DISSERTATION

SOIL WATER CONCENTRATIONS OF SELECTED IONS FOLLOWING CLEARCUTTING OF A LODGEPOLE PINE FOREST

Submitted by

Jay C. Hokenstrom

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY JAY C. HOKENSTROM ENTITLED SOIL WATER CONCENTRATIONS OF SELECTED IONS FOLLOWING CLEARCUTTING OF A LODGEPOLE PINE FOREST BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

Committee on Graduate Work

[redacted]

[redacted]

Adviser

[redacted]

Head of Department

ABSTRACT

Subsurface water was collected from three 3.4 ha treatment sites during the summers of 1973 and 1974 to determine the effect of clear-cutting lodgepole pine on the concentration of nutrients in subsurface water. One site was uncut; the other two sites, a "new" and an "old" clearcut, were clearcut in 1972 and 1965, respectively.

Water quality was examined by collecting soil water samples from depths of 1.0, .75, .50 and .10 m with tube-tension lysimeters on each of the three sites. Sampling was conducted from late May to early October in 1973, and from mid-May until the end of July in 1974.

When compared to the uncut site, average soil water concentrations during 1973 from the 1.0 m deep lysimeters were higher from the "new" clearcut by 79 percent for NO_3, 58 percent for Ca, and 33 percent for PO_4. For the same period, NH_4 and Cl from the "new" clearcut were 42 and 32 percent less, respectively. In 1974, average concentrations of NO_3 and Ca were 1,079 and 93 percent greater from the "new" clear-cut than from the uncut site during the sampling period while tannins, which were only measured in 1974, were about equal in concentration to those from the uncut site.

Average concentrations from the "old" clearcut during 1973 were greater than from the uncut area by 711 percent for NO_3, 50 percent for Ca, and 50 percent for PO_4. Average soil water concentrations of NH_4 and Cl from the "old" clearcut were 50 to 59 percent less, respectively. During 1974, average concentrations from the "old" clearcut were greater than from the uncut area by 672 percent for NO_3 and 27 percent for Ca, and less than from the uncut site by about 39 percent for tannins.

The data suggest that, following clearcutting of lodgepole pine forests, significant increases in soil water concentrations of nitrate and calcium can be expected for up to 9 years after cutting. Implications of nutrient additions to streams draining clearcut areas are discussed.

JAY C. HOKENSTROM
Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523
April 1976

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To my son, Jason Christopher, who is always complaining - "Not that dumb thesis again," I offer my apology for all the time I have not spent with him.

Finally, to my wife, Merekay, I express my greatest thanks for her patience, love, and encouragement during this undertaking.

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INTRODUCTION

Lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) is a major subclimax forest type over much of the Rocky Mountain region. For reasons including its susceptibility to windthrow, control of dwarf mistletoe and damage to reserve trees during partial cutting, clearcutting, i.e. the removal of an entire stand of trees in one cut, is usually the only practical harvest method in mature stands (Wellner, 1971).

Previous studies in hardwood (Bormann, Likens, Fisher, and Pierce, 1968; Likens, Bormann, Johnson, Fisher, and Pierce, 1970) and coniferous (Fredriksen, 1970; Gessel and Cole, 1965) forests have indicated that potentially significant losses of nutrients occur when forested areas are clearcut. These losses may not only reduce the fertility of the forest site for future timber production, but they also pose potential problems for streams draining these areas.

Streams draining forested areas typically are some of the least eutrophic of water sources (Cooper, 1969). Many forested watersheds serve as catchments for municipal water supplies. Headwater streams in the Rocky Mountain area are characteristically infertile as regards plant growth. Accelerated addition of plant nutrients to these streams from clearcut areas could alter their water quality and trophic status. The addition of nutrients to streams draining clearcuts might result from particulate and dissolved material in surface and subsurface runoff and from leaching of slash deposited in the stream channel during harvesting operations.

Essentially no information is available on the impacts of clear-cutting lodgepole pine on water quality. This thesis reports a study of selected chemical properties of subsurface water from two clearcut lodgepole pine areas and one uncut site. It is hoped that the results of this study will provide a better understanding of the possible consequences of this harvest practice in lodgepole pine forests.

LITERATURE REVIEW

Literature on the effects of forest management practices, principally clearcutting, on water quality has dealt mainly with physical alterations (sedimentation, temperature), water yields, and more recently with nutrient losses following cutting.

Increases in water yield from cut areas by reduction of transpiration and interception are well documented (Goodell, 1964; Hibbert, 1967; Kochenderfer and Patric, 1970; Kovener, 1957; Rothacher, 1970a). Increased water yields can sometimes result in the supplementation of stream flow during periods of normally low flow, i.e. during the summer and early fall (Goodell, 1959; Hoyt and Troxell, 1932; Kochenderfer and Patric, 1970; Hornbeck, 1973; Reinhart and Eschner, 1962; Rothacher, 1970b; Pierce, Hornbeck, Likens, and Bormann, 1970). Increases in base flows could be beneficial in providing increased living space for stream organisms (Chapman, 1962) and supplying needed water exchange in gravel beds for incubating fish eggs (Hall and Lantz, 1969; Pollard, 1955; Vaux, 1962).

Clearcutting usually results in earlier snowmelt but probably does not increase flood events at this time (Rothacher, 1973; Leaf, 1975; Hornbeck, 1973; Pierce, et al., 1970). Quickflow volumes and peaks will probably be greater during the growing season from clearcut watersheds than from forested areas because of wetter soil conditions on the clearcut sites (Hornbeck, 1973; Kochenderfer and Patric, 1970). Because of this, floods could result if storms of sufficient duration and intensity occurred on clearcut watersheds during this period.

Forest soils generally have high infiltration rates that reduce surface runoff and noticable erosion (Brown, 1972; Hewlett and Helvey, 1970). The physical act of felling all trees on a watershed is usually insufficient to cause significant increases in turbidity (Brown, 1972). The major cause of erosion from clearcut areas is the result of a decrease in the soil infiltration rate. Decreased infiltration may result from soil compaction during road construction and skidding of logs (Burns, 1972; Hornbeck and Reinhart, 1964; Megahan and Kidd, 1972; Reinhart and Eschner, 1962) and from slash burning that destroys surface organic material causing a hydrophilic soil condition (Brown and Krygier, 1971; Fredriksen, 1970; Swanston, 1971). Logging too close to streaam channels may cause bank disturbance and result in increased sedimentation. The effects of increased sedimentation on stream biota are well documented (Gibbons and Salo, 1973).

Cutting riparian vegetation on small forested streams generally results in increased water temperatures (Levno and Rothacher, 1967; Meehan, Farr, Bishop, and Patric, 1969). Brown and Krygier (1970) reported temperature data following clearcutting treatments on the Alsea Watershed in Oregon. On a patch cut watershed with 50- to 100-ft. buffer strips along the stream channel, no temperature changes were attributed to the cutting practice. A second watershed was clearcut and later burned. Mean monthly maximum temperatures were increased by 14 F following this treatment, and the annual maximum was increased by 28 F. It was apparent from this and similar studies that stream temperature increases need not be associated with cutting if a buffer strip is employed along the stream to maintain protection from insolation. Buffer strips can also aid in reducing turbidity and deposition of slash in streams by keeping the logging operation away from the channel.

Studies on nutrient fluxes in undisturbed forest watersheds reveal that forest ecosystems generally lose very little of their nutrient reserves through leaching (Cole, Gessel and Held, 1961; Cole, Gessel, and Dice, 1967; Likens, Bormann, Johnson, and Pierce, 1967; Peck and Hurle, 1973). In early studies on clearcutting at the Cedar Creek watershed in western Washington, Gessel and Cole (1965) followed nutrient movements through the soil profile on 0.2 ac plots with the use of tension lysimeters. Douglas-fir was removed from the plots by clearcutting and tension lysimeters were installed at depths of 1 and 36 in. Clearcutting resulted in increased water yields and only slightly greater losses of nitrogen, potassium and calcium than were reported from the control site. Because of the greater volumes of water moving through the clearcut area, concentrations of the solutes in the soil water were actually less than from the control area. Total nutrient losses in soil water were considered insignificant to the forest system as they represented less than 1 percent of the total elements in the soil system.

Studies on nutrient cycling in forest systems began to receive increased attention following the dramatic results obtained from an experiment at the Hubbard Brook Experimental Forest in New Hampshire (Bormann, et al., 1967, 1968, 1969; Likens, et al., 1970; Pierce, et al., 1970). Treatment at Hubbard Brook consisted of felling all trees on a 39 ac watershed and leaving them. The area was subsequently treated with a herbicide to prevent any regrowth. Results of this drastic treatment probably represent the maximum amounts of nutrients that could be lost through leaching from a forested area (Likens, et al., 1970).

Following removal of the vegetation, tremendous increases in nitrate concentrations in stream water were noted at Hubbard Brook. Nitrate concentrations were about 56 times greater 2 years after cutting than in a control stream. Ammonium concentration during the same period showed a small decrease (Likens, et al., 1970). In the first 3 years after cutting, the loss of nitrate amounted to about 342 kg/ha (Pierce, Martin, Reeves, Likens, and Bormann, 1972). Of the total nitrogen lost, approximately 97 percent occurred as dissolved substances. Overall, 85 percent of all material lost at Hubbard Brook occurred as dissolved substances (Bormann, Likens, and Eaton, 1969).

Concentrations of other nutrients also increased following devegetation of the Hubbard Brook site, but less drastically than nitrate. Average stream concentrations for the second year following cutting showed cation losses were 3 to 20 times greater than from the uncut watershed. Concentration decreases were noted for sulfate, bicarbonate, and ammonia (Likens, et al., 1970).

A subsequent study at Hubbard Brook in which trees were harvested by standard clearcutting techniques resulted in similar trends in nutrient removal, but losses were of lesser magnitude (Pierce, et al., 1972).

Likens, Bormann, and Johnson (1969) theorized that the increase in nitrate in the stream was the result of increased nitrification in the humus layers of the clearcut area. Although the pH of the stream was very low (5.1 in 1965-66 and 4.3 in 1966-68), nitrate concentrations increased during this period along with increases in soil nitrifying bacteria.

Anion mobilization as a mechanism for nutrient removal was clearly demonstrated during the Hubbard Brook study, since the total equivalents of nitrate lost almost complete balanced the equivalents of cations released (Likens, et al., 1969). McColl and Cole (1968) demonstrated that, in other forest systems, bicarbonate ions are important in cation movement.

Loss of nitrate from a clearcut oak-hickory and yellow poplar watershed at the Fernow Experimental Forest, West Virginia, was about 10 times greater than from a control watershed but only about one-third as great as that reported at Hubbard Brook during the first year following clearcutting (U.S. Forest Service, 1971).

The effects of four watershed treatments on nutrient losses were investigated at Coweeta Hydrologic Laboratory in North Carolina (Johnson and Swank, 1973). Treatments consisted of (1) a mature hardwood forest, (2) a 7-year-old hardwood coppice that was clearcut and allowed to regrow without timber removal, (3) a 13-year-old white pine plantation, and (4) a weed field that had been fertilized several times. The weed-to-forest succession treatment showed the greatest cation losses, but this may have been a reflection of past treatments. The smaller losses were reported from the white pine plantation.

A comparison of cation budgets from the undisturbed watersheds at Coweeta and Hubbard Brook revealed slightly greater losses of sodium, potassium, and magnesium at Coweeta but a slightly smaller loss of calcium than from Hubbard Brook (Johnson and Swank, 1973; Johnson, Likens, Bormann, Fisher, and Pierce, 1969).

Other studies of nutrient losses from undisturbed eastern forests have been reported by Elwood and Henderson (1973) and Best and Monk (1974).

In a study of the effects of clearcutting on aspen in northern Minnesota, Verry (1972) could detect no changes in the concentrations of various nutrients measured at stream gaging sites the first year after cutting. He attributed the lack of measurable increases in nutrients to several possible factors: (1) insufficient time to allow for significant decomposition, (2) vigorous regeneration, (3) high exchange capacity of the soils, (4) low topography, and (5) possible adsorption of nutrients by organic colloids or sphagnum moss in a nearby bog area.

Studies on nutrient cycling and the effects of clearcutting in coniferious forests have been conducted mostly in the Pacific Northwest. Prominent among these are those of Gessel and Cole, 1965; Cole, et al., 1967; Grier and Cole, 1972; Fredriksen, 1970 and 1972; and Brown, Gahler, and Marston, 1973.

An early study by Cole, et al., 1961, designed to demonstrate the utility of tension-plate lysimeters, revealed total nitrogen losses (mostly as ammonium) of less than 1.0 kg/ha at a depth of 28 in (71 cm) from a 30-year-old Douglas-fir stand for a January to July period.

Fredriksen (1970) analysed nutrient levels in a stream draining an area that was clearcut and later burned to remove slash. Losses of all nutrients measured increased following cutting. Following slash burning the second year, nutrient losses again increased. The second year following burning, losses of nutrients decreased relative to the previous year, except for nitrate which increased almost four times over the control value. Ammonia and magnesium concentrations in the stream exceeded drinking water standards of the U.S. Public Health Service for 12 days following slash burning (Fredriksen, 1970). Concentrations of both these nutrients decreased to almost undetectable levels following the initial increase. Neal, Wright, and Bollen, (1965) (in Fredriksen, 1970) also reported increased ammonium concentrations following slash burning of Douglas-fir. Likens, et al. (1969) suggested that nitrification occurs in mature hardwood forests in New Hampshire, but the forest is very efficient in utilizing ammonia and/or nitrate. The removal of the forest vegetation results in increased oxidation of ammonia to nitrate and its subsequent loss in drainage water.

Fredriksen (1972) reported on the loss of various nutrients from an undisturbed watershed at the H. J. Andrews Experimental Forest. Losses of cations were higher than any reported elsewhere in the Pacific Northwest. Losses of phosphorus and calcium were an order of magnitude greater than those reported by Cole, et al. (1967). Losses of calcium, magnesium, and sodium were approximately four to five times greater than losses from the Hubbard Brook control watershed (Likens, et al., 1970).

The primary anion lost at the H. J. Andrews site was bicarbonate (Fredriksen, 1970), in contrast to the Hubbard Brook study but consistent with the findings of McColl and Cole (1968) for a similar vegetation type.

In another study in Oregon (Brown, et al., 1973), nutrients were monitored in streams following clearcutting and slash burning of a red alder and Douglas-fir watershed. Significant losses of nitrates occurred following cutting and burning, but concentration data are difficult to interpret because of the presence of the alders, a nitrogen fixing species. On another watershed, where only 25 percent of the timber was cut, no increases in stream nitrate concentrations were detected, probably because concentrations were initially high due to the presence of red alder.

The study by Stottlemyer (1968) appears to represent the only available literature on nutrient losses from lodgepole pine forests. Four cations (calcium, magnesium, sodium, and potassium) were measured in precipitation and streams at the Fraser Experimental Forest, Colorado. Total cation concentration of snow and rain were about the same. The estimated annual input of cations through precipitation was about 15 kg/ha, while annual losses of cations measured were estimated to be about 26 to 29 kg/ha, for a net loss of about 14 kg/ha. Nitrates were not measured during this study, but the author felt that low cation concentrations precluded significant amounts of anions in the streams.

Fredriksen (1970) speculated that even small additions of nitrogen and phosphorus resulting from clearcutting and burning, if fully utilized, could result in significant increases in primary production in infertile mountain streams.

Most studies on the effects of nutrient additions to streams have concerned themselves with organic additions (Darnell, 1964; Hynes, 1970; Jones, 1964; Nelson and Scott, 1962; Warren, Wales, Davis, and Doudoroff, 1964; Waters, 1969; Vannote, 1969), while there is a paucity of studies on the effects of nutrient salts on biological systems in streams (Hynes, 1969; Keup, 1968).

The majority of information available on the effects of nutrient salts on aquatic systems has resulted from fish culture experiments (Gooch, 1967; Hickling, 1962; Liang, 1967; Neess, 1946; Polisini, Boyd, and Didgeon, 1970; Rabanal, 1967; Snow, Jones, and Rogers, 1964; Swingle and Smith, 1939; Swingle, Gooch, and Rabanal, 1963). These authors have generally concluded that addition of nitrogen to ponds results in only a small (if any) increase in fish production, because sufficient nitrogen is available as the result of fixation and/or from mobilization from pond sediments. Phosphorus was generally considered the limiting nutrient in these studies and the addition of phosphorus to pond waters resulted in greater plankton and fish production than in ponds that received no additional phosphorus.

Denton (no date), Boyd (1969), and Lawrence (1969), attempted to correlate nutrient concentrations in plants with nutrient levels in the soil and water and with previous chemical conditions but did not examine production rates under various nutrient regimes.

Extensive in vitro experiments were conducted by Chu (1943) to determine specific nitrogen and phosphorus requirements of selected algal species. Results indicated that the lower optimum nitrogen range for the various planktonic algae tested ranged from 0.26 to 1.30 ppm, while lower optimum phosphorus concentrations ranged from 0.018 to 0.098 ppm. Chu concluded that, since natural water concentrations of these two elements were frequently below these levels, both elements must frequently operate as limiting factors.

Round (1965) discussed algal requirements of other macronutrients (S, Ca, Mg, Na, K) and concluded that, in most natural water systems, these elements would only occasionally limit algal production.

Recent studies on Canadian lakes (Schindler, 1974; Schindler, Armstrong, Holmgren, and Brunskill, 1971, Schindler, Kling, Schmidt, Prokopowich, Frost, Reid, and Capel, 1973; Schindler and Fee, 1973) indicate that, in these lakes, phosphorus was the nutrient primarily responsible for blooms of phytoplankton, while nitrogen and carbon did not appear to be limiting to plant production. Brehmer, Ball, and Kevern (1969) concluded that nitrogen was the limiting nutrient in a river receiving sewage effluent, while Seruya and Berman (1970) noted that nitrogen, rather than phosphorus, was the critical nutrient factor in the initiation and growth patterns of phytoplankton in a reservoir. Goldman (1961) reported higher rates of photosynthesis from an area of a lake receiving runoff from alder stands (nitrogen fixing species), and Alexander (1972) suggested that, even where other nutrients may be limiting, reduction of nitrogen in aquatic systems can be expected to reduce growth of algae to some extent.

Ryther and Dunstan (1971) concluded nitrogen was usually limiting in eastern coastal waters (river and streams) where cultural inputs had occurred for many decades. Ryther and Guillard (1959) noted that, although surface concentrations of nitrates and phosphates were extremely low in the Sargasso Sea, additions of these nutrients had no effect on plankton production, which appeared to be limited by one or more trace elements and silica. Regarding limiting factors, O'Brien (1972) noted that one nutrient may control the rate at which standing crops increase, while another may limit the maximum attainable standing crop.

Many early studies of productivity in lakes were initiated to discern the degree of relationship between physical and chemical parameters of the body of water to productivity. Moyle (1946) indicated that alkalinity and phosphorus were the most valuable indices of productivity in Minnesota lakes; Sawyer (1947) examined Wisconsin lakes and predicted algal blooms would occur whenever late winter concentrations of molybdate reactive phosphorus exceeded 10 ug/l or dissolved inorganic nitrogen exceeded 0.3 mg/l.

Many investigators, however, are of the opinion that nutrient concentrations in aquatic systems are not representative of available nutrients because of the dynamic nature of the systems and that a more accurate assessment of the production potential can be obtained by measuring nutrient inputs to the system (Kemmerer, Glucksman, Stewart, and McConnell, 1968; Keup, 1968; Schindler and Comita, 1972; Schindler, et al., 1971; Ryther and Guillard, 1959). Gooch (1967), however, in assessing fish production in ponds, concluded that nutrient levels in the soil and water were more closely related to fish production than to levels of fertilizers applied.

Reviews of the effects of nutrients in natural waters are presented by Keeney (1972), Little (1970), Martin and Goff (no date), and Vollenweider (1967).

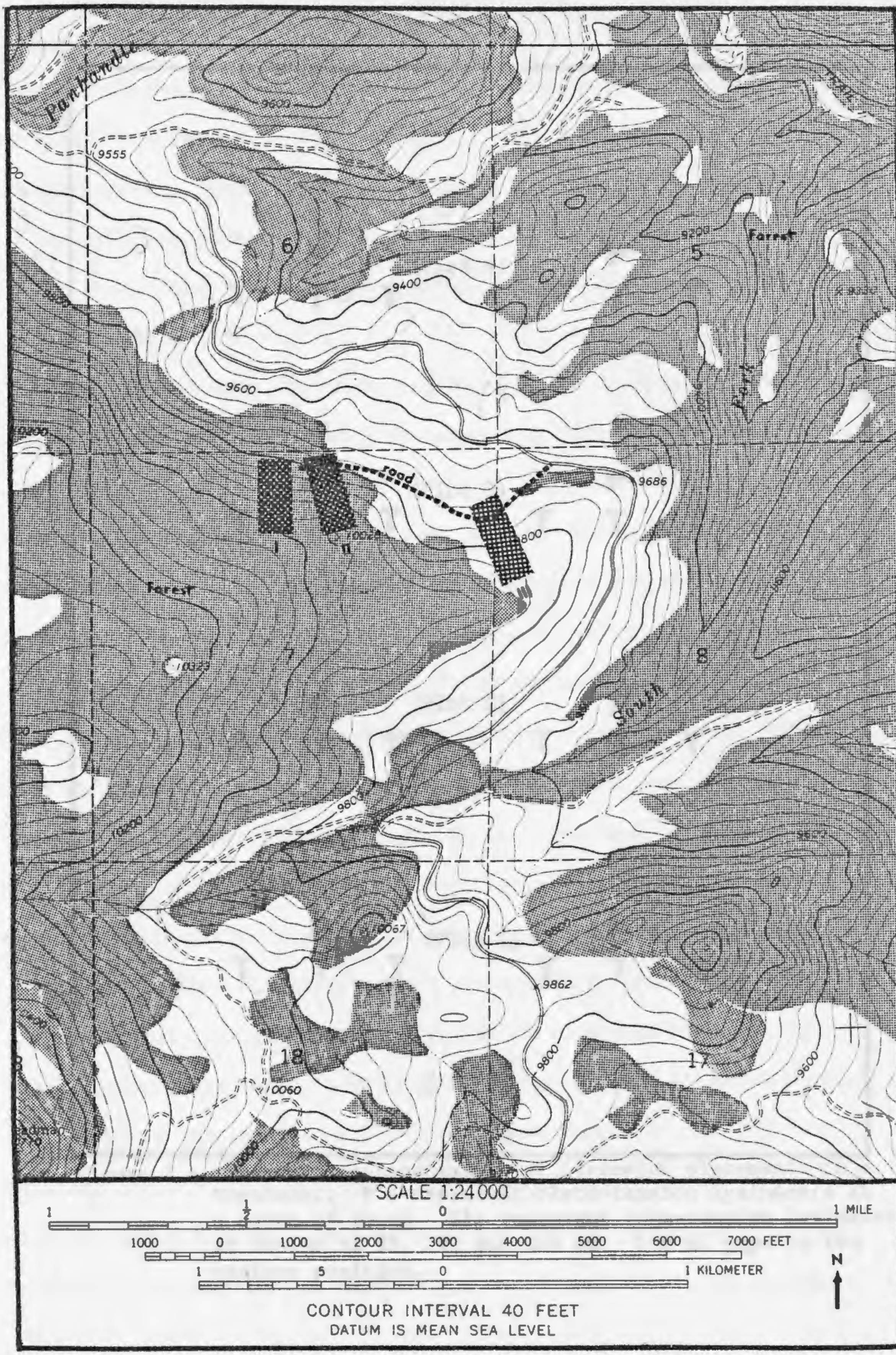
METHODS

Site Locations

Three treatment sites were selected during the fall of 1971. Study sites were located in the Roosevelt National Forest, approximately 80 km northwest of Fort Collins, Colorado. The area, locally referred to as the Deadman Lookout area, is located in sections 7 and 8, T10N, R47W, 6th P.M., in Larimer County in the Panhandle Creek drainage. The sites, which range in elevation from 2963 to 3048 m, are at the upper end of the elevation range for lodgepole pine (Reid, Odegard, Hokenstrom, and McConnell, 1974). Soils are sandy loams with a high gravel content, originating from decomposed granite, and alfisols of coarse texture, low fertility, and moderate depth (Reid, et al., 1974). A technical description of soil profiles from the three sites is presented in Appendix A.

The study area was selected for its accessibility, history of past clearcuttings, and current clearcutting operations. The three study sites were located on a north-northwest facing slope of approximately 10 to 12 percent. Treatment I was a 3.4 ha clearcut made in September 1972, treatment II was an uncut forested area (referred to in the text as the control), and treatment III was a 1965 clearcut (Figure 1).

Within each treatment, four slope positions (plots) were selected on a central transect parallel to the main slope such that the distances between plots and between the upper and lower plots and the upper and lower boundaries of the treatments were equidistant (Figure 2).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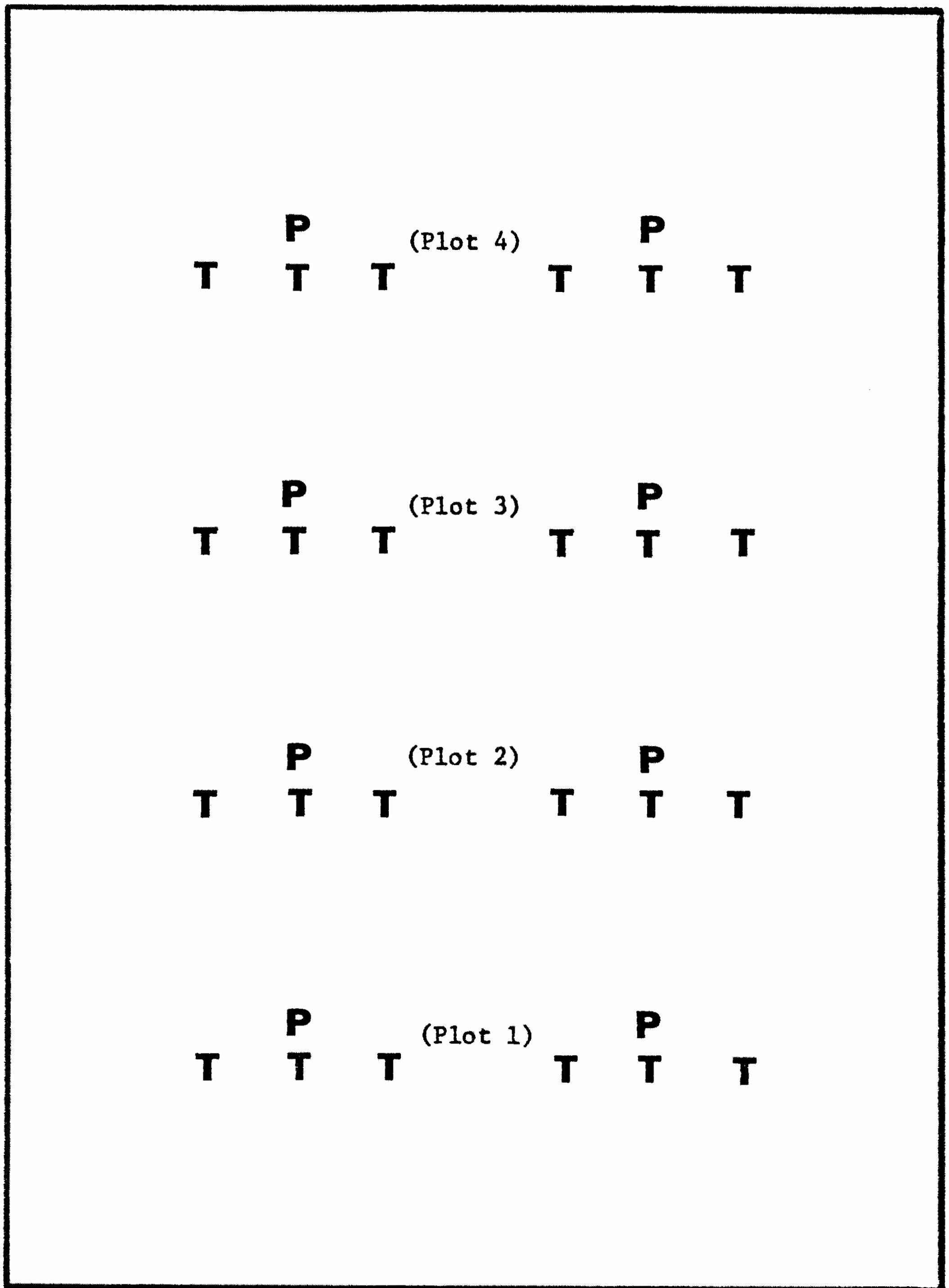


Figure 2 - Schematic representation of lysimeter placements on a treatment. P's represent plate-tension lysimeters at a depth of 10 cm. T's represent tube-tension lysimeters at depths of 50, 75, and 100 cm. Top of page is the upslope position.

Climate

Collection of climatological data during this study was very sporadic. Because of this deficiency, a brief description of the conditions on a nearby watershed (Little South Poudre) are included to acquaint the reader with general climatological characteristics of the area. The following desciptive data is from Meiman and Leavesley, 1974.

The Little South Poudre watershed occupies an area of about 169 Km^2. It is located approximately 48 Km west of Fort Collins, Colo. (lat. 40^{o} 35' N, long. 105^{o} 33' N). The watershed has a mean elevation of 22,959 m with nearly 80 percent of the area lying between 2,530 m and 3,444 m. Average annual temperature for the period from 1961 to 1971 was 1.7 C with extreme values of -43.1 C to 26.9 C.

Mean annual precipitation from 1963 and 1971 was 53.6 cm. Precipitation from November to April usually occurs as snow; from June to September, thunderstorms of short duration and high intensity and with small areal coverage deliver precipitation in the form of rain. From June to September (1966-70), the individual mean monthly precipitation ranged from about 3.8 to 6.4 cm. Precipitation during the months of October to May accounted for about 62 percent (33 cm) of the average annual precipitation on the watershed.

The hydrology of the Little South Poudre watershed was described as typical of the hydrology of mountain watersheds of the Northern Colorado Rocky Mountains. The runoff pattern is dominated by snowmelt with the major portion (about 75 percent) of the annual water yield occurring from May through August. About 45 percent of the average annual water yield occurs during the month of June. The average annual water yield from the Little South Poudre was equivalent to about 26 cm of runoff from the entire watershed or about 43 percent of the average annual precipitation for the years 1961-71.

<u>Water Collection</u>

Tension lysimeters were employed during the study to collect soil water from the three study sites.

Four lysimeters (three tube and one plate) were installed on either side of the central transect at each slope position and on a line perpendicular to the central transect which resulted in two "replications" at each plot (Figure 2). The distance between lysimeters and the order of depth of the lysimeters was random.

Plate-tension lysimeters (Cole, 1958) were constructed and installed at eight locations on each treatment site (two replicates at each of four plots). The vacuum reservoir for each plate lysimeter was a 1-l thick-walled glass bottle. The plates were installed by cutting a circular area slightly larger than the plate in the surface soil and then carefully removing this soil core to a depth of 10 cm. The plate lysimeter was then placed in the resulting hole and soil core replaced on top of the lysimeter and tamped gently into place. After installation there was no visible evidence of the lysimeter. Installation of plate lysimeters at depths deeper than 10 cm was impractical because of the rocky nature of the soils.

To collect soil water samples at depths greater than 10 cm, tube-tension lysimeters were used. These were constructed after the design developed at Pennsylvania State University (Parizek and Lane, 1970).

Tube-tension lysimeters were placed at random along the previously selected transect. Plate lysimeters were installed about 2 m upslope from the tube lysimeters. All lysimeters were operational by October 1973.

A two-way hand pump was used for applying pressure or tension to the lysimeters. A vacuum gauge was used to measure the tension applied. A vacuum of approximately 0.3 atm. (160 mm Hg) was applied to each tube lysimeter, and approximately 0.6 atm. (300 mm Hg) was applied to the plate lysimeters. The tension of 0.3 atm. was selected because it appeared to yield an amount of water sufficient for chemical analyses. The 0.6 atm. tension was selected because water in the upper 10 cm of the soil column was extremely transient and had to be collected as quickly as possible.

No attempt was made to adjust the tension of the lysimeters in response to the actual soil water tension on the treatment sites. For this reason, the amount of water collected can not be related to actual water movement on the sites. When water was collected by a lysimeter, it can be assumed that soil water in the vicinity of the lysimeter was under less natural tension than that caused by the lysimeter. Failure of a lysimeter to collect soil water may have been due to higher natural soil water tension or to instrument malfunction. No predictions of actual water yield can be made based on the soil water collections during this study. At best the data represent relative soil water conditions as they existed at the time of sampling. The effect of the lysimeters on natural drainage is unknown at present as is their zone of influence (soil volume from which the water is drawn) and their effect on soil microorganisms.

The lysimeter depths of 1, .75, 0.5 m and 10 cm were selected because it was not known at what depth soil water could be consistently collected from the three sites. The maximum depth of 1 m was selected after initial lysimeter instlalation attempts revealed that this was the depth to which it was possible to excavate with considerable difficulty. In addition, pits excavated for soil sampling revealed the majority of the visible tree roots were concentrated in the upper 1 m of the soil.

Soil water sampling was conducted from late May 1973 until mid-October 1973 and from mid-May 1974 until the end of July 1974. During 1973, lysimeter water samples were collected at all depths and were analyzed for various solutes. The 1974 sampling, however, did not include the 50- and 10-cm lysimeters from the upper two plots on each site, and the number of solutes analyzed was reduced.

Lysimeters were serviced on a weekly basis. Soil water samples collected were stored in plastic bottles and kept in an ice-filled cooler until they were returned to the laboratory and refrigerated later the same day.

Samples were analyzed for nitrate, ammonium, phosphate, and occasionally bicarbonate within 2 days in the Cooperative Fishery Unit Laboratory. Sample pH was determined in the field using a Hellige color comparator. Following the analyses listed above, the samples were stored for one week and then combined with the following week's samples from the same lysimeter to provide a sufficient volume for additional analyses. The combined samples were sent to the Soil Testing Laboratory on the CSU campus, for analysis of calcium, chloride, bicarbonate, and conductivity. Analyses of chloride, phosphate and ammonium were discontinued in 1974 because of time and financial limitations. Analyses for tannins were only performed on the 1974 samples. Several conductivity measurements were also made at the Cooperative Fishery Unit Laboratory in 1974.

Chemical Analysis

Chemical analysis methods were taken directly from Standard Methods (American Public Health Association, 1971). The methods used were: Nitrate--phenoldisulfonic acid method using KOH instead of NH_4OH; Ammonium--phenate method; Phosphate--stannous chloride method using a benzene-methanol extraction (40 ml sample, 30 ml extractant) after digestion with H_2SO_4 and HNO_3; Bicarbonate--titrimetric using pH meter; Calcium--atomic adsorption; Chloride--silver nitrate-potassium chromate; Tannins--HACH tanniver III; and Conductance--Beckman model RB3 solu bridge and a Beckman micro-cell with a cell constant of 0.5. A Turner model 350 spectrophotometer was used for all coloimetric methods.

Snow Surveys

Snow surveys were conducted on three occasions during the winter of 1972-73 and once during 1973-74. A Mount Rose snow tube was used to collect data on snow depth and water equivalent. Samples were taken along a central transect on each plot. Although the snow samples were taken only sporadically, and at least in the case of the 1973-74 sample, the survey was taken after the start of snowmelt, the data are presented below to allow the reader more insight into the hydrology of the area.

Plot	Date	Average Depth in	Average Depth cm	Average Water Equivalent in	Average Water Equivalent cm
Control	3-2-73	30.9	78.5	10.3	26.2
"New" Cut		24.3	61.7	6.5	16.5
"Old" Cut		15.0	38.1	3.1	7.9
Control	4-29-73	62.7	159.2	19.8	50.3
"New" Cut		43.9	111.5	14.8	37.6
"Old" Cut		25.5	64.8	8.5	21.6
Control	6-6-73	24.5	62.2	18.3	46.5
Control	4-26-74	59.9	152.1	20.0	50.8
"New" Cut		27.3	69.3	8.0	20.3
"Old" Cut		14.3	36.3	5.2	13.2

In 1973, only small patches of snow remained on the control by 22 June and both clearcuts had lost all snow cover 1 to 2 weeks earlier.

In 1974, both clearcuts were essentially free of snow by 3 June, while the control still had about 66 percent of its area covered with snow on that date. A heavy snow occurred on 7 June 1974; on 12 June the control had a complete snow cover while the "new" clearcut exhibited about a 50 percent cover and almost no snow remained on the "old" clearcut. By 17 June only the control had any snow remaining, but this amounted to only about 2 percent coverage and was gone by 24 June 1974.

Statistical Analysis

Statistical treatment of the concentration data consisted of an analysis of variance using three treatments, two slope positions (two upper plots combined and two lower plots combined), and two depths (75 to 100 cm) as main sources of variation. Contrasts of grand mean treatment concentrations were made using a modification of Scheffe's

S-contrasts (Frayer, 1968). Treatment means and standard errors for 10-, 50-, and 75-plus 100-cm samples were also calculated without consideration of slope position.

Plots of mean weekly concentrations and weekly losses were made using a Hewlett-Packard Model 9810A calculator and 9862A calculator plotter.

Quantification of nutrient losses from the three treatments was not possible because water yields from the treatments were not determined. Mean volumes of water collected and mean concentrations were calculated for each weekly sampling period and for each year. Mean weekly volumes of water were determined by summing water volumes collected from each treatment and dividing by the total number of tube lysimeters sampled at depths of 75 and 100 cm on each treatment (usually 16). This procedure resulted in a lower mean volume because it included several lysimeters on each treatment that did not collect any water. Mean concentrations were determined by summing individual concentrations from a treatment at 75 and 100 cm for a given sampling period and dividing by the total number of individual analyses.

The total weights (mg) of nitrate, calcium, ammonium, and chloride collected during the 1973 period were calculated. The weight of each solute was the product of the average weekly water volume and the solute concentration (in mg/1). During the 1974 period only weights of nitrate collected were determined.

RESULTS

Throughout the remainder of the text several terms will be employed for which definitions are necessary. Tube-tension lysimeters at depths of 75 and 100 cm will be referred to as "deep" lysimeters, while "shallow" lysimeters will refer to tube-tension lysimeters at a depth of 50 cm. Plate lysimeters will refer to plate-tension lysimeters at a depth of 10 cm. Weekly mean concentrations were calculated by summing all individual concentrations from "deep" lysimeters from a treatment for a given sampling period and dividing by the number of individual samples analyzed. Grand mean concentrations were calculated in a similar manner for the entire yearly sampling period. Weekly mean volumes were calculated by summing all water collected by "deep" lysimeters from a treatment for a given sampling period and dividing by the number of "deep" lysimeters sampled on each treatment, which was usually sixteen. Grand mean volumes were calculated by summing all water collected from "deep" lysimeters during the yearly sampling period and dividing by the total number of individual lysimeter sample collections during the period (usually sixteen per week).

The 1972 clearcut treatment will be referred to as the "new" clearcut, the 1965 clearcut treatment as the "old" clearcut, and the uncut site as the control.

In addition to results presented in this manuscript, analyses for magnesium, sodium, potassium and sulfate were conducted and analyzed in a manner similar to that presented herein. These results were not presented in this manuscript because of their usually minor importance in aquatic systems. Results of the above analyses, along with tabulations of analysis of variance results and concentration data from "shallow" and plate lysimeters, are presented in Reid, et al., 1974.

Water

Grand mean water volumes collected during the 1973 sampling period were greatest from the "new" clearcut (188 ml), intermediate from the "old" clearcut (161 ml), and lowest from the control (101 ml) (Table 1).

The control exhibited the greatest range in weekly mean volumes for both sampling years. From a mean weekly high of 216 ml in early June 1973, the mean volume decreased to 94 ml in mid-July, increased to 166 ml a week later and then rapidly decreased to zero in early September. Collections in early October showed an increase to 72 ml (Figure 3).

The weekly mean volume from the "new" clearcut decreased from 181 ml in early June 1973, to 141 ml by the end of June. Volumes then increased and remained fairly constant from July 21 to August 17, decreased to a low of 135 ml in early September, and then increased sharply to 229 ml in October (Figure 3).

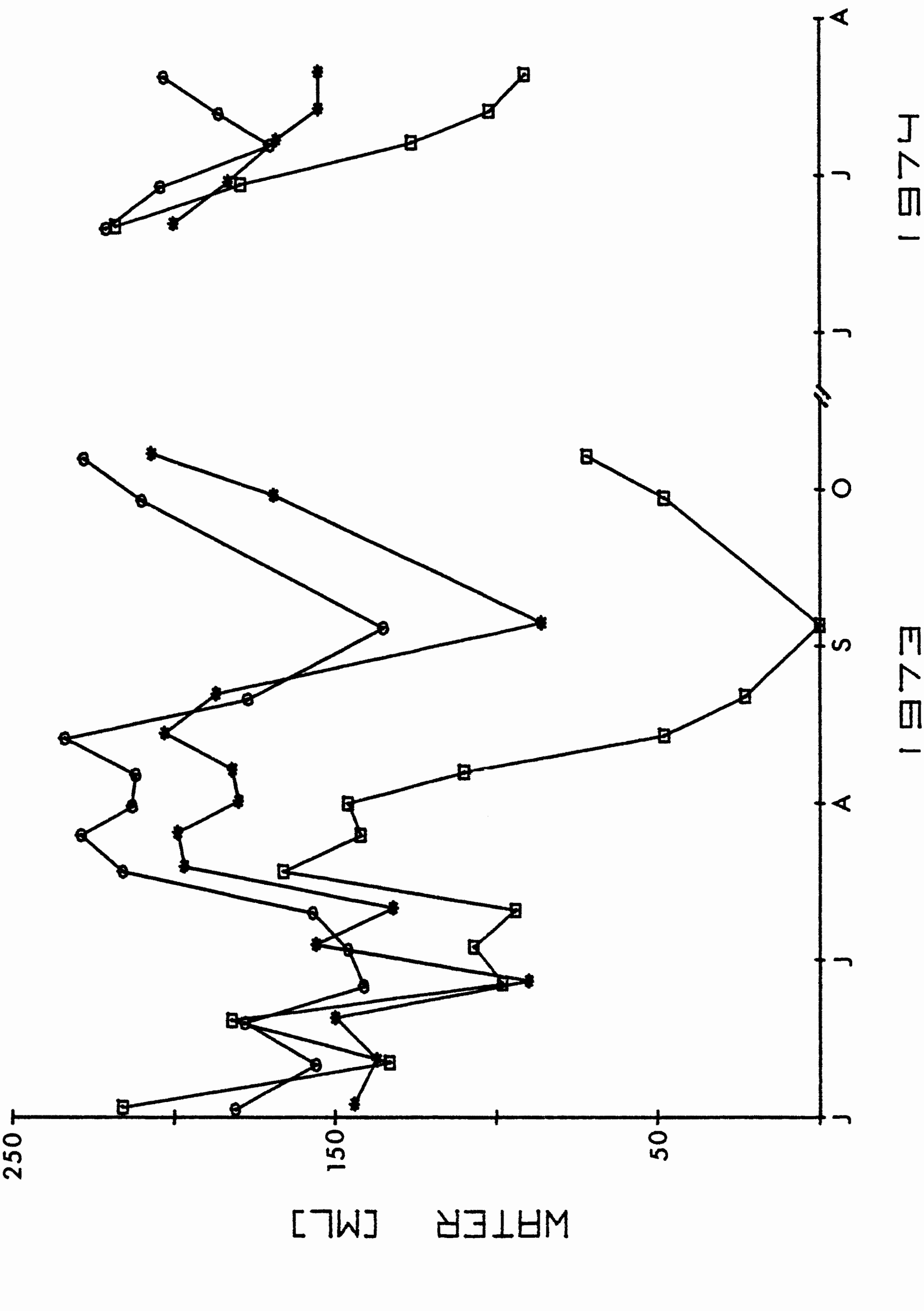
The "old" clearcut exhibited a pattern that was almost identical to that of the other two treatments during 1973 but with intermediate volumes (about 30 ml less than the "new" clearcut).

Weekly mean volumes during 1974 were slightly greater than for a comparable period in 1973 (Table 2). Water volumes were not recorded before June 17 in 1974.

Table 1. Weekly and grand mean[1] water volumes (ml) from "deep" lysimeters[2] during 1973.

Sampling Date	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
	Mean	S.E.(3)	N(4)	Mean	S.E.	N	Mean	S.E.	N
6-06-73	216	32.2	7	181	26.4	16	144	22.2	16
6-15-73	133	23.5	12	156	21.8	16	137	23.1	16
6-22-73	182	20.0	16	178	21.7	16	150	15.0	16
6-29-73	98	17.0	16	141	18.0	16	90	12.7	16
7-06-73	107	17.2	16	146	19.3	16	156	27.9	16
7-13-73	94	16.6	16	157	21.0	16	132	26.0	16
7-21-73	166	27.3	16	216	24.5	16	197	25.8	16
7-27-73	142	24.9	16	229	22.7	16	199	28.8	16
8-03-73	146	25.3	16	213	22.0	16	180	29.1	16
8-09-73	110	23.9	16	212	22.0	16	182	27.5	16
8-17-73	48	16.8	16	234	24.3	16	203	34.7	16
8-24-73	23	10.5	16	177	20.1	16	187	28.5	16
9-07-73	0	0.0	16	135	26.2	16	86	24.6	16
10-10-73	48	25.9	16	210	20.7	16	169	31.4	16
10-10-73	72	28.9	16	228	15.2	16	207	26.0	16
Grand Mean	101	6.5	227	188	5.8	240	161	6.9	240

(1) Total water collected from a specific treatment during a sampling period divided by the number of "deep" lysimeters serviced during that period.
(2) Tube-tension lysimeters at depths from 75 to 100 cm.
(3) Standard error of the mean.
(4) Number of lysimeters serviced.



WATER [ML]
250
150
50
J
J
A
S
O
J
J
A
1973
1974

Table 2. Weekly and grand mean[1] water volumes (ml) from "deep" lysimeters[2] during 1974.

	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Mean	S.E.(3)	N(4)	Mean	S.E.	N	Mean	S.E.	N
6-24-74	218	19.5	16	221	21.6	16	200	22.8	16
7-03-74	179	21.6	16	204	22.6	16	183	25.4	16
7-09-74	126	19.1	16	170	23.2	16	168	23.8	16
7-16-74	102	22.1	16	186	20.5	16	155	24.2	16
7-23-74	91	24.6	16	203	18.4	16	155	24.0	16
Grand mean	143	10.8	80	197	9.4	80	172	10.6	80

(1) Total water collected from a specific treatment during a sampling period divided by the number of "deep" lysimeters served during that period.

(2) Tube-tension lysimeters at depths from 75 to 100 cm.

(3) Standard error of the mean.

(4) Number of lysimeters serviced.

Grand mean water volumes collected from the "new" and "old" clearcuts from the 1973 period were approximately 86 percent and 59 percent greater, respectively, than those from the control during 1973 (Table 1). In 1974, grand mean volumes were about 38 percent and 20 percent greater than those from the control for the "new" and "old" clearcuts, respectively (Table 2).

The weather station at Red Feather Lakes recorded over 7.6 cm of precipitation for July 12-22, 1973, (U.S. Dept. Commerce). In addition, 1.4 cm was recorded on August 1, 1973, and 1.8, 3.0, and 0.6 cm on September 11, 25, and 28, 1973, respectively. Significant precipitation events during the 1974 sampling period included snow on June 8 with a water equivalent of 6.2 cm and rain on June 18 of 1 cm.

Nitrate

Grand mean nitrate concentrations for 1973 were 0.43, 0.77, and 3.49 mg/l for the control, "new" clearcut, and "old" clearcut, respectively (Table 3). The grand mean concentration from the "new" clearcut was 79.1 percent greater than the control, while the concentration from "old" clearcut was 711.1 percent greater than from the control. For 1974, grand mean nitrate concentrations were 0.29, 3.42, and 2.24 mg/l for the control, "new" and "old" clearcut, respectively (Table 4). The nitrate concentration for the "new" clearcut was 1179.3 percent greater than that from the control during 1974, while the concentration from "old" clearcut was 672.4 percent greater than that from the control for the same period.

Table 3. Weekly and grand mean nitrate concentrations (mg/1) in soil water samples from "deep" lysimeters[1] during 1973.

	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Mean	S.E.(2)	N(3)	Mean	S.E.	N	Mean	S.E.	N
6-06-73	.30	.70	6	.35	.08	13	2.39	.73	12
6-15-73	1.56	.63	9	.45	.05	13	.77	.47	12
6-22-73	.15	.05	14	.62	.28	13	2.51	.64	14
6-29-72	.38	.06	11	.51	.10	13	2.39	.66	13
7-06-73	.35	.05	10	.53	.09	13	3.21	1.06	11
7-13-73	.37	.13	12	.50	.14	13	4.69	2.38	10
7-21-73	.42	.06	12	.58	.10	13	5.00	1.28	13
7-27-73	.50	.09	11	.88	.23	14	3.82	1.22	13
8-03-73	.27	.07	12	.60	.17	14	3.38	1.07	11
8-17-73	.11	.05	5	.66	.35	15	3.28	.99	11
10-03-73	.41	.18	3	2.30	1.70	15	6.66	2.61	11
10-10-73	.29	.10	6	1.10	.41	12	4.60	2.63	9
Grand mean	.43	.06	111	.77	.17	161	3.49	.38	140

(1) Tube-tension lysimeters at depths from 75 to 100 cm.
(2) Standard error of the mean.
(3) Number of samples analyzed.

Table 4. Weekly and grand mean nitrate concentrations (mg/l) in soil water samples from "deep" lysimeters[1] during 1974.

	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Mean	S.E.(2)	N(3)	Mean	S.E.	N	Mean	S.E.	N
5-27-74	.40	.07	11	3.92	2.28	14	3.58	1.59	13
6-03-74	.15	.05	11	2.58	.99	15	2.54	.85	14
6-12-74	.19	.05	12	2.15	.89	15	2.60	.79	14
6-17-74	.35	.06	15	1.44	.65	15	1.53	.52	15
6-24-74	.24	.05	15	1.66	.78	14	1.14	.48	14
7-09-74	.30	.05	14	3.74	1.42	14	2.05	.61	14
7-16-74	.32	.06	12	4.66	1.91	15	2.50	.69	13
7-23-74	.34	.06	11	6.93	3.45	15	2.09	.72	13
Grand mean	.29	.02	101	3.42	.64	117	2.24	.29	110

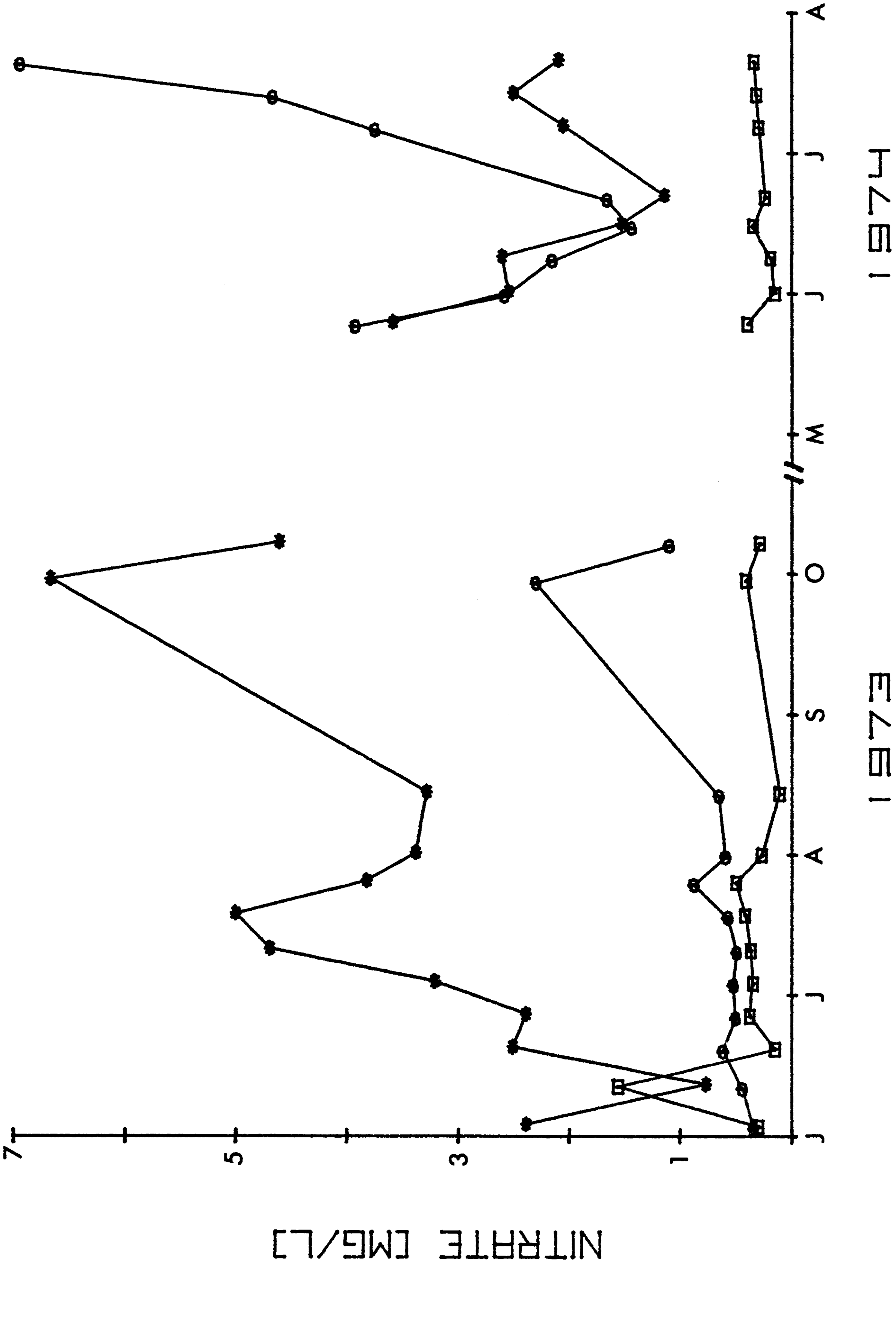
(1) Tube-tension lysimeters at depths from 75 to 100 cm.
(2) Standard error of the mean.
(3) Number of samples analyzed.

Comparison of average nitrate concentrations for the period from June 6 to July 21, 1973, with a similar time period in 1974, i.e. June 3 to July 23, revealed that the concentrations for the control were 42.6 percent less in 1974 (0.47 mg/l versus 0.27 mg/l), those for the "old" clearcut were 30.4 percent less in 1974 (2.96 mg/l versus 2.06 mg/l) and those for the "new" clearcut were 570 percent greater in 1974 (0.50 mg/l versus 3.35 mg/l).

Weekly mean nitrate concentrations from the control were amazingly constant during both years (Figure 4). With the exception of the June 15, 1973, sample, weekly mean concentrations from the control ranged from 0.11 to 0.50 mg/l in 1973 and from 0.15 to 0.40 mg/l in 1974.

Individual sample maximum nitrate concentrations from the control were 1.68 mg/l (July 13, 1973) and 0.84 mg/l (July 17, 1974). A maximum of 6.16 mg/l was obtained on June 15, 1973. The mean weekly concentrations from the control and the "old" clearcut for this date appear to be inconsistent with subsequent results. It is possible that samples were incorrectly labeled on this date. The values were not changed, however, and appear in the grand mean calculations for the appropriate treatments. A preliminary sampling in late October 1972, yielded a mean nitrate concentration from the control of 0.57 mg/l for four samples.

Nitrate concentrations from the "old" clearcut exhibited the greatest weekly mean values and weekly variation during 1973. After an initial decrease from 2.39 mg/l on June 6, 1973 the weekly mean nitrate concentration gradually increased through mid-July to 5.00 mg/l.


NITRATE (MG/L)
1
3
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7
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J
A
S
O
M
J
J
A
1973
1974

The mean concentration then decreased to 3.28 mg/1 in mid-August. By the October 3 sample, the mean nitrate concentration had increased sharply to a season high of 6.66 mg/1 and then decreased to 4.80 mg/1 with the final sample on October 10.

During 1974, the "old" clearcut, except for two occasions, had lower weekly mean nitrate concentrations than those from the "new" clearcut; however, they were still higher than those from the control. From an initial weekly mean concentration of 3.58 mg/1 in late May, the nitrate concentration decreased to a low of 1.14 mg/1 in late June and then increased to 2.50 mg/1 in mid-July. A slight decrease to 2.09 mg/1 was noted with the final sample on July 23, 1974.

The preliminary sampling in late October 1972, from the "old" clearcut resulted in a mean nitrate concentration of 3.06 mg/1 for eight samples. Individual sample maximum nitrate concentrations from the "old" clearcut were 28.19 mg/1 (October 3, 1973) and 18.24 mg/1 (May 27, 1974).

The most dramatic differences in nitrate concentrations from the three treatments for the two years were observed from the "new" clear-cut. Preliminary samples in late October 1972 (immediately after clearcutting), yielded a mean nitrate concentration of 0.37 mg/1 from three samples.

Weekly mean nitrate concentrations from the "new" clearcut were always greater than those from the control during 1973 (except for the June 15 sample) and less than those from the "old" clearcut during 1973. By mid-August, weekly mean nitrate concentrations from the "new" clearcut began to diverge from control concentrations, reaching a 1973 maximum for the treatment of 2.30 mg/l on October 3. The final sample in 1973 showed a decrease to 1.10 mg/l.

On May 27, 1974, the "new" clearcut weekly mean nitrate concentration was 3.92 mg/l. The weekly mean concentration decreased to 1.44 mg/l in mid-June and then increased sharply to a two-year high of 6.93 mg/l on July 23, 1974.

A 1973 individual sample maximum nitrate concentration from the "new" clearcut of 26.42 mg/l occurred on October 3, while, in 1974, an individual sample maximum concentration of 51.21 mg/l was obtained on July 23, from the same "deep" lysimeter. After analysis revealed this extremely high concentration, the "deep" lysimeter was replaced with a new tube lysimeter. The following week (July 29, 1974) a nitrate concentration of 54.89 mg/l was obtained from the new lysimeter. The porcelin cup from the original lysimeter was allowed to soak in about 200 ml of distilled water for one week after it was removed from the ground. Analysis of the water after the "leaching" period yielded a nitrate concentration of only 0.21 mg/l, probably indicating no nitrate production within the lysimeter.

Due to low soil moisture conditions, an insufficient number of samples from the plate and "shallow" lysimeters precluded statistical analyses of these collections. It appears that, for both years, the nitrate concentrations obtained at 10 cm were higher than those from greater depths for the control, about the same as those at greater depths for the "new" clearcut, and lower than the deeper lysimeter concentrations from the "old" clearcut (Table 5). The nitrate concentrations from the "shallow" (50 cm) lysimeters were consistent with those at greater depths for all three treatments.

Comparisons between treatment grand mean nitrate concentrations for 1973, using all individual samples from "deep" lysimeters, revealed the "old" clearcut nitrate concentrations to be significantly greater than those from either the "new" clearcut or from the control at an alpha level of 0.005. There was no statistically significant difference between grand mean nitrate concentrations from the "new" clearcut and the control for 1973.

Comparison of the 1974 samples revealed that the grand mean nitrate concentration from the "new" clearcut was significantly greater than those from the control and the "old" clearcut at alpha levels of 0.005 and 0.250, respectively. For the 1974 period the grand mean nitrate concentration from the "old" clearcut was significantly greater than from the control at an alpha level of 0.025.

The average amount (mg) of nitrate collected by "deep" lysimeters for each treatment was claculated for both sampling years (Tables 6 and 7). During the 1973 period, an average of 7.3 mg of nitrate was collected from the "old" clearcut, while average amounts collected from the "new" clearcut and the control were 1.9 mg/l and 0.6 mg/l, respectively. Over 11 times more nitrate was collected from the "old" clearcut than was collected from the control during the 1973 period, while the average amount of nitrate collected from the "new" clearcut was almost three times greater than that from the control for the same period.

Table 5. Mean nitrate concentrations (mg/l) in soil water samples at 10 and 50 cm during 1973 and 1974.

		Treatment								
		Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Data	Depth	Mean	S.E.(1)	N(2)	Mean	S.E.	N	Mean	S.E.	N
6-06-73	10	-	-	-	-	-	-	2.09	.90	4
	50	.52	.06	5	.41	.12	5	8.28	4.88	6
6-15-73	10	-	-	-	.40	-	1	2.11	-	1
	50	2.62	1.14	5	.70	.13	6	.62	.58	3
6-22-73	10	1.22	-	1	.21	.15	2	.70	-	1
	50	.22	.07	7	.69	.27	7	1.57	.82	5
6-29-73	50	.44	.08	5	.71	.29	4	3.44	2.72	2
7-06-73	10	-	-	-	.48	-	1	1.97	.25	2
	50	.44	.09	3	.88	.30	5	9.34	-	1
7-13-73	50	.33	.23	2	.88	.29	5	-	-	-
7-21-73	10	2.91	1.03	2	-	-	-	2.57	.44	3
	50	.56	.10	7	.94	.32	6	4.15	2.76	6
8-03-73	50	.32	.10	6	.87	.29	6	8.18	5.80	4
8-17-73	50	.24	.17	3	.53	.22	5	17.84	13.54	2
5-27-74	10	-	-	-	1.13	-	1	-	-	-
	50	-	-	-	1.44	.42	3	5.35	5.07	3
6-03-74	10	-	-	-	1.92	.92	2	-	-	-
	50	.36	-	1	1.14	.30	3	.29	.15	3
6-12-74	10	1.96	-	1	-	-	-	1.17	-	1
	50	.29	-	1	1.46	.73	4	1.12	.79	4

(1) Standard error of the mean.
(2) Number of samples analyzed.

Table 6. Average amount (mg) of nitrate collected by "deep" lysimeters[1] during 1973.

Sampling Date	Treatment		
	Control	"New" Clearcut (1972)	"Old" Clearcut (1965)
6-06-73	.065	.063	.344
6-15-73	.207	.070	.150
6-22-73	.027	.110	.379
6-29-73	.037	.072	.215
7-06-73	.037	.077	.501
7-13-73	.035	.078	.619
7-21-73	.070	.216	.985
7-27-73	.071	.202	.760
8-03-73	.039	.130	.608
8-17-73	.005	.154	.666
10-03-73	.027	.483	1.126
10-10-73	.021	.251	.952
Grand Total	.641	1.906	7.302

(1) Tube-tension lysimeters at depths of 75 to 100 cm.

Table 7. Average amount (mg) of nitrate collected by "deep" lysimeters[1] during 1974.

Sampling Date	Treatment: Control	"New" Clearcut (1972)	"Old" Clearcut (1965)
5-27-74[2]	.069	.674	.516
6-03-74[2]	.026	.444	.366
6-12-74[2]	.033	.370	.374
6-17-74[2]	.060	.278	.220
6-24-74	.052	.367	.228
7-09-74	.038	.636	.344
7-16-74	.033	.867	.388
7-23-74	.029	1.407	.324
Grand Total	.340	5.043	2.760

(1) Tube-tension lysimeters at depths of 75 to 100 cm.

(2) Mean water volumes of 172, 172, and 144 ml applied to the Control, 1972 Clearcut, and 1965 Clearcut, respectively. These volumes are the average for the period from 6-06-73 to 6-22-73 from the appropriate treatment. Water volumes were not recorded for this period in 1974.

For the 1974 period, average amounts of nitrate collected by "deep" lysimeters were 0.35, 5.0, and 2.8 mg for the control, "new" clearcut, and "old" clearcut, respectively. For 1974, the amount of nitrate collected from the "new" clearcut was almost 15 times greater than that from the control and almost twice that collected from the "old" clearcut.

Ammonium

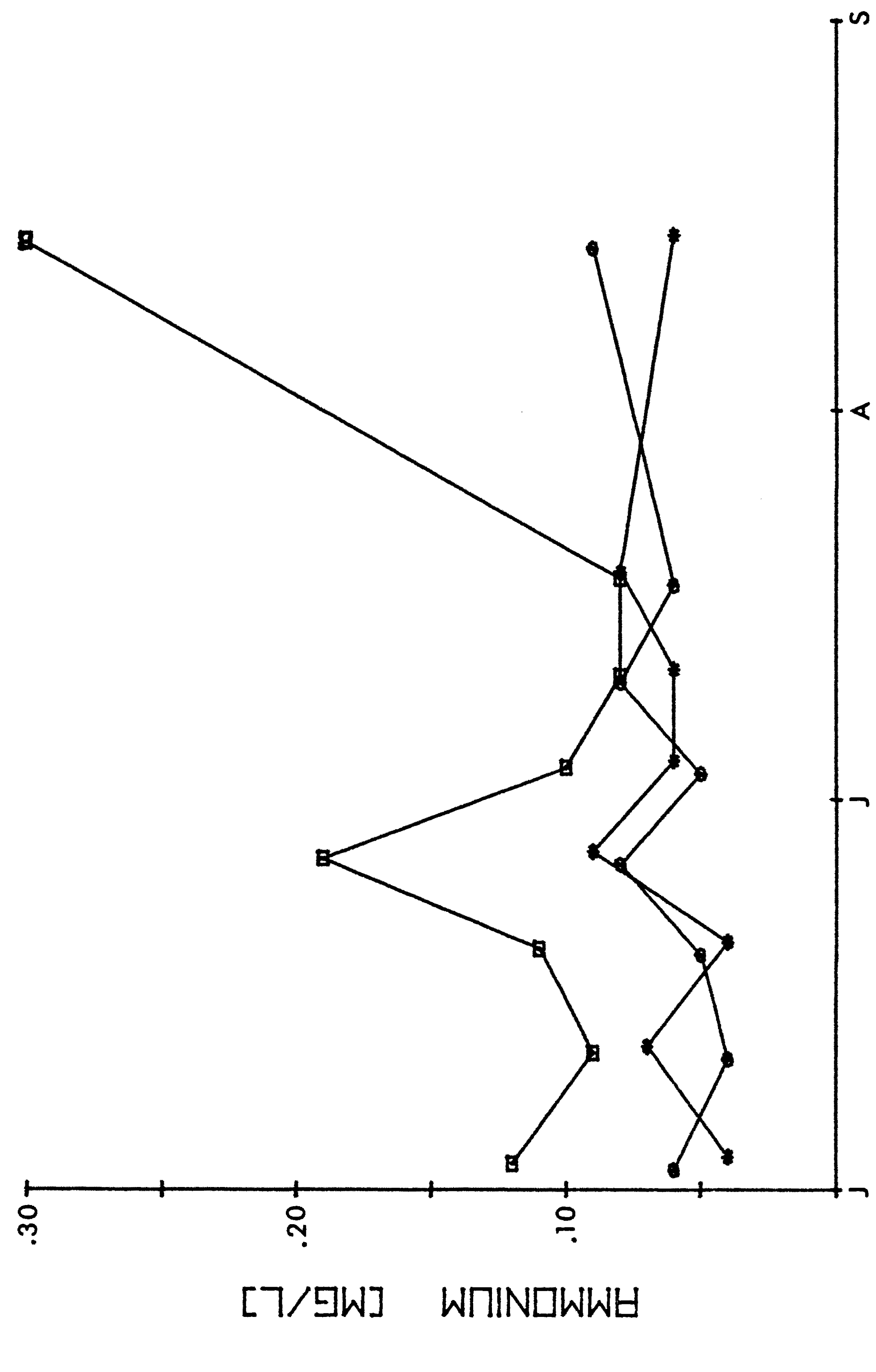
For the period of sampling in 1973, grand mean ammonium concentrations were 0.12 mg/l for the control, 0.07 mg/l for the "new" clearcut, and 0.06 mg/l for the "old" clearcut (Table 8). Based on these grand mean concentrations, "new" and "old" clearcut means were almost 42 and 50 percent less than that of the control.

The control, except on two occasions, exhibited the greatest weekly mean ammonium concentrations of the treatments, and on all occasions exhibited greater variability than either of the two clearcuts (Table 8 and Figure 5). From an initial mean concentration of 0.12 mg/l in early June, the mean weekly ammonium concentration decreased to 0.09 mg/l by mid-June, and then increased to 0.19 mg/l in late June. This rise was followed by a decrease to a season low of 0.08 mg/l in late July and a subsequent sharp increase to a season high of 0.30 mg/l on August 17. An individual ammonium concentration sample maximum of 0.91 mg/l was recorded on August 17. Analyses for ammonium were not conducted prior to collection of the 1973 samples.

Table 8. Weekly and grand mean ammonium concentrations (mg/1) in soil water samples from "deep" lysimeters(1) during 1973.

	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Mean	S.E.(2)	N(3)	Mean	S.E.	N	Mean	S.E.	N
6-06-73	0.12	0.06	6	0.06	0.02	13	0.04	0.01	12
6-15-73	0.09	0.03	9	0.04	0.01	13	0.07	0.01	12
6-22-73	0.11	0.05	14	0.05	0.02	13	0.04	0.02	14
6-29-73	0.19	0.07	11	0.08	0.02	13	0.09	0.02	11
7-06-73	0.10	0.04	10	0.05	0.02	13	0.06	0.02	11
7-13-73	0.08	0.03	11	0.08	0.01	13	0.06	0.02	10
7-21-73	0.08	0.04	7	0.06	0.01	10	0.08	0.03	9
8-17-73	0.30	0.17	5	0.09	0.02	10	0.06	0.04	8
Grand mean	0.12	0.02	73	0.07	0.005	98	0.06	0.008	87

(1) Tube-tension lysimeters at depths from 75 to 100 cm.
(2) Standard error of the mean.
(3) Number of samples analyzed.



AMMONIUM [MG/L]
.30
.20
.10
J
J
A
S
1973

Weekly mean ammonium concentrations from both the "new" and "old" clearcuts followed a pattern similar to those of the control, although concentrations were less than from the control. Ranges from both clearcuts were between 0.04 and 0.09 mg/l. Individual sample maxima were 0.20 mg/l (June 22) for the "new" clearcut and 0.34 mg/l (July 21) for the "old" clearcut.

Comparisons between grand mean ammonium concentrations revealed that those from the control were significantly greater than those from either clearcut treatment at an alpha level of .005. There were no significant differences between grand mean ammonium concentrations from the two clearcuts.

The average amounts of ammonium collected by "deep" lysimeters for the 1973 period were 0.12, 0.09, and 0.07 mg from the control, "new" and "old" clearcuts, respectively (Table 9). Total amounts of ammonium collected from the "new" and "old" clearcuts were about 24 to 40 percent less, respectively, than that collected from the control. Average amounts of ammonium collected were equivalent to 0.10, 0.08, and 0.06 mg of nitrogen for the control, "new" and "old" clearcuts, respectively.

Calcium

Grand mean calcium concentrations for the 1973 sampling period were 4.0, 6.3, and 6.0 mg/l for the control, "new" clearcut, and "old" clearcut, respectively (Table 10). During the sampling period in 1974, grand mean concentrations were 2.6 mg/l for the control, 5.0 mg/l for the "new" clearcut, and 3.3 mg/l for the "old" clearcut (Table 11). The "new" and "old" clearcut mean calcium concentrations were 57.5 and 50.0 percent greater, respectively, than those from the control

Table 9. Average amount (mg) of ammonium collected by "deep" lysimeters[1] during 1973.

Sampling Date	Treatment		
	Control	"New" Clearcut (1972)	"Old" Clearcut (1965)
6-06-73	.026	.011	.006
6-15-73	.012	.006	.009
6-22-73	.019	.008	.006
6-29-73	.018	.011	.008
7-06-73	.011	.008	.009
7-13-73	.007	.013	.007
7-21-73	.013	.014	.016
8-17-73	.014	.020	.011
Grand Total	.120	.091	.072

(1) Tube-tension lysimeters at depths of 75 to 100 cm.

Table 10. Weekly and grand mean calcium concentrations (mg/l) in soil water samples from "deep" lysimeters(1) during 1973.

	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Mean	S.E.(2)	N(3)	Mean	S.E.	N	Mean	S.E.	N
6-06 + 15-73	5.3	1.05	9	8.2	1.47	15	9.6	1.14	14
6-22 + 29-73	2.6	.54	14	4.4	.37	14	2.8	.39	16
7-06 + 13-73	2.6	.58	13	2.8	.41	14	7.0	.83	12
7-21 + 27-73	3.6	.72	13	7.9	.66	14	4.9	.54	15
8-03 + 09-73	4.3	.47	13	5.6	.48	14	5.6	.39	14
8-17 + 24-73	5.1	.77	10	6.2	.38	16	6.9	1.10	14
10-03 + 10-73	6.1	1.00	9	8.4	.93	16	6.2	.44	12
Grand mean	4.0	.29	81	6.3	.34	103	6.0	.34	97

(1) Tube-tension lysimeters at depths of 75 to 100 cm.
(2) Standard error of the mean.
(3) Number of samples analyzed.

Table 11. Weekly and grand mean calcium concentrations (mg/l) in soil water samples from "deep" lysimeters(1) during 1974.

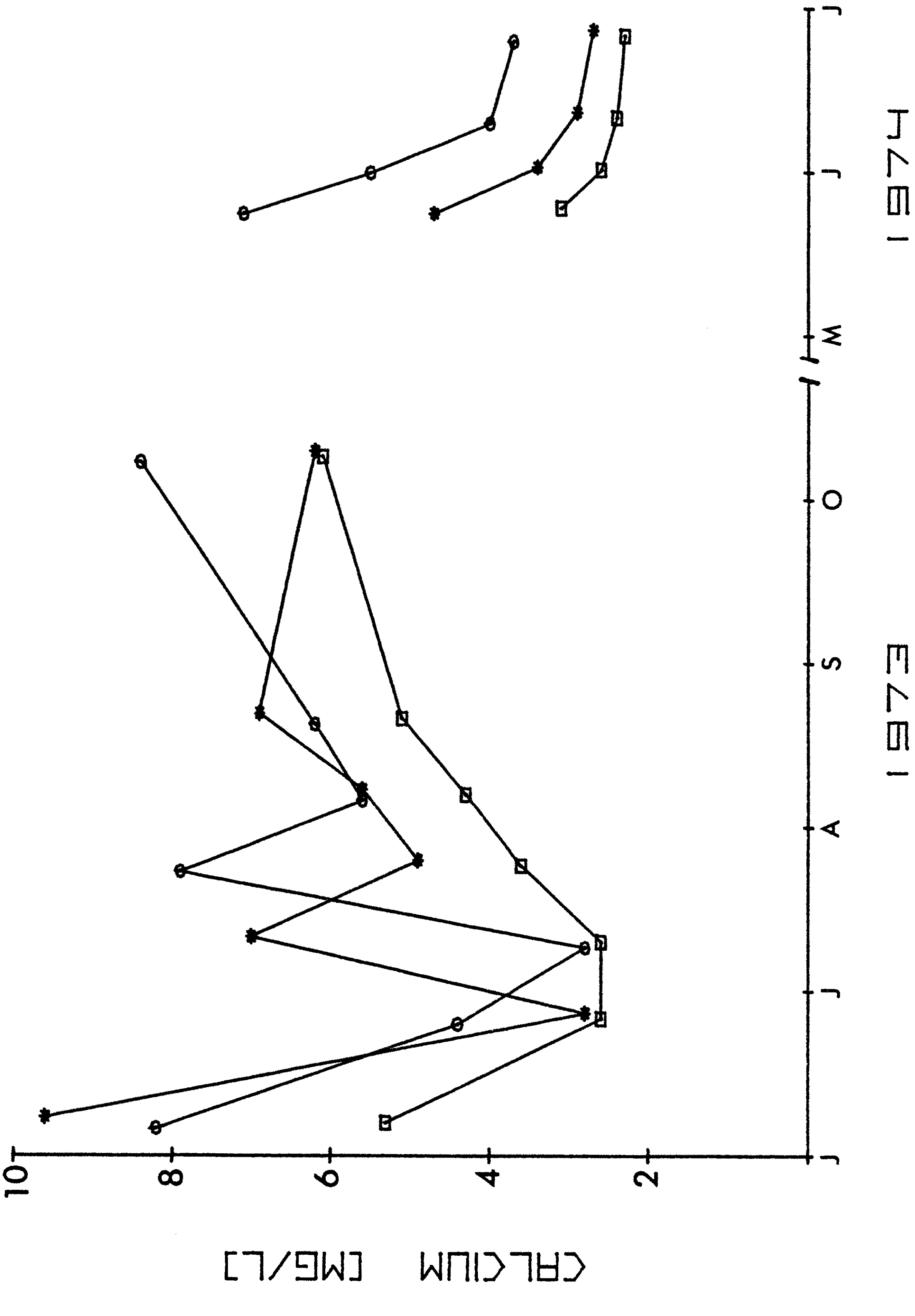
	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Mean	S.E.(2)	N(3)	Mean	S.E.	N	Mean	S.E.	N
5-27-74	3.1	.50	10	7.1	1.43	14	4.7	1.11	12
6-03-74	2.6	.30	11	5.5	.75	15	3.4	.30	14
6-12 + 17-74	2.4	.16	15	4.0	.61	16	2.9	.37	16
6-24 + 7-03-74	2.3	.13	15	3.7	.33	15	2.7	.26	15
Grand mean	2.6	.13	51	5.0	.44	60	3.3	.29	57

(1) Tube-tension lysimeters at depths of 75 to 100 cm.
(2) Standard error of the mean.
(3) Number of samples analyzed.

in 1973; in 1974, grand mean calcium concentrations from the two clearcuts were approximately 93 and 27 percent greater, respectively, than from the control.

Samples from the control always exhibited lower weekly mean calcium concentrations, during both years, in comparison to the two clearcuts (Figure 6). From a mean concentration of 5.3 mg/l in early June 1973, the weekly mean calcium concentration from the control decreased sharply to 2.6 mg/l near the first of July. From this 1973 season low, the concentrations gradually increased to a season high of 6.1 mg/l in early October. The weekly mean concentrations from the control in 1974 gradually decreased from 3.1 mg/l in late May to 2.3 mg/l in late June when analyses were terminated. Individual concentration maxima of calcium from the control were 12.0 mg/l for the October 3 + 10, 1973 sampling period and 7.0 mg/l on May 27, 1974.

Calcium concentrations from the "old" clearcut exhibited a trend similar to those from the control during both years. The notable exception was a peak in early July 1973, of 7.0 mg/l. From a 1973 season high of 9.6 mg/l in early June, mean weekly calcium concentrations from the "old" clearcut decreased sharply in late June, increased sharply in early July to 7.0 mg/l, then decreased, increased, and final decreased again to 6.2 mg/l in early October. During 1974, the calcium concentrations from the "old" clearcut paralleled those of the control but were approximately 0.5 to 1.5 mg/l greater. Individual sample maxima from the "old" clearcut were 20.0 mg/l for the August 17 + 24, 1973 sampling period and 15.0 mg/l on May 27, 1974.


CALCIUM (MG/L)
10
8
6
4
2
J
J
A
S
O
M
J
J
1973
1974

Weekly mean calcium concentrations from the "new" clearcut followed patterns similar to those from the "old" clearcut during both years. With the exceptions of the peak in early July 1973, occurring approximately two weeks later on the "new" clearcut, and the lack of a decrease in early October from the "new" clearcut, the patterns are almost identical. The weekly mean calcium concentrations from the "old" clearcut decreased from 8.2 mg/l in early June 1973, to 2.8 mg/l in early July, increased to 7.9 mg/l two weeks later, then decreased to 5.6 mg/l in early August, and finally rose gradually to 8.4 mg/l in early October. During 1974, weekly mean concentrations from the "new" clearcut decreased from 7.1 mg/l in late May to 3.7 mg/l in early July.

Comparisons between grand mean calcium concentrations from the three treatments during 1973 showed those of the two clearcuts to be significantly greater than that of the control at an alpha level of 0.005. There was no significant difference between grand mean calcium concentrations from the two clearcuts during 1973. For the 1974 period, the grand mean concentration from the "new" clearcut was significantly greater than that of either the control or the "old" clearcut at an alpha level of 0.005. Grand mean calcium concentrations from the control and the "old" clearcut during the 1974 sampling period were not significantly different at alpha level of 0.250.

The average amounts of calcium collected from "deep" lysimeters during 1973 were 6.4, 17.1, and 14.4 mg from the control, "new" clearcut, and "old" clearcut, respectively (Table 12). The total collected from the "new" clearcut was 167 percent greater than that from the control, while that from the "old" clearcut was 124 percent greater than that from the control.

Table 12. Average amount (mg) of calcium collected by "deep" lysimeters[1] during 1973.

Sampling Dates	Treatment		
	Control	"New" Clearcut (1972)	"Old" Clearcut (1965)
6-06 + 15-73	1.850	2.762	2.695
6-22 + 29-73	.730	1.400	.673
7-06 + 13-73	.523	.846	2.019
7-21 + 27-73	1.111	3.516	1.942
8-03 + 09-73	1.102	2.380	2.030
8-17 + 24-73	.362	2.548	2.691
10-03 + 10-73	.736	3.680	2.329
Grand Total	6.414	17.132	14.379

(1) Tube-tension lysimeters at depths of 75 and 100 cm.

Chloride

Grand mean chloride concentrations were 4.1 mg/l from the control, 2.8 mg/l from the "new" clearcut, and 2.5 mg/l from the "old" clearcut for the period of sampling in 1973 (Table 13). Grand mean concentrations were 32 and 39 percent less, respectively, from the "new" and "old" clearcuts than those from the control. Chloride analyses were only conducted in 1973.

The weekly mean chloride concentration from the control decreased from 5.8 mg/l in early June to 2.8 mg/l in late June (Figure 7). The mean concentration increased gradually through July, increased shaply in early August to 6.6 mg/l, and then decreased to 2.2 mg/l in early October 1973.

The weekly mean chloride concentration from the "new" clearcut decreased from 3.5 mg/l in early June to 2.2 mg/l in late June and then held fairly constant at between 3.0 mg/l and 2.5 mg/l for the remainder of the year.

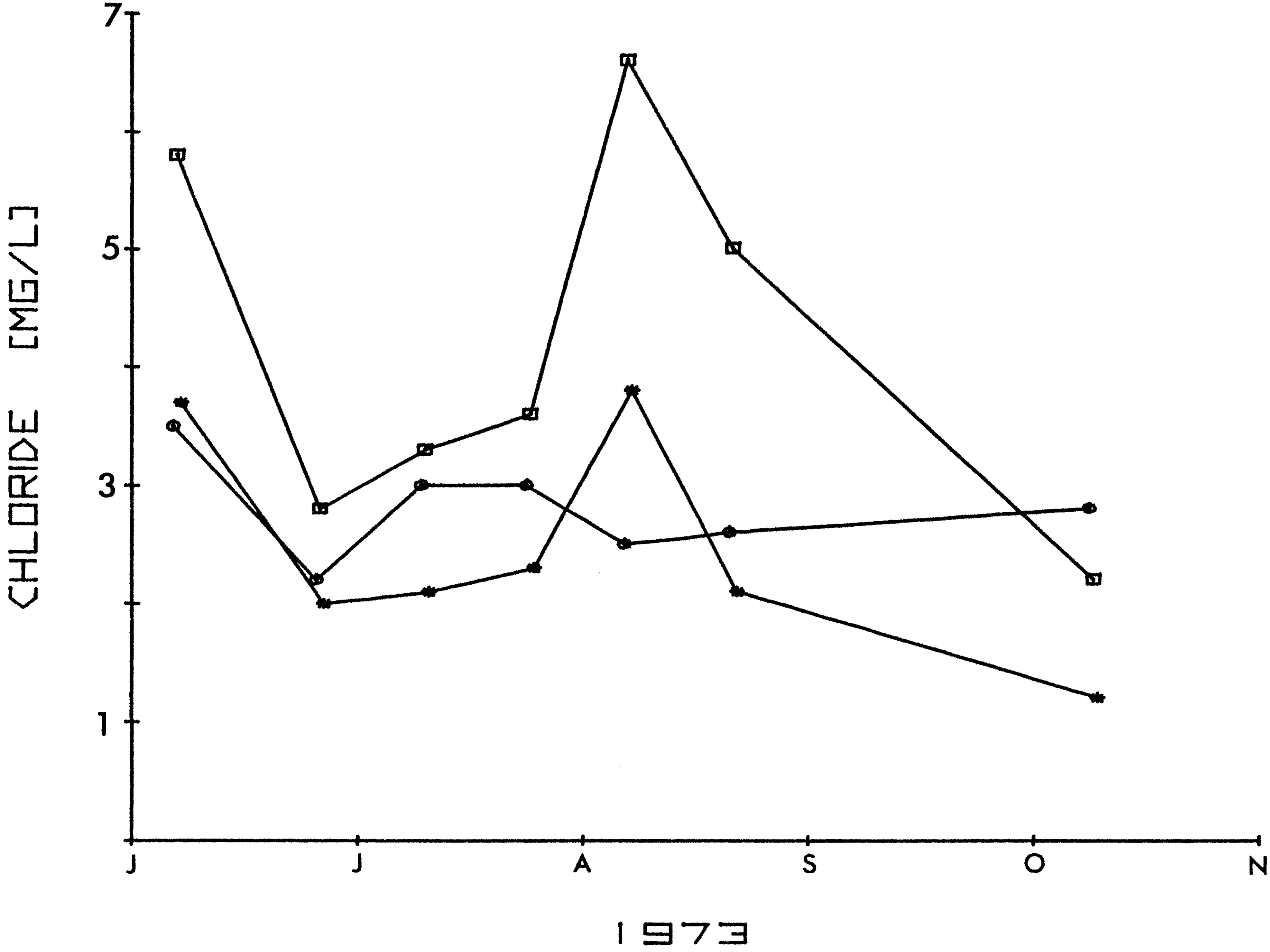
The weekly mean chloride concentrations from the "old" clearcut closely paralleled concentrations from the control, but were lower. From an initial chloride concentration of 3.7 mg/l, the mean decreased to 2.0 mg/l in late June, remained constant during July at about 2.2 mg/l, increased to 3.8 mg/l in early August, and then decreased to 1.2 mg/l in early October.

Comparison of grand mean chloride concentrations showed the concentrations from the clearcut treatments to be significantly less than the control concentrations at an alpha level of 0.005. There was no statistically significant difference between grand mean chloride concentrations from the two clearcuts.

Table 13. Weekly and grand mean chloride concentrations (mg/l) in soil water samples from "deep" lysimeters(1) during 1973.

	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Mean	S.E.(2)	N(3)	Mean	S.E.	N	Mean	S.E.	N
6-06 + 15-73	5.8	1.42	9	3.5	.87	15	3.7	.61	14
6-22 + 29-73	2.8	.76	14	2.2	.30	14	2.0	.19	16
7-06 + 13-73	3.3	.68	13	3.0	.46	14	2.1	.26	13
7-21 + 27-13	3.6	1.10	13	3.0	.34	14	2.3	.44	15
8-03 + 09-73	6.6	1.90	13	2.5	.33	14	3.8	.84	13
8-17 + 24-73	5.0	1.26	4	2.6	.32	16	2.1	.12	11
10-03 + 10-73	2.2	.18	9	2.8	.38	16	1.2	.17	12
Grand mean	4.1	.40	75	2.8	.17	103	2.5	.19	94

(1) Tube-tension lysimeters at depths of 75 to 100 cm.
(2) Standard error of the mean.
(3) Number of samples analyzed.


CHLORIDE (MG/L)
7
5
3
1
J
J
A
S
O
N
1973

During 1973, an average of 6.9, 7.5, and 5.7 mg of chloride was collected by "deep"lysimeters from the control, "new" and "old" clearcuts, respectively (Table 14). The total amount of chloride collected from the "new" clearcut was 8.5 percent greater, and that from the "old" clearcut was 16.7 percent less, than the amount collected from the control.

Phosphate

The grand mean phosphate concentrations for 1973 were 0.012, 0.016, and 0.018 mg/l from the control, "new" clearcut, and "old" clearcut, respectively (Table 15). The "new" clearcut grand mean concentration was 33.3 percent greater than the control grand mean concentration, while the "old" clearcut grand mean concentration was 50.0 percent greater than that from the control.

The weekly mean phosphate concentration from the control declined steadily during the season from 0.016 mg/l in early June 1973, to 0.007 mg/l in mid-August (Figure 8). The weekly mean phosphate concentration from the "new" clearcut decreased from 0.027 mg/l in early June to 0.009 mg/l in early July, increased to 0.014 mg/l in late July, and then decreased to 0.012 mg/l in mid-August. The weekly mean phosphate concentration from the 1965 clearcut decreased from 0.027 mg/l in early June to 0.013 mg/l in late June, increased to 0.016 mg/l in early July, and then steadily decreased to 0.011 in mid-August.

Table 14. Average amount (mg) of chloride collected by "deep" lysimeters(1) during 1973.

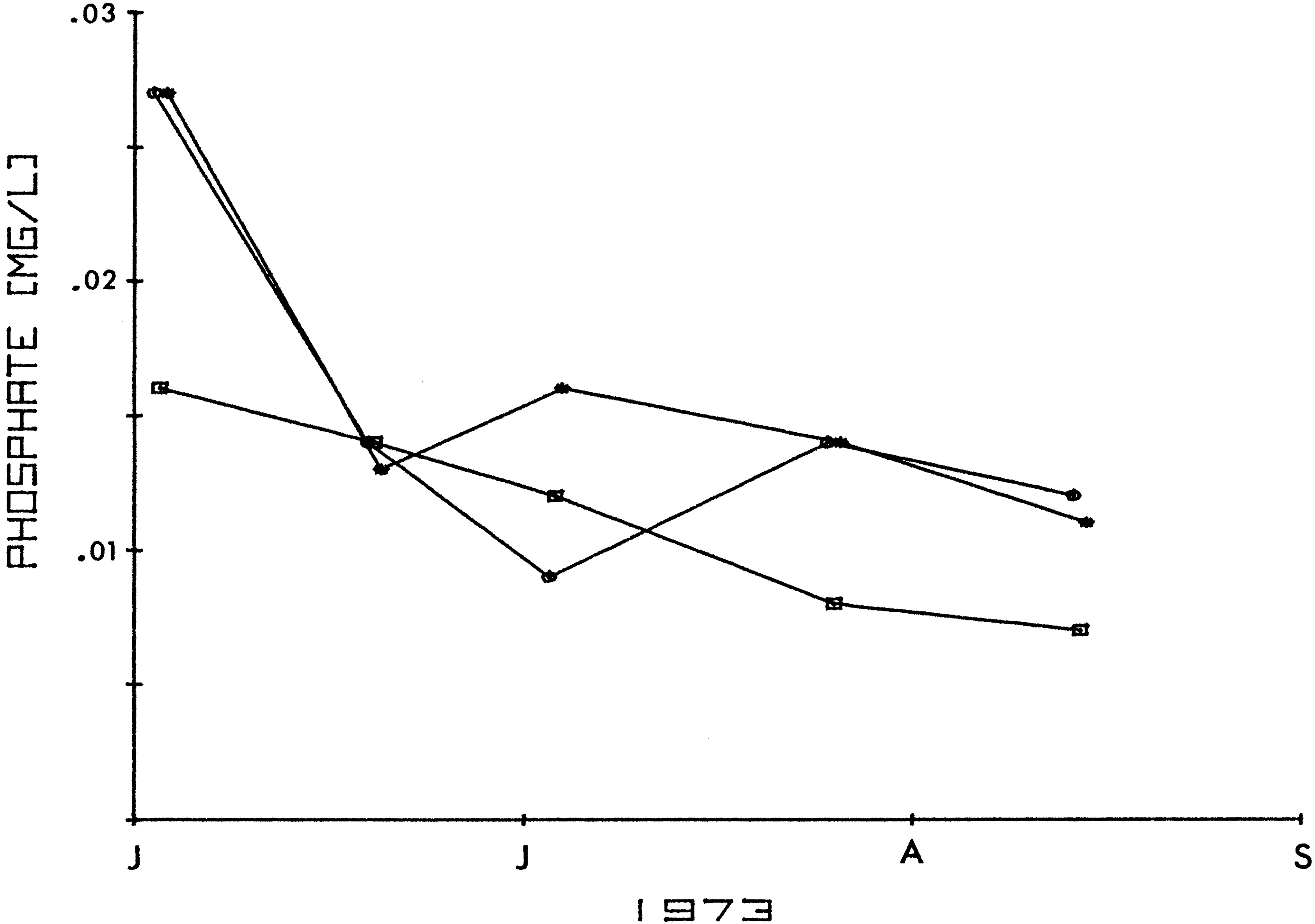
Sampling Dates	Treatment: Control	"New" Clearcut (1972)	"Old" Clearcut (1965)
6-06 + 15-73	2.024	1.179	1.039
6-22 + 29-73	.786	.700	.481
7-06 + 13-73	.663	.907	.663
7-21 + 27-73	1.111	1.335	.911
8-03 + 09-73	1.691	1.063	1.378
8-17 + 24-73	.355	1.069	.819
10-03 + 10-73	.265	1.227	.451
Grand Total	6.895	7.480	5.742

(1) Tube-tension lysimeters at depths of 75 to 100 cm.

Table 15. Weekly and grand mean phosphate concentrations (mg/l) in soil water samples from "deep" lysimeters(1) during 1973.

Sampling Date	Control Mean	Control S.E.(2)	Control N(3)	"New" Clearcut (1972) Mean	"New" Clearcut (1972) S.E.	"New" Clearcut (1972) N	"Old" Clearcut (1965) Mean	"Old" Clearcut (1965) S.E.	"Old" Clearcut (1965) N
6-06-73	.016	.006	6	.027	.004	13	.027	.004	12
6-22-73	.014	.002	9	.014	.002	10	.013	.002	10
7-06-73	.012	.001	7	.009	.002	10	.016	.003	8
7-27-73	.008	.003	4	.014	.004	8	.014	.005	6
8-17-73	.007	.006	3	.012	.005	7	.011	.005	6
Grand mean	.012	.002	29	.016	.002	48	.018	.002	42

(1) Tube-tension lysimeters at depths of 75 to 100 cm.
(2) Standard error of the mean.
(3) Number of samples analyzed.



PHOSPHATE [MG/L]
.03
.02
.01
J
J
A
S
1973

S-contrasts between grand mean phosphate concentrations showed that the concentration from the "old" clearcut was significantly greater than that from the control at an alpha level of 0.250. This was the only statistically significant contrast based on grand mean phosphate concentrations from the three treatments.

The total amounts (mg) of phosphate collected were not calculated because of the infrequency of the analyses.

Miscellaneous Determinations

Specific conductance and bicarbonate analyses were conducted only infrequently (Tables 16 and 17). In most cases, analyses were conducted at least three weeks after the date of sampling. Because of the time interval, these results are considered only as rough approximations of conditions at the time of sampling.

Measurements of pH were occasionally made when samples were removed from the lysimeters. The pH values from "deep" lysimeters ranged from 5.6 to 6.6, while means from all treatments were approximately 6.0. The pH values are also difficult to interpret because the process of removing the water sample from the lysimeter involved forcing air through the instrument which undoubtedly altered the pH of the sample.

Determinations of solutes from sources other than lysimeter samples, i.e. streams, precipitation, surface-runoff, and from a spring located near the control plot, were made of several occasions during the two years (Table 18). A rain sample was taken at Fort Collins, four hours after commencement of a rain that lasted most of the day. Snow samples were collected within one week of the particular precipitation

Table 16. Weekly and grand mean specific conductance (micrmhos/cm) from "deep" lysimeters(1) during 1973 and 1974.

	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Mean	S.E.(2)	N(3)	Mean	S.E.	N	Mean	S.E.	N
6-06 + 15-73	64	10.0	9	81	12.8	15	76	5.6	14
6-22 + 29-75	47	9.0	14	45	3.9	14	52	4.1	16
7-06 + 13-73	44	5.4	13	60	5.2	13	60	4.9	12
7-21 + 27-73	46	3.7	13	58	4.9	14	58	3.2	14
8-03 + 09-73	52	6.1	13	69	4.8	14	70	4.8	14
8-17 + 24-73	74	14.1	10	75	3.6	16	83	11.4	14
10-03 + 10-73	50	6.4	9	96	8.8	16	58	5.4	12
Grand mean - 1973	53	3.1	81	70	3.1	102	65	2.5	96
5-27-74	47	5.7	10	90	16.2	14	69	14.1	12
6-03-74	34	6.1	11	67	7.5	15	45	4.2	14
6-12 + 17-24	30	2.5	15	56	5.9	16	38	4.8	16
6-24 + 7-03-74	31	1.9	15	57	3.5	15	35	2.2	14
7-09-74(4)	25	1.8	13	55	4.7	14	28	1.7	13
7-16-74(4)	40	2.3	12	79	4.6	14	40	2.1	12
7-23-74(4)	42	5.1	9	86	6.1	14	38	2.3	13
Grand mean - 1974	35	1.5	85	70	3.2	102	41	2.4	94

(1) Tube-tension lysimeters at 75 to 100 cm.
(2) Standard error of the mean.
(3) Number of samples analyzed.
(4) Samples analyzed one day after sampling date. All other samples were analyzed at least three weeks from date of sampling.

Table 17. Weekly and grand mean bicarbonate concentrations (mg/l) from "deep" lysimeters(1) during 1973.

	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Mean	S.E.(2)	N(3)	Mean	S.E.	N	Mean	S.E.	N
6-06-73(4)	12	1.3	6	22	1.7	12	29	8.1	12
7-21 + 27-73	18	2.0	13	16	1.4	14	12	2.4	15
8-03 + 09-73	13	1.4	13	12	1.0	14	13	1.7	13
8-17 + 24-73	8	0.2	3	14	1.7	16	11	2.8	12
10-03 + 10-73	10	1.5	9	9	0.7	16	8	0.8	12
Grand mean	13	0.9	44	14	0.8	72	14	1.9	64

(1) Tube-tension lysimeters at depths of 75 to 100 cm.
(2) Standard error of the mean.
(3) Number of samples analyzed
(4) Samples analyzed on 6-8-73. All other samples analyzed at least three weeks from date of sampling.

event. A spring, located about 360 m east of the control treatment, in a contiguous uncut area, was also sampled. Streams sampled during the study included the South Fork of Panhandle Creek and Sign Creek, both of which drain a mosaic of cut and uncut areas. Several clearcuts were present in the upstream area of Killpecker Creek, but samples were taken approximately 1.6 km downstream from these areas. North Lone Pine Creek had no known clearcuts above the point of sampling, but it drained a small meadow and was in an area that contained several small abandoned mining sites.

Solute concentrations obtained from streams, surface runoff, and the spring were generally within the range of concentrations, for the same solute, obtained from control "deep" lysimeters. Solute concentrations from snow and rain samples were generally less than the mean concentrations from control "deep" lysimeters.

Table 18. Mean concentrations (mg/1) of nitrate and calcium determined from several water sources in the general vicinity of the clearcut treatments. Values in parenthesis are the number of samples analyzed. Rain samples was taken at Fort Collins, Colorado

Source	Solutes	
	NO_3	Ca^{++}
Surface runoff	.32 (14)	1.6 (10)
Spring	.09 (5)	2.1 (4)
S. F. Panhandle Cr.	.05 (4)	3.1 (2)
Killpecker Cr.	.16 (4)	3.1 (2)
Sign Cr.	.30 (4)	3.1 (2)
N. Lone Pine Cr.	.03 (4)	3.4 (2)
Rain	.40 (1)	1.0 (1)
Snow	.33 (3)	1.0 (3)

Plant Analyses

Plant and water samples were obtained from a Wyoming stream on August 8, 1974. The stream was a tributary of Mullen Creek, and it appeared that over 50 percent of its contributing drainage originated from a three-to-four-year-old lodgepole pine clearcut. The stream originated from a spring within the cut area, flowed down a steep bank, through approximately 180 m of uncut timber, and then entered a beaver pond. Rocks in the stream exhibited a heavy cover of moss while grasses and sedges grew well along its banks and in the stream channel. Stream discharge at the time of sampling was very low. The discharge was estimated at 1 cfs, although turbulence made estimation difficult.

Plant samples were analyzed for percent total nitrogen and water samples for nitrate concentrations (Table 19). Plant samples subjected to analyses were composites from several individual plants and consisted only of the terminal portions of approximately the same color. One water sample was obtained from each general location along the stream, i.e. from an area about 15-30 m from the issuance of the stream (middle of clearcut), from an area immediately above the stream's entrance into standing timber (bottom of clearcut), and from an area upstream of its entry into the beaver pond (before beaver pond).

Table 19. Percent total nitrogen of moss and grass samples, and nitrate concentration of a tributary of Mullen Creek, Wyoming.

Location of sample	Moss-(% N)	Grass-(% N)	Nitrate (mg/1
Middle of clearcut	2.10	1.71	-
Bottom of clearcut	2.30	1.36	0.78
Before beaver pond	2.59	2.30	1.50

The plant analyses showed a definite trend of increased nitrogen as samples proceeded downstream from the stream source. This trend was most evident for the moss samples, although the percent nitrogen of the grass samples decreased and then increased to the highest level at the downstream site.

Concentration of nitrate in the stream water almost doubled over the length of stream sampled. No water was analyzed from immediately below the spring because the sample was accidentally destroyed.

Tannin

Average concentrations of tannins (or "tannin-like" substances) were determined from soil water samples from "deep" and "shallow" tube lysimeters and from plate-lysimeters for the 1974 sampling period (Tables 20 and 21). Hach reagents were employed for the analyses (Tanniver III), while tannic acid was used to obtain standard curves.

Average weekly tannin concentrations at all three depths from the "old" clearcut were about 50 percent less than those obtained at similar depths from the other two treatments. "Deep" lysimeter collections from the "new" clearcut and the control yielded similar tannin concentrations of about 1.0 mg/l; at shallower depths the concentrations from the "new" clearcut were approximately 1.3 to 2.0 times greater than those obtained from the control for the same depth.

Table 20. Weekly and grand mean tannin(1) concentrations (mg/l) in soil water samples from "deep" lysimeters during 1974.

	Treatment								
	Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Mean	S.E.(2)	N(3)	Mean	S.E.	N	Mean	S.E.	N
6-24-74	1.18	.22	15	1.06	.08	15	.75	.08	14
7-09-74	.86	.15	13	.94	.08	13	.62	.07	12
7-16-74	.98	.18	14	1.00	.15	8	.66	.10	12
7-23-74	1.05	.16	14	1.14	.19	7	.73	.10	12
7-29-74	1.22	.21	7	1.04	.32	2	.57	.15	7
8-06-74	1.25	.23	7	1.04	.12	5	.56	.13	7
Grand mean	1.06	.08	70	1.02	.05	50	.66	.04	64

(1) Tannins or tannin-like substances.
(2) Standard error of the mean.
(3) Number of samples analyzed.

Table 21. Mean tannin(1) concentrations (mg/l) in soil water samples at 10 and 50 cm during 1974.

		Treatment								
		Control			"New" Clearcut (1972)			"Old" Clearcut (1965)		
Sampling Date	Depth	Mean	S.E.(2)	N(3)	Mean	S.E.	N	Mean	S.E.	N
6-17-74	10	7.78	1.81	4	3.40	.38	4	5.54	1.03	2
	50	2.22	.54	4	1.49	.15	4	.88	.38	4
6-24-74	10	-	-	-	5.48	-	1	-	-	-
	50	2.26	.45	4	1.57	.18	3	.86	.19	3
7-23-74	10	-	-	-	8.08	-	1	-	-	-
7-29-74	10	14.51	-	1	5.23	1.74	3	2.72	-	1
	50	1.88	.34	4	1.35	.12	2	.92	-	1
8-06-74	10	-	-	-	4.59	-	1	-	-	-
	50	1.57	.29	4	1.69	.20	2	.96	-	1
Grand mean	10	9.13	1.94	5	4.75	.66	10	4.60	3.33	3
	50	1.98	.20	16	1.52	.08	11	.88	.16	9

(1) Tannin or tannin-like substances.
(2) Standard error of the mean.
(3) Number of samples analyzed.

DISCUSSION

Water

The average amount of water collected from the three sites followed an expected order. The greatest average annual (sampling period only) volume of soil water was collected from the "new" clearcut, where almost all vegetation capable of causing significant transpirational loss was removed during the clearcutting operation. The amount of water collected from the control exhibited the lowest average annual volume due to much greater transpiration and interception (evaporation). The average amount of water collected from the "old" clearcut was intermediate between the control and the "new" clearcut. It is likely that transpiration from the "old" clearcut was much less than from the control but greater than from the "new" clearcut, because some revegetation had occurred since the time of its cutting.

Hoover (1973), in discussing watershed management of lodgepole pine systems, reported that clearcutting influenced snow distribution in cut and uncut areas. Increased water yields, which occur primarily during the snowmelt period of May-July, result from decreased evapotranspiration, greater accumulation of snow, and more rapid melting on clearcut areas (Hoover, 1973). The limited snow data collected during the present study would support all but the accumulation aspect discussed by Hoover. Because snow samples were taken along a central transect on the plots, it is highly probable that the data were not representative of the entire cut area, i.e. areas of greater snow accumulation along the edges of the "new" cut were noted but were not sampled.

Snow surveys on the three treatments during 1973 and 1974 revealed the average snow water equivalent on the control was about 50 percent greater than on the "old" clearcut and 25 percent greater than on the "new" clearcut. Snow cover on the "old" clearcut was gone by the first of June in both years, while snow still remained until the second week of June on the "new" clearcut and until the third week of June on the control. The longer retention of snow appears to explain the greater weekly mean volumes collected from the control during the first few weeks of June 1973.

The sharp increases in weekly mean water volumes observed from all treatments in mid-July 1973, were probably the result of the 7.9 cm of precipitation from July 12 to 22, 1973. A small storm (1.8 cm) on August 1, 1973, was probably the cause of the slight increase in mean volumes from the two clearcuts noted subsequent to that date. The lack of response of the control to this storm was probably due to interception losses and a greater soil moisture deficit than was present on the clearcut plots.

Fredricksen (1972), in a study of a Douglas-fir forest in western Oregon, reported that water in the upper 30 cm of the forest soil exhibited a minimum value in late August or early September. Fredriksen's findings agree with the results obtained in this study; all three of my plots exhibited seasonal low soil moisture levels in early September 1973, as indicated by the lysimeter collections. Results from the control were the most dramatic in this regard; no water was collected from the 16 "deep" lysimeters at that time. The increased amounts of water collected from the three plots later in September were apparently the result of precipitation events during that month and signaled the beginning of the fall and winter soil water recharge period.

While studies in more temperate climates have indicated that summer base flows are increased following clearcutting (Pierce, et al., 1970; Lynch, Sopper, and Partridge, 1973; Rothacher, 1970a; Hornbeck, Pierce, and Federer, 1970), which would benefit aquatic communities in these streams, Leaf (1975) and Hoover (1973) reported that increased water yields resulting from clearcutting lodgepole pine areas occur primarily during spring snowmelt. The increased water yields are reflected in the rising stream hydrographs, and little (if any) effect is noted on the decreasing limb of the hydrograph. This is the major reason that storage reservoirs are necessary, i.e. because the major water yield period occurs before the greatest water demand period (Hoover, 1973).

Because of the apparently higher soil water content on the clearcut sites, however, high intensity summer storms on clearcut watersheds could result in stream discharges that were greater and that responded more rapidly than would occur from uncut areas (Kochenderfer and Patric, 1970).

Perhaps a more significant consideration than an increase in water yields from clearcut areas is the possibility that conditions of increased soil moisture, which Leaf (1975) indicates could occur for up to 50 years following clearcutting, would allow mineralization and subsequent leaching of nutrients during major runoff periods.

Nitrogen

Nitrogen losses from undisturbed forest sites are generally very small relative to losses of other nutrients. Comparison of data collected during this study with results of related studies presented in the literature is very difficult because of the different methods used to collect water samples and because a relationship between soil water nutrient concentrations and solute losses from the treatments has not been described. Results of other clearcut studies, in which data on water yields and solute losses were determined from analysis of stream flows, are presented, however, so that the reader would have a "feel" for potential nutrient losses that could occur as a result of clearcutting lodgepole pine areas.

In a study of a 30-year-old Douglas-fir system in Washington, Cole, et al. (1961) collected soil water at a depth of 28 in (78 cm) with plate lysimeters similar to those employed during my study. They reported an average nitrogen concentration for a period from January to July of 0.37 mg/l. They did not present data for the distribution of the various nitrogen species but did state that the majority of the nitrogen was present as ammonium. Results from my study indicated that nitrogen concentrations from the control for the 1973 summer period were about half that reported by Cole, et al. (1961) and that ammonium and nitrate contributed equally to the total nitrogen concentration.

In a study of nutrient losses from a clearcut Douglas-fir system the first year following clearcutting, Gessel and Cole (1965) reported that nitrogen losses from the surface inch (2.5 cm) of soil increased from 4.81 kg/ha/yr to 11.10 kg/ha/yr or about 112 percent following clearcutting. At a soil depth of 36 in (91 cm), however, only 0.48 kg/ha/yr additional nitrogen was lost from the clearcut area compared to the control, an increase of about 76 percent. Because there were greater volumes of water moving through the soil from the clearcut plot, actual nitrogen concentrations from the Douglas-fir clearcut were lower than from the control. Although Gessel and Cole did not present seasonal concentration data they did state that movement of nutrients from the plots was greatest during the first rains of the fall and early winter after a late summer period of little or no water movement.

A similar situation probably occurred on my plots with an increase in soil water nitrate concentrations during the summer. The period of greatest leaching, however, would probably have occurred during the spring snowmelt with the majority of accumulated nutrients being flushed out of the system during the early stages of snowmelt. This period was not sampled during the present study (earliest samples were from the middle of May) which precludes a more quantitative discussion of nutrient losses because the general hydrology of the lodgepole pine zone indicates water yield during the spring snowmelt period provides about 80 percent of the annual stream discharge (Hoover, 1973).

In general, studies from Douglas-fir systems indicated that about 0.5 to 0.6 kg/ha of nitrogen are lost annually from undisturbed areas (Cole, et al., 1967; Gessel and Cole, 1965; Fredriksen, 1972). A study by Stottlemyer (1968), of a lodgepole pine system in Colorado, concluded that, although nitrates were not determined, low cation concentrations in streams draining uncut watersheds precluded large amounts of nitrates in stream effluents.

Losses of nitrates from undisturbed eastern deciduous forests appear to be greater than from western coniferous systems. An oak-hickory and yellow pine forest in West Virginia exhibited an annual nitrate loss of 3.0 kg/ha, (U.S. Forest Service, 1971). At Hubbard Brook in New Hampshire, the annual losses of nitrates from a control watershed were 1.3 and 2.8 kg/ha for two consecutive years. Verry (1972) reported average nitrate concentrations of 0.30 to 0.12 mg/l in streams draining an aspen, birch, and black spruce watershed in northern Minnesota.

Increased nitrogen losses have been reported following clearcutting operations on eastern deciduous forests. The most dramatic example of this occurred at the Hubbard Brook Experimental Forest, where all trees were cut and left lying and herbicide was applied to the watershed to prevent any vegetation regrowth (Likens, et al., 1969, 1970; Borman, et al., 1968; Pierce, et al., 1970, 1972). Average nitrate concentrations in stream water increased from 0.69 to 38.4 mg/l during the first year following clearcutting. By the second year following cutting, the average concentration had reached 52.9 mg/l. In a study following a conventional clearcutting operation at Hubbard Brook, Pierce, et al. (1972) reported nitrate concentrations were only about one-third as great as those from the herbicided watershed. At the Fernow Experimental Forest in West Virginia, nitrate losses, as measured in stream water, increased from about 3.0 kg/ha to 36.0 kg/ha the first year following clearcutting (U.S. Forest Service, 1971).

Differences in soil water concentrations between the control and the "new" clearcut in my study were not great until mid-August 1973, and, by 1974, the nitrate concentrations from the "new" clearcut had exceeded those from the "old" clearcut. For the 1974 sampling period, about 15 times more nitrate was collected from the "new" clearcut than from the control and almost twice as much as was collected from the "old" clearcut.

Many studies, reporting only small increased nitrient losses following clearcutting, have reported data for only the first year after cutting. It may be, as Verry (1972) suggests, that one year is simply not enough time for a significant amount of decomposition to occur in many climates. In this regard, the slash needles remaining after my clearcutting were still green the following August. Studies conducted by Reid, et al. (1974), in cooperation with the IBP Coniferous Biome Program, showed that the total litter fall for a one year period (from July 1973 to June 1974) on the control site was 1211 kg/ha. Considering that the biomass of the 0_1 horizon on the control site in 1972 was 15,625 kg/ha, this indicates that the 0_1 horizon represents 12.9 years accumulation of litter. This further emphasizes the relatively long period of time required before complete decomposition of litter takes place (Reid, et al., 1974).

Soil water nitrate concentrations obtained from the control in late October 1972, were similar to those obtained from the same plot the following year. The October 1973 nitrate concentrations from the "new" clearcut were lower than those obtained the following spring but were similar to control concentrations. The 1972 samples were obtained immediately after clearcutting and should reflect "control" values. The 1972 nitrate concentrations from the "old" clearcut were probably representative of 1973 values, considering the late fall samples in 1973 and allowing for the decreasing trend evident during that period.

Ammonium concentrations from the two clearcuts averaged only one-half that from the control treatment during 1973. Of the average amount of inorganic nitrogen (ammonium plus nitrate) collected during 1973, ammonium accounted for 40 percent of that collected from the control, while ammonium collected from the "new" and "old" clearcuts accounted for only 18 and 3 percent, respectively. Likens, et al. (1970) noted a decrease in stream ammonium concentrations in each of two years following clearcuting, and Fredricksen (1970) reported a large increase in stream ammonia concentration following slash burning and a sharp decrease in concentration the second year after burning.

An apparent explanation for the increase in nitrate concentrations and reduced ammonium concentrations is that an increase in the rate of nitrification occurred on the clearcut treatments (Likens, et al., 1970, 1969; Pierce et al., 1972). If nitrogen concentrations were only related to the volume of water collected, then total nitrate concentrations and amounts collected would have been considerably less and the amount of ammonium collected much greater from the two clearcuts during my study. At Hubbard Brook, nitrifying soil bacteria of the genera *Nitrosomas* and *Nitrobacter* increased 18 and 34 times, respectively, following clearcutting (Likens, et al., 1969; Smith, Bormann, and Likens, 1968).

Whether a significant amount of nitrification occurs in a climax coniferous forest is still unknown (Likens, et al., 1969). Nitrification may be suppressed in a climax forest, and ammonium may be the primary nitrogen compound utilized by growing vegetation. In soils with low pH, e.g., most coniferous forests soils, nitrification proceeds slowly even in the presence of an adequate substrate, and nitrifying bacteria may even be absent (Alexander, 1961; Remezov and Pogrebryak, 1965). No attempt was made during my study to determine whether or to what degree nitrification occurred in lodgepole pine forests. Concentration data were inconclusive in this regard, because nitrate concentrations from the control site were similar to that measured in precipitation samples.

Evidence supporting a change in nitrogen metabolism after clear-cutting was presented by Rice and Pancholy (1973). Reporting on results from several vegetation types in various stages of succession, the authors demonstrated that, as succession proceeds toward a climax system, nitrogen metabolism shifts from a nitrate base to an ammonium base. They also observed a decrease in the number nitrifying bacteria as succession proceeded. They attributed these changes to inhibition of nitrifying bacteria by tannins and their derivates, which accumulate as a climax system is approached.

The significance of Rice and Pancholy's results is that both nitrogen and energy would be conserved in a climax community where ammonium was the principal nitrogen source available to plants. As a cation, ammonium is subject to adsorption on cation exchange complexes in the soil and is less subject to leaching. Nitrate, in contrast, is a highly soluble anion and is subject to rapid leaching from the system. Energy would also be conserved because a reduction step would not be required before ammonium could be incorporated into organic compounds, i.e. as an amine group.

Comparison of tannin concentrations from the "old" clearcut and the control would tend to support this theory. Tannin concentrations from the "new" clearcut, however, do not appear to support the above theory.

The tannin concentrations appear in a logical order. Concentrations within a given treatment exhibited an inverse relationship to depth, as expected. Concentrations would be highest in the surface layers while decomposition and leaching would result in lower concentrations at greater depths. The concentration relationship between the treatments was also expected. The "old" clearcut would be expected to exhibit lower tannin concentrations because of leaching and decomposition, while the "new" clearcut would have the greatest concentrations because of the influx of new plant material.

The results of the present study appear to be somewhat in conflict with the results of Rice and Pancholy (1973). It is possible that their laboratory cultures did not duplicate natural conditions. They found levels of tannins in their soil samples that, based on laboratory results, would have completed inhibited nitrification, but nitrates were found in the natural soils.

Following clearcutting, light, temperature, and water conditions within the soil system may be altered in such a way as to permit an increase in the number of nitrifying bacteria. It is also possible that resistent forms of the nitrifying bacteria are present (as Rice and Pancholy suggest) and/or that tannin decomposition products are of such a nature as to be less toxic to the bacteria. My results, as well as those of other studies (Likens, et al., 1969; Pierce, et al., 1972) tend to suggest that bacterial inhibition by tannins is not complete under natural conditions.

An increase in nitrification appears to be the most logical expalnation for the nitrogen concentrations observed from the three treatments. Ammonium concentrations and the amounts collected from the control were high relative to those from the clearcuts, while nitrate concentrations and amounts collected were greater from the clearcut plots. Nitrate concentrations from the "new" clearcut were not significantly greater than concentrations from the control until almost one year after clearcutting, perhaps the time required for the nitrifying bacteria to increase to the levels necessary to produce amounts of nitrate in excess of heterotrophic demands. Any ammonium produced during this time could have been adsorbed on exchange sites and would not have appeared in soil water samples.

The seasonal pattern of nitrate concentration was also changed following clearcutting at Hubbard Brook (Likens, et al., 1970; Johnson, et al., 1969). At Hubbard Brook, nitrate concentrations in streams on the uncut watershed exhibited seasonal lows during the summer with concentrations increasing during November and reaching seasonal highs in the spring. After cutting, the highest concentrations were observed in late summer and fall, and lows occurred in the spring. Similar patterns were observed in my study during the 1973 sampling period, although they were soil water samples. The decrease in nitrate concentration in late July 1973, can be accounted for by the rainstorms prior to this time. These rains apparently increased the concentration at 75 to 100 cm by flushing accumulated nitrates from the upper soil layers. After this flushing, nitrate concentrations returned to levels present before the rains and then continued to build to fall highs. During the period in 1974, the nitrate concentrations from the "new" clearcut exhibited a pattern similar to that from the "old" clearcut in the previous year, while the "old" clearcut nitrate concentrations were lower than those from the year before.

Comparison of nutrient composition of logging residues in 1973 and live trees (Reid, et al., 1974) revealed lower nitrogen in twigs, stems, and branches from the "old" clearcut while the nitrogen content of the slash from the "new" clearcut and live trees showed little difference. Leaching and decomposition apparently reduced the total nitrogen content from logging slash on the "old" clearcut, which increased the nitrogen source for nitrifying bacteria. The percent total nitrogen in the 01 and 02 soil layers also supports the theory of increased nitrification. The 01 horizon from the "old" clearcut had the lowest percent total nitogen of the three treatments in 1971 and 1972. The 02 horizon from the "old" clearcut had the lowest nitrogen percent for all 3 years measured. The quantity of total nitrogen (kg/ha) in the forest floor was also lower for the "old" clearcut (Reid, et al., 1974).

Nitrate-nitrogen composition of the soils during 1971 revealed that concentrations present in the organic horizons of the control were greater than those from the "old" clearcut. Nitrates were not detectable in A2 and B2 horizons. For the control, the soil nitrate data are probably not in conflict with soil water data since nitrate concentrations in soil water samples at 10 cm were at times greater than those from the clearcuts (Table 5). Because of less soil water movement on the control during the summer and fall, nitrates that are produced probably accumulate at shallower depths than those produced on the clearcuts where water movement and leaching is greater during the summer and fall.

Occasional analyses of streams in the same general area as the three treatments failed to reveal nitrate concentrations similar to those in soil water samples from the clearcut treatments; although, in some cases apparently over 50 percent of the stream water originated from clearcut areas. Concentrations in streams more nearly reflected concentrations from the control. Several investigators (Kemmerer, et al., 1968; Keup, 1968; Schindler and Comita, 1972; Schindler et al., 1971) believe that in situ concentrations are probably not true indicators of potential aquatic production because of the dynamic nature of the systems and that more accurate assessments could be made by determining nutrient inputs. Hynes (1972) concurs by noting that normal nitrate concentrations in streams are usually low because of rapid uptake by aquatic plants. Brehmer, et al. (1969) noted that in a Michigan stream, accrued nutrients were removed from solution within 0.6 mile (1.0 km) downstream from a sewage outfall. Adams, Mackenzie, Cole, and Price (1971) also noticed this occurrence and attempted to use nutrient contents of plants as an indicator of past water quality. Brehmer, et al., (1969) also reported that biological response to introduced nutrients, and thus removal, was greatest during periods of high production, i.e. during the summer and fall.

The plant samples obtained from a Wyoming stream tended to support the theory that aquatic plants might be responsible for the low nitrate levels in the study area streams. Mosses showed a definite increase in nitrogen as samples progressed downstream. Since mosses were the only plants present in the study area streams in consistently high quantities, it is possible that they could have contributed to the low nitrate concentrations observed.

The greater nitrate concentration observed downstream in the Wyoming stream is difficult to explain. Sampling error may have been involved. Because only one sample was anlyzed, there is no way to assess this possibility. In addition, the Wyoming stream was fed along its course by numerous springs. These springs could have added nitrate at concentrations greater than upstream concentrations.

Assuming that nutrients entering streams draining clearcut watersheds could be rapidly removed from solution (resulting in lower stream concentrations), nutrient losses based on stream concentrations would then underestimate actual nutrient losses. "Enriched" plants could become detached at some later date and flush downstream without ever being detected by standard water sampling techniques, i.e. grab samples.

Streams are heavily dependent upon allochthonous material to provide an energy base to support their heterotrphic communities (Nelson and Scott, 1962; Darnell, 1965; Warren, et al., 1964; Waters, 1969; Vannote, 1969; Hynes, 1972). In many streams, nitrogen may be in inadequate supply to provide for maximum growth of algae (Hynes, 1972; Martin and Goff). If such were the case in streams draining lodgepole pine forests, the addition of nitrogen in the form of nitrates could result in increased primary production. This increase would eventually be reflected in the herbivore community and eventually in increased production at higher trophic levels. Pierce, et al., (1972) noted growth of algae (Ulothrix zonata) in streams following clearcutting. This species was not evident in streams draining uncut watersheds. Warren, et al. (1964) artifically enriched sections of Berry Creek in Oregon with 1 to 4 mg/l of sucrose and subsequently caused large increases in numbers of the bacterim Sphaerotilus natans and chironomid larvae, and ultimately increases in trout production. McConnell (1968) estimated that the organic compounds in oak litter extracts that entered a small southwestern impoundment could account for a 16 percent increase in fish production. Results published by Sawyer (1947) and Chu (1943) suggest that the soil water nitrate concentrations from the present clearcuts would be sufficient to support large algal populations (if these concentrations occurred in an aquatic system). Excessive algal growths were not, however, observed in area streams. This could be due to the lack of other nutrients, unfavorable physical conditions such as current and unstable substrates, dilution-mixing of water from the clearcuts in aquifer-type areas with release at some future time at lower concentrations, and/or rapid flushing of nutrients during the spring snowmelt period.

In any event, Hynes (1963) suggested that the effects of enrichment in streams are not long-lasting after the addition of the nutrients is eliminated. Lakes, however, act as nutrient traps and can remain eutrophic for long periods of time. The effects of enrichment apply equally for lakes and streams. Lakes, however, are more complicated because of seasonal cycling of nutrients resulting from thermal stratification. During summer thermal stratification in lakes, nitrogen may be depleted from the epilimnion, while hypolimnetic waters may exhibit high ammonia concentrations resulting from reducing conditions present below the thermocline. Upon mixing (overturn), ammonia becomes distributed through the entire water column and is rapidly oxidized to ammonium and nitrate (Seruya and Berman, 1970). Some nitrogen is lost to bottom sediments (Edmondson, 1970; Sawyer, 1947), but a continual input of nitrogen in inflow water could contribute to accelerated eutrophication.

It is difficult to predict whether concentrations of nitrates in soil water have reached a maximum value on the 1972 clearcut or whether they will increase even more. At their present level they would probably result in some increased plant production in streams, but excessive plant growth would probably not occur. Just how long the increased nitrate concentration will persist can not be determined, but the 1965 clearcut still exhibits significantly higher values nine years after clearcutting. Pierce, et al. (1972) indicated that peak nitrate losses probably occur during the second year in New Hampsire and that, after four years, the losses begin to decrease following utilization of readily available nitrogen sources. In lodgepole pine forests in Colorado, the maximum soil water concentration probably occurs later, and nitrate losses probably occur over a longer period of time, than in more temperate climates because of slower decomposition rates. There is some reason to suspect that nitrate concentrations may continue at higher than control levels as long as the water regime remains altered, which as Leaf (1975) suggests could be from 20 to 50 years.

Calcium

Calcium is along the most geographically variable of the common solutes found in natural waters. Concentrations of calcium are highly dependent upon the types of geologic formations through which the water passes, and since there are so many types of rock containing calcium (Hem, 1970), it is difficult to compare losses of this element reported from different forest systems.

Cole, et al. (1961), reporting an early study designed to demonstrate the utility of plate-tension lysimeters, found average concentrations of calcium in soil water of 1.82 mg/l, from an infertile Douglas-fir site in Washington. Samples were obtained from a soil depth of 28 in (71 cm) and were averaged for a period from January to June. Assuming that this period was one of reduced biological activity, and that concentrations of this cation would be greater during periods of increased respiration, the calcium concentrations obtained on the control during my study are probably of similar magnitude.

Weekly mean calcium concentrations from my three plots, during both sampling seasons, were within the range of concentration for this element reported by Stottlemyer (1968) for four streams in the Fraser, Colorado, area. Two of the streams studied by Stottlemyer exhibited calcium concentration ranges of from 4.8 to 9.4 mg/1, while the other two streams had calcium concentrations of from 1.7 to 2.6 mg/1. Stottlemyer suggested that the higher ranges may have resulted because the streams drained thin limestone deposits.

Calcium concentrations from the "new" clearcut exhibited rapid response to the clearcut treatment. Concentration from the "new" clearcut were significantly greater than those from the control during the first spring following the cutting, something that was not as apparent with nitrate concentrations. Results from a Douglas-fir clearcut during the first year following cutting (Gessel and Cole, 1965) showed a two-fold increase in the amount of calcium lost below a depth of 36 in (91 cm) over that from a control plot, however, because of increased water movement on the clearcut area, average calcium concentrations were about the same on the clearcut and the control plots. Actual losses of calcium reported by Gessel and Cole were 4.49 kg/ha/yr from the control and 9.25 kg/ha/yr from the clearcut. About 83 percent of the calcium increase measured at a soil depth of 1 in (2.5 cm), in the above study, was detected at a soil depth of 36 in (91 cm), while of the increased nitrogen lost at 1 in (2.5 cm), only about 7 percent was detected at 36 in (91 cm).

At Hubbard Brook and other areas in New Hampsire, average stream concentrations from uncut watersheds were approximately 1.5 mg/1 (Likens, _et al_., 1970; Pierce, _et al_., 1972), while the annual output of calcium from the Hubbard Brook control watershed was about 11 kg/ha (Likens, _et al_., 1970).

Fredriksen (1970) determined that, following clearcutting and burning of a Douglas-fir site, calcium concentrations in streams increased 1.5 to 2 times while total losses were more than double those from a control watershed. The relative magnitude of Fredriksen's concentration data are in close agreement with the results obtained during my study, even though exact comparison of concentrations are not possible. Likens, et al. (1970) reported an increase in the concentration of calcium of four to five times in streams draining a clearcut and herbicided treatment, while Pierce, et al. (1972) noted about a two-fold increase in average stream calcium concentrations following conventional clearcutting operations in the same general area. Data from Pierce, et al. (1972) were for a period from April to November.

The pattern of weekly mean soil water calcium concentrations, and the amount collected from my two clearcut treatment during 1972, i.e. low in the spring and increasing throughout the summer to a maximum in the fall, was similar to that reported in streams from other forest systems (Likens, et al., 1970; Johnson and Swank, 1973). Johnson and Swank (1973) reported that, at Coweeta, where precipitation is rather uniform throughout the year, losses were lowest during the winter months when biological activity was low and highest during the spring and summer when biological activity was high and streamflow was relatively high. Likens, et al. (1970) reported that calcium concentrations followed nitrate concentrations and increased through the summer to peak in the fall. Although stream concentrations and actual losses of nutrients were not measured during my study, the increased calcium concentrations from the clearcut treatments were not merely in response to the greater soil moisture content on these plots. If they had been, then concentrations from the clearcut treatments would have been lower than concentrations obtained from the control plot (dilution effect).

Fredriksen (1972) reported that outputs of calcium from an uncut Douglas-fir system were highest in the winter months and lowest during the summer, just the reverse of calcium concentrations from drainage streams.

Soil data from the three plots (Reid, et al., 1974), indicate that calcium was being leached from the surface horizons of the "old" clearcut and was being deposited in the A2 and B2 horizons. It also appeared, upon examination of the calcium composition of slash and live trees, that a large part of the calcium came from the decomposition of the slash and litter. In general, there appears to be a net loss of calcium from most undisturbed forest systems (Likens, et al., 1970; Fredriksen, 1972; Best and Monk, 1974; Johnson and Swank, 1973). The initial concentration increase of calcium from the "new" clearcut may have originated from the 01 horizon and subsequent increases may have been due, in large part, to losses from slash. Since the concentration patterns from the three treatments were similar, leaching mechanisms were also probably the same but proceeded at greater rates as a result of clearcutting. Likens, et al. (1969, 1970) demonstrated at Hubbard Brook, that increase nitrification, and its resultant increase in nitrate anions and hydrogen cations, was the principal factor regulating cation losses from the forest system.

McColl and Cole (1968), however, reported experimental results that support the hypothesis that bicarbonate and carbonate are the principal regulating anions. In either case, increased leaching of cations would occur during periods of increased temperature and ample water movement (Grier and Cole, 1972). The bicarbonate theory appears more applicable to the results obtained from my control treatment. Increased nitrification and bicarbonates are probably causes of increased cation concentrations from the two clearcuts.

An increased loss of calcium from clearcut lodgepole pine areas would probably not have any significant effects on stream biota, since calcium is not generally considered a limiting nutrient for most algae (Smith, 1950). There could, however, be changes in the species of algae present if sufficient amounts of calcium were added to streams over a period of time (Smith, 1950). More important to aquatic plants, however, are the associated carbonates of calcium which could supply additional amounts of carbon dioxide for photosynthesis (Reid, 1961; Smith, 1950).

Chloride

Chloride and ammonium were the only two solutes measured during the present study that decreased in concentration following clearcutting. Although grand mean chloride concentrations were lower by about 35 percent from the two clearcuts in comparison to the control, the total amounts collected for the sampling period were about the same for all three treatments.

Chloride has little significance to freshwater ecosystems at the concentrations observed in soil water samples during the present study. The chloride data were included, however, in an attempt to validate the assumption that the tension lysimeters collected soil water and associated solutes in proportion to their availability, i.e. the amount present at soil depths of 75 and 100 cm.

Results presented by Likens, et al. (1970) and Peck and Hurle (1973) indicate that chlordie budgets are balanced for forested watersheds in New England and Australia, respectively. Johnson, et al. (1969) indicated that stream chloride concentrations in forested watersheds were essentially independent of discharge due to chemical buffering in the soil systems. If a balanced chloride budget for the lodgpole pine system investigated in my study can be assumed, then the average amounts of chloride collected by the lysimeters should be comparable.

If it can be assumed that during the spring melt period, chloride accumulated in the soil water system is "flushed" from the system, then during the summer and early fall, when water movement is minimal from the plots, chloride would be accumulated in the system as a result of input through precipitation and dry fallout. During this period the soil water chloride concentrations would reflect changes in soil moisture as mitigated by the soil buffer system discussed by Johnson, et al. (1969). Collections of soil water during this time should provide a rough estimate of the amount of chloride that could be leached from the system during major runoff events.

Although differences in chloride concentrations were evident between soil water samples from the three plots, the average amounts (mg) of chloride collected during the 1973 sampling periods were similar. These results would seem to support the assumption that although the tension lysimeters were not quantitative, they were qualitative and comparisons between treatments on a relative basis is justified.

Phosphate

Phosphorus and nitrogen, as noted earlier, are generally considered the nutrient most often responsible for excessive growth of aquatic plants. It is becoming increasingly evident that phosphorus is more important in this regard (Schindler, 1974; Schindler, et al., 1971 and 73; Murphy, 1973).

It has been generally accepted for some time that phosphorus was the single nutrient that resulted in the largest increase in fish and plant production in small ponds (Hickling, 1962; Neess, 1946; Swingle and Smith, 1939; Swingle, et al., 1963). Several authors have noted a significant correlation between phosphorus concentrations in lake or inflow waters and plant production in the lake. Moyle (1946) noted heavy algal blooms in Wisconsin lakes exhibiting phosphorus concentrations of between 0.055-0.55 mg/l. Sawyer (1947) predicted, on the basis of the examination of several Wisconsin lakes, that when late summer phosphorus concentrations exceeded 0.01 mg/l, algal blooms could be expected. Kemmerer, et al. (1968) noted that total phosphate and alkalinity of inflow water were closely related to gross primary production in several southwest reservoirs. In Canada, Schindler and his group (Schindler, 1974; Schindler, et al., 1971, 1973) demonstrated, through fertilization studies, that phosphorus, and not nitrogen or carbon, was the most limiting nutrient in natural lakes in their study area.

I did not think, on the basis of literature reviews, that significant amounts of phosphorus would be lost from the present clearcut treatments. I felt that phosphorus analysis of the soil water samples should be conducted, however, because of the potential significance of phosphorus in the eutrophication process.

Concentrations of phosphate in my soil water samples from all treatments were very low during 1973 in comparison to other solutes measured. Variability within a given set of samples was relatively high, which suggests the precision of the method may have been low.

The grand mean phosphate concentration from the control plot was lower than that reported by Cole, <u>et al</u>. (1961) at a depth of 28 in (71 cm) from a Douglas-fir site in Washington. Their results were for a period from January to July, which may account for the difference. My samples were taken during the growing season and phosphate concentrations would probably be higher during winter and spring months. Fredriksen (1970) reported that the average stream phosphate concentrations from an undisturbed Douglas-fir watershed ranged from 0.016 to 0.026 mg/l and that the average stream concentration from a cut watershed decreased slightly during the first year following clearcutting of Douglas-fir.

Total annual losses of phosphates appear to be very small from undisturbed watersheds. Reported annual losses have been 0.18 kg/ha (Fredriksen, 1970), 0.5 kg/ha (Fredriksen, 1972), 0.02 kg/ha, (Cole, et al., 1967), 2.0 kg/ha (U.S. Forest Service, 1971), and 0.07 kg/ha for a period from January to July (Cole, et al., 1961). Following clearcutting, total phosphate losses have been reported to either increase or decrease slightly (Fredriksen, 1970; U.S. Forest Service, 1971a).

Soil phosphorus data from my three treatments exhibited considerable variation between years but generally showed lower concentrations in all horizons from the "old" clearcut (Reid, et al., 1974). Herbaceous vegetation and tree reproduction on the "old" clearcut, however, had significantly higher phosphorus levels than from the other two treatments. The rapid utilization of phosphorus by the remaining vegetation and tree reproduction on the two clearcuts appears to reduce potential losses of this nutrient. The pattern of decreasing soil water concentrations of phosphate during the summer tends to support the idea of rapid biological utilization.

The increase concentrations of phosphate observed in the soil water samples following clearcutting probably would not represent a significant phosphorous source to an aquatic system, as the average concentration increase from the "old" clearcut was only 2 ug/1 as phosphorus. Chu (1943) determined that a limiting effect occurred on various algae at phosphorus concentrations of 0.009 mg/1 or less while the minimal concentration for optimal growth ranged from 0.018 to 0.09

mg/l. The small amount of phosphorus added to streams as a result of the clearcut would probably be quickly incorporated through physical and/or biological processes and would eventually end up in the bedload of the stream (Keup, 1968).

Various authors have suggested phosphorus concentrations which should not be exceeded in aquatic systems if potential eutrophication problems are to be reduced. Sawyer (1947) suggested 0.01 mg/l; Moyle (1946) indicated 0.055 mg/l, and Machenthun (1968) suggested 0.1 mg/l for lotic systems and 0.05 mg/l for lentic systems. All of these concentrations are considerably greater than the average phosphorus concentration exhibited by the "old" clearcut (0.018 mg/l as PO4 = 0.006 mg/l as P).

SUMMARY AND CONCLUSIONS

This manuscript reports the concentrations of selected ions in soil water samples from three lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) treatment sites during the summers of 1973 and 1974. One treatment was clearcut in 1965, another was clearcut in the fall of 1972, and the third, which served as the control, was an uncut stand of lodgepole pine.

Studies of eastern deciduous forests have indicated that significant amounts of nutrients, particularly nitrogen, are added to streams draining clearcuts for several years following the clearcutting. Ionic concentrations also increased in streams draining western coniferous forests, although nitrogen concentrations in these streams were usually quite low and did not represent significant increases over control area streams.

The objective of this study was to determine the potential effects of clearcutting lodgepole pine on the water quality of streams on the eastern slope of Colorado through the measurement of selected ions in the soil water of the three treatments. Clearcutting was found to dramatically increase nitrate concentrations in soil water samples from clearcut areas, while other solutes measured showed smaller increases or decreased in concentration following clearcutting.

The average amounts of soil water collected by "deep" lysimeters and "new" clearcuts, i.e. the 1965 and 1972 clearcuts, were 59 and 86 percent greater, respectively, than the average amount collected from the control in 1973, and 20 and 38 percent greater, respectively, than from the control in 1974. The average amount of soil water collected from the "new" clearcut was consistently greater than from the "old" clearcut during both years. The amounts of water collected from the clearcut treatments were generally of similar relative magnitude and followed similar patterns to water yields reported in the literature for other clearcut operations.

Although water yield could not be inferred from my measurements, the amounts of water collected did indicate greater water content of soils on the clearcut treatments than on the control. The differences in the average amount of water collected from the three plots were assumed to be the result of reductions in evaporation (interception) and transpiration following removal of the forest.

Average amounts of soil water collected from the clearcut plots were dramatically greater than from the control plot during periods of high biological activity, i.e. from late July to Mid-September. At the extreme, no water was collected from the control in early September, while I was still able to collect a significant amount of soil water from the two clearcut plots.

Previous studies (Leaf, 1975; Hoover, 1973) indicate that clear-cutting lodgepole pine increases water yield from these areas but the majority of the increase occurs during the spring melt period. It appears, however, that the soil moisture during the summer and fall was higher on the clearcut areas than on the timbered area during this study. If clearcutting results in conditions (temperature, moisture, and light) that are more favorable for microbial populations, then nutrient losses from clearcut areas could be increased. Through respiration-mitigated reactions (bicarbonates) and through oxidation reactions (organic matter, ammonium), products could be accumulated in the soil water and leached from the system during spring runoff and during significant precipitation events.

The effects of clearcutting lodgepole pine on nutrient concentrations in soil water collections were most dramatically demonstrated by the nitrogen changes, which represented the greatest potential for nutrient enrichment of aquatic systems receiving runoff from the clearcut areas.

An analysis of variance was used to test the null hypothesis of no difference between average soil water solute concentrations, and a modification of Scheffe's S-contrasts was used to determine specific differences between concentration means from the three plots.

Although there was no significant difference between grand mean nitrate concentrations from the "new" clearcut and the control during 1973, mean weekly concentrations from the two plots started to diverge in early August; by October (one year after clearcutting) the average weekly nitrate concentration from the "new" clearcut was four to five times greater than that from the control. This trend continued during 1974, with the grand average nitrate concentration from the "new" clearcut being an order of magnitude greater than that from the control, i.e. 3.42 mg/l versus 0.29 mg/l. In addition, during the July 1974 sampling, nitrate concentrations from the "new" clearcut were one and one-half to three times greater than those from the "old" clearcut. A high nitrate concentration of almost 55 mg/l was obtained from the "new" clearcut in late July 1974. It appeared that nitrate concentrations from the "new" clearcut had not yet reached a maximum at the time this study was terminated.

Nitrate concentrations from the "old" clearcut were significantly greater than those from the control during both sample years.

In contrast to the nitrate results, ammonium concentrations were consistently greater from the control than from either clearcut during 1973. Ammonium concentrations from the two clearcuts exhibited no significant differences. Ammonium was not determined during 1974. The average amount of ammonium collected from "deep" lysimeters from the control was about one and one-half times greater than that collected from the clearcut treatments.

It seems that a significant change occurred in the nitrogen metabolism of the lodgepole pine system following clearcutting. More dramatic changes than those reported during the present study have been reported following clearcutting of eastern deciduous forests (where changes in stream concentrations were measured) and in shorter period of time. Possible explanations for the differences in concentrations and timing of the increase are that I measured soil water concentrations, but other authors reported stream concentrations, and at least one year was required for populations of nitrifying bacteria to attain numbers that were great enough to produce quantities of nitrate in excess of the demand by the heterotrophic organisms present. Since soil water ammonium concentrations decreased the spring following the clearcutting, while about one year elapsed from the time of cutting until significant differences in nitrate concentrations were detected in the soil water, ammonium may have been oxidized almost immediately by the nitrifying bacteria present in the system prior to clearcutting.

Because anion adsorption is of minor significant in soil systems, nitrates produced in excess of community demands could be rapidly leached through the soil profile. Apparently an increase in nitrate production coupled with higher soil moisture on the clearcuts resulted in an average amount of nitrate being collected from the "new" clearcut that was about 15 times greater than from the control during the second year. Even eight years after clearcutting, about nine times more nitrate was collected from the "old" clearcut during the summer and early fall than was collected from the control for the same period.

The longer response time required to detect changes in soil water nitrate concentrations may have resulted because a longer time was required to attain sufficient bacterial populations under the present conditions. This could have resulted from less than optimal physical factors such as light and temperature. It may also be possible, as suggested in the literature, that organic materials such as tannins exert inhibitory effects and require a certain amount of time to break down into non-toxic compounds and/or to be leached from the surface layer, where microbial activity is usually greatest.

Investigators, utilizing stream concentrations, have not detected differences in nitrate concentrations following clearcutting of Douglas-fir stands that might be expected based on the results of the present study. Possibly, these studies were not continued long enough to allow bacterial populations the time needed to reach sufficient numbers. Other explanations for the lower nitrates values reported might be that: utilization by stream biota could have resulted in lower apparent stream concentrations; rapid revegetation on a site could utilize the available nitrates; drainage from a clearcut area accounted for less than the assumed portion of the measured stream flow; or sampling techniques and/or schedules did not provide representative samples. Unfavorable physical and/or chemical factors may also have prevented significant increases in nitrate production from these areas.

Streams in the area of the present study exhibited nitrate concentrations that were similar to those observed in soil water samples from the control, even though some of the streams apparently drained large clearcut areas. Analysis of stream plant samples during this study, as well as results reported in the literature, suggests that aquatic plants are capable of rapidly assimilating nutrients such as nitrogen and phosphorus from the surrounding aqueous medium, thereby reducing the stream concentrations. Standard sampling procedures (grab samples) would prove inadequate in such situations for detecting the changes evident from the analysis of lysimeter samples.

Concentrations of phosphate in soil water samples from the clearcut treatments, although from 30 to 50 percent greater than from the control, probably did not indicate that a significant reduction of phosphorus reserves was occurring. Potential phosphorus losses from clearcut areas during runoff periods would probably not be considered a significant nutrient source for streams draining the clearcut areas. These results, on a relative basis, were generally consistent with literature reports of stream phosphorus concentrations (losses) from other clearcut studies. The relatively minor increases in phosphate concentrations in the soil water samples from all three plots were probably related to its rapid assimilation (and turnover) by biological systems and its rather slow rate of mineralization.

Average chloride concentrations from the two clearcuts were significantly less than from the control, however, the total amount of chloride collected from the three treatments were approximately the same. Studies of other forest systems indicated that chloride budgets were almost balanced. Results from my study, assuming balanced chloride budgets, suggest that water and dissolved ions were collected in proportion to their abundance by the tube lysimeters. This was interpreted to mean that average amounts of solutes collected, although not absolute, were quantitative on a relative basis, and could be used to provide a rough estimate of potential solute losses from the treatments.

In the undisturbed lodgepole pine system investigated during the present study, sulfate, chloride, and probably bicarbonate appeared to be the principal anions in the soil water solution. Following clear-cutting, nitrate increased in importance in the ionic balance of the solution and was largely responsible for the increased concentrations of cations in soil water samples from the clearcut treatments.

Calcium was the predominant cation measured in the soil water samples from all three treatments. Calcium also exhibited the greatest response (magnitude of change) to clearcutting of the cations measured. The significantly greater concentrations of calcium from the two clearcuts were probably the result of additions from slash and from exchange sites within the mineral and organic soil layers. The latter probably occurred through the exchange of calcium for hydrogen, which is produced during the nitrification process.

Results from the present study and from others reported in the literature indicate the need for more knowledge concening nitrification in coniferous forest systems, its rate under natural conditions, changes that occur following perturbations to the system (such as those associated with clearcutting), and what physical and/or chemical properties limit nitrification in climax or subclimax systems. There is also a lack of knowledge concerning the fate of the end products of nitrification and other metabolic processes; how rapidly they pass through the rooting zone, where they go after movement below this level, and what fate befalls them when they emerge in drainage streams.

It is difficult to predict the consequences of potential additions of nitrates and other nutrients to high mountain streams without more knowledge as to which nutrients, if any, are limiting production in these streams. It has been suggested that, because many of these streams are infertile, the addition of nitrates could be beneficial in stimulating production at all trophic levels within the lotic system. The eventual addition of these nutrients to downstream impoundments with long residence times could result in a eutrophication rate in excess of the natural condition. In this connection, it would be desirable to know how rapidly nitrogen is utilized by the aquatic biota of these high mountain streams and what concentrations or loading levels are required to cause a significant increasein the production of the various trophic levels present within the system.

From the results of other investigations it appears that phosphorous is usually the critical nutrient in aquatic systems, and its' normally low occurrence is primarily responsible for limiting production in a system. Soil water concentrations of phosphorous from the lodgepole pine clearcuts in this study were much lower than those reported in the literature as causing problems (algal "blooms") in aquatic systems. Stream concentrations in the study area were also very low.

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APPENDIX A

TECHNICAL DESCRIPTIONS OF SOIL PROFILES IN THE THREE LODGEPOLE PINE SITES ARE GIVEN BELOW. EACH PROFILE DESCRIPTION REPRESENTS EXAMINATION OF FOUR SOIL PITS PER SITE. (DESCRIPTIONS ARE FROM REID, *ET. AL.*, 1974)

Typical Profile of 1972 Clearcut Site(1)

Horizon	Depth	Description
01	5-3 cm	Mostly needles with some twigs, cones, and bark flakes of lodgepole pine; pH 4.4.
02	3-0 cm	Decomposed debris of plant material, copiously penetrated by small roots; pH 4.7.
A2	0-14 cm	Light yellowish brown (10 YR 6/2, dry) to dark reddish brown (5 YR 3/3, moist); structureless, single-grained; non-sticky, non-plastic, friable; pH 4.1; many roots; clear, irregular boundary.
B2	14-61 cm+	Light yellowish brown (10 YR 6/4, dry) to dark brown (7.5 YR 4/2, moist); cobbly, gravelly sandy clay loam, distinct clay films on peds and pores; structureless, massive; slightly plastic, slightly sticky, friable; pH 4.4; a few roots present; many large stones.

Range in Characteristics

Thickness: 01 horizon 1 to 2 cm; 02 horizon 1 to 4 cm; A2 horizon 6 to 18 cm.

(1) Soil profile descriptions completed prior to clearcutting.

Typical Profile of Undisturbed Forest Site

Horizon	Depth	Description
01	5-3 cm	Primarily needles with some twigs and cones of lodgepole pine; pH 4.3.
02	3-0 cm	Decomposing unrecognizable organic matter, held together as a mat by many small roots; pH 4.4.
A2	0-14 cm	Light yellowish brown (10 YR 6/2, dry) to dark reddish brown (5 YR 3/3, moist); charcoal present; gravelly sandy clay loams; structureless, single-grained, but slightly tendency for granular structure; non-sticky, non-plastic, friable; pH 4.1; many roots; clear, irregular boundary.
B2	14-61 cm+	Light yellowish brown (10 YR 6/4, dry) to dark brown (7.5 YR 4/2, moist); cobbly, gravelly sandy clay loam, clay films complete and distinct on peds and in pores; structureless, massive; plastic, slightly sticky, friable; pH 4.4; few roots; mixed with coarse, weathered material and stones.

Range in Characteristics

Thickness: 01 horizon 1 to 6 cm; 02 horizon 1 to 6 cm; A2 horizon 12 to 15 cm thick.

Texture: A2 horizon sandy clay loam or clay loam.

Typical Profile of 1965 Clearcut Site

Horizon	Depth	Description
01	4-3 cm	Twigs, needles, cones, and bark flakes of lodgepole pine, with isolated accumulations or organic matter; pH 4.5.
02	3-0 cm	Needles, twigs, and bark fragments in advanced stages of decomposition, with noticeable amounts mineral material and few roots; pH 4.8.
A2	0-17 cm	Light yellowish brown (10 YR 6/2, dry) to dark reddish brown (5 YR 3/3, moist); charcoal present; gravelly sandy clay loam; structureless, single-grained; non-plastic, non-sticky, friable; pH 4.4; many roots (many dead), diffuse, irregular boundary.
B2	17-101 cm+	Light yellowish brown (10 YR 6/4, dry) to dark brown (7.5 YR 4/2, moist); cobbly, gravelly sandy clay loam, clay films complete and distinct on peds and in pores; structureless, massive; plastic, sticky; pH 4.7; no roots; large boulders.

Range in Characteristics

Thickness: 01 horizon 0 to 1 cm thick; 02 horizon 0 to 6 cm thick; A2 horizon 9 to 27 cm thick.

Texture: A2 horizon sandy clay loam to loam;
B2 horizon sandy clay loam to clay loam.