.

Table 5.--*Elements essential for the growth and reproduction of algae*[1/]

Element	Symbol	Minimum requirements
Calcium	Ca	[2/] Trace quantities
Chlorine	Cl	Trace quantities
Magnesium	Mg	Trace quantities
Nitrogen	N	Trace - 5.3 mg/ℓ
Phosphorus	P	0.002 - 0.09 mg/ℓ
Potassium	K	Trace quantities
Silicon	Si	0.5 - 0.8 mg/ℓ
Sodium	Na	[2/] Trace quantities
Sulphur	S	<5.0 mg/ℓ

[1/] Condensed from Greeson's (1969) table 1, page 26, except calcium and sodium.
[2/] Personal communication, Dr. A. J. Lingg, University of Idaho.

Buffer Strips

The utility of buffer strips as filters for suspended sediment is suggested by the significant differences in filterable solids between ABOVE- and ON-site stations and the nonsignificant increases between ABOVE- and BELOW-site stations. We also observed the effectiveness of the forest floor as a microbarrier to sediment-laden water. We cannot quantify the utility of strips as sediment traps. However, our data, along with those of others, indicate that utility in stream-temperature moderation and reduction in bank scouring suggest that buffer strips should continue to be used as a management tool.

Whether or not buffer strips will filter nutrients in solution is problematical. Perhaps, the major benefit of a buffer strip is that it will act as a physical barrier to direct contact with a nutrient source. In view of the high concentration of nutrients measured at the ON-site station we can speculate that unlogged or unburned strips adjacent to water courses within the clearcut unit would not have provided a ready source of nutrients for leaching. Until more knowledge is gained, the prudent manager should be very cautious about removing trees in the proximity of springs, seeps, and water courses. If he wishes to eliminate logging slash, he should do so by means other than burning.

LITERATURE CITED

American Public Health Association, Inc.
1971. Standard methods for examination of water and wastewater including bottom sediments and sludges. 13th ed. 874 p. Am. Public Health Assoc., Inc.

Brown, E., M. W. Skougstad, and M. J. Fishman.
1970. Methods for collection and analysis of water samples for dissolved minerals and gases. U.S. Geol. Surv., Book 5, Ch. Al, 160 p.

Brown, G. W., A. R. Gabler, and R. B. Marston.
1973. Nutrient losses after clear-cut logging and slash burning in the Oregon coast range. Water Resour. Res. 9(5):1450-1453.

Cole, D. W., and S. P. Gessel.
1963. Movement of elements through a forest soil as influenced by tree removal and fertilizer additives. *In* Forest-soil relationships in North America. p. 95-104. Chester T. Youngber, ed. Oreg. State Univ. Press, Corvallis.

Cole, D. W., and S. P. Gessel.
1968. Cedar River research, a program for studying the pathways, rates, and processes of elemental cycling in a forest ecosystem. Inst. For. Prod., Univ. Wash., No. 4, 54 p.

DeByle, N. V., and P. E. Packer.
1972. Plant nutrient and soil losses in overland flow from burned forest clearcuts. *In* Natl. Symp. Watersheds in Transition, p. 296-307. Colo. State Univ.

Fredriksen, R. L.
1971. Comparative chemical water quality - natural and disturbed streams following logging and slash burning. *In* Forest and land uses and stream environment, p. 125-137. Oreg. State Univ., Corvallis.

Greeson, P. E.
1969. Lake eutrophication--a natural process. Water Resour. Bull. 5(4):16-30.

Likens, G. E., F. H. Bormann, N. M. Johnson, and R. S. Pierce.
1967. The calcium, magnesium, potassium, and sodium budgets for a small forested ecosystem. Ecology 48(5):772-785.

Likens, G. E., F. H. Bormann, N. M. Johnson, and others.
1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. Ecol. Monogr. 40(1):23-47.

Marston, R. B.
1967. Pollutional concentrations and loads of some natural constituents and their relation to streamflow, before and after road building and tree harvesting in some small Alsea River watersheds in Western Oregon. U.S. Dep. Inter., FWPCE, Pac. Northwest Water Lab. Prog. Rep., 18 p.

Packer, P. E.
1965. Forest treatment effects on water quality. *In* International Symposium on Forest Hydrology, p. 687-699. Penn. State Univ.

Rothacher, J., C. T. Dryness, and R. L. Fredriksen.
1967. Hydrologic and related characteristics of three small watersheds in the Oregon Cascades. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., 54 p. Portland, Oreg.

Skau, C. M., R. 0. Meeuwig, and J. H. Humphrey.
1971. Watershed research on the eastside Sierra Nevada. Presented before IUFRO, 15th Congr., Gainesville, Fla., 4 p.

Streebin, L. E., J. M. Robertson, C. Bradshaw, and others.
1970. Rock Creek water quality study. 105 p. Sch. Civil Eng. and Environ. Sci., Univ. Okla.

Tarrant, R. F.
1971. Statement of, presented before hearing of the Subcommittee on Public Lands, Committee on Interior and Insular Affairs, U.S. Senate. On the Management of Public Lands. U.S. Gov. Print. Off., Washington, D.C.

Tiedemann, A. R.
1974. Stream chemistry following a forest fire and urea fertilization in North Central Washington. USDA For. Serv. Res. Pap. PNW-203, 20 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

U.S. Public Health Service.
1962. Drinking water standards. 956 p. U.S. Dep. Health, Educ., and Welfare, Public Health Serv., Washington, D.C.

U.S. Senate.
1971. Hearing of the Subcommittee on Public Lands, Committee on Interior and Insular Affairs. On the Management of Public Lands. U.S. Gov. Print. Off., Washington, D.C.

Weisel, G. F., and R. L. Newell.
1970. Quality and seasonal fluctuation of headwater streams in western Montana. Mont. For. and Conserv. Exp. Stn. Bull. 38, 16 p.

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SNYDER, GORDON G., HAROLD F. HAUPT, and GEORGE H. BELT, JR. 1975. Clearcutting and burning slash alter quality of streamwater in northern Idaho. USDA For. Serv. Res. Pap. INT-168, 34p., illus. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

In the cedar-hemlock-grand fir ecosystem clearcutting of units of varying size (2.6 to 44 ha) and subsequent disposal of slash by prescribed burning resulted in on-site stream water quality changes. But off-site changes were of less intensity. Two of three clearcut units responded in this manner; a third unit gave different results. The physical and chemical components discussed represent the mean concentration per unit volume of discharge (or precipitation input) over a timespan of 21 months following land treatment.

OXFORD: 116.0, 116.25, 221.1, 116.28, 232.213.
KEYWORDS: watershed management, fire (hydrology), clearcutting systems, logging (hydrology), regeneration (fire use).

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