AN ABSTRACT OF THE THESIS OF

JAMES H. MILLER for the DOCTOR OF PHILOSOPHY
(Name) (Degree)

in FOREST MANAGEMENT presented on March 14, 1974
(Major) (Date)

Title: NUTRIENT LOSSES AND NITROGEN MINERALIZATION ON FORESTED WATERSHEDS IN OREGON'S COAST RANGE

Abstract approved: Signature redacted for privacy.
Michael Newton

Nutrient losses of the biologically responsive anions, nitrate and bicarbonate together with the major cations, were monitored on 14 small watersheds in Oregon's Coast Range and evaluated in relation to management-induced disturbance. Mixed forests of Douglas-fir and red alder had dominated these high-nitrogen sites prior to treatment.

A paired-watershed experimental design with duplicated treatments and untreated controls was employed at three study sites to examine effects of deforestation treatments on nutrient retention. The treatments represent combinations of conventional techniques for converting mixed hardwood-shrub forests to conifer stands: 1) herbicide suppression of competing alder and shrub layer; 2) pre-harvest herbicides and clearcut logging; and 3) clearcut logging, herbicides and slash burning.

During the approximately two years of streamwater monitoring following treatments, no significant increases in dissolved solids were observed. No consistent differences appeared between treatments or between cut and uncut watersheds. Nitrate concentrations (2.8 ppm N maximum) never exceeded U.S. Public Health Service (1962) standards for drinking water. Clearfelling and herbicide treatment on one south-facing watershed did result in abnormally high concentrations of the bicarbonate anion (82 ppm maximum) and the sodium cation (21 ppm maximum) during summer base flows. Total bicarbonate loss was small because streamflow was low, preventing excessive loss of accompanying cations. Moderately high nitrate levels were characteristic of all watersheds, regardless of treatment, due to the presence of red alder. Average streamwater concentrations of nitrate ranged from 0.4 to 1.9 ppm N, for all samples collected from the individual watersheds.

Soil solution samplers were used to monitor the nitrate and bicarbonate anions in the soil profile under a residual red alder stand and an adjacent alder site recently cleared. Samples of soil solution were extracted weekly during the spring from three soil depths, 10, 65, and 130 cm. Higher concentrations of nitrate were found in soil solution than were observed in the streamwater. Concentration decreased with soil depth in both the residual stand and devegetated area. Nitrate uptake and immobilization by tree roots does not appear essential for nitrogen conservation on the gently sloping reliefs examined.

Nitrogen mineralization was further scrutinized using a soil incubation experiment with soils from under Douglas-fir and under red alder. Sixteen combinations of four soil moistures and four temperatures were utilized for study over three incubation periods. Nitrification rates are substantially greater in alder soils; while ammonification rates appear similar for the two soils within the normal operating regimes of temperature and moisture. In very wet alder soils the mobile nitrate anion is reduced to the less mobile ammonium cation and ammonification rates are minimal. This behavior appears to be important in nutrient retention during winter flushings when high soil moisture is prevalent in the lower soil profile and in wet source areas (slowly draining areas) that characterize parts of these watersheds.

The combinations of temperature and moisture exhibiting the highest rates of nitrogen mineralization (suggesting unstable states) were not encountered in the field under stands or in cleared situations. Soil temperatures above 21°C combined with moist but unsaturated conditions results in the highest rates of nitrate production. This, and the observed behavior of the nitrogen-rich watersheds, suggest that nitrate losses in streamwater following forest disturbance are only likely in climatic regions of summer-surplus precipitation.

Nutrient Losses and Nitrogen Mineralization on Forested Watersheds in Oregon's Coast Range

by

James H. Miller

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

June 1974

APPROVED:

Signature redacted for privacy.

Professor of Forest Management
in charge of major

Signature redacted for privacy.

Head of Department of Forest Management

Signature redacted for privacy.

Dean of Graduate School

Date thesis is presented March 14, 1974

Typed by Mary Jo Stratton for James H. Miller

ACKNOWLEDGMENTS

I would like to acknowledge the help of many people given during the course of this study.

Much appreciation is extended to Dr. Michael Newton for his advice and assistance in formulating, preparing, and presenting this research endeavor.

My thanks are due also to Dr. Richard Waring (Forest Management), Dr. William Chilcote (Botany), Dr. Arnold Appleby (Agronomic Crop Science), Dr. George Brown (Forest Engineering), and Prof. Louis Stone (Graduate School Representative) for participating on my committee and sharing personal and professional advice. Assistance from Dr. Duanne Moore, Dr. Richard Fredriksen, Ms. Elly Holcombe, and other staff members of the Forest Sciences Laboratory, U. S. F. S., was much needed and sincerely appreciated.

Selection and description of study sites was made possible by the forest management personnel of Starker Forest, Inc. (Philomath, Oregon), Oregon State Forestry Dept. (Philomath, Oregon), Publisher Paper Co. (Toledo, Oregon), and Siuslaw National Forest, U. S. F. S.

Special thanks is given to Mr. Don Smith for his devotion to this project and the long hours spent in the field and laboratory. And likewise, thanks is given to Albert Abee, Jim Harrow, Jeff and

Cindy Wasson for making trying field conditions more enjoyable and much more fruitful. I also place considerable importance on the support and fellowship afforded by my friends and co-workers at the Forest Research Laboratory.

Anne Miller, my wife, is deserving of all the loving appreciation I can muster, which I plan to bestow on her during the rest of our lives.

Finally, I feel extremely fortunate to have been a part of the training program of the Environmental Health Sciences Center, here at Oregon State University. Their training program and mode of financial support should stand as examples for others who are dedicated to seeing that future needs for environmentally concerned and knowledgeable personnel are met. Drs. Virgil Freed, Ian Tinsley, and Frank Dost are deserving of special appreciation from me and my fellow trainees.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDIX TABLES

LIST OF FIGURES

NUTRIENT LOSSES AND NITROGEN MINERALIZATION ON FORESTED WATERSHEDS IN OREGON'S COAST RANGE

INTRODUCTION

Oregon's Coast Range forests, on a worldwide comparison of temperate forests, rate exceedingly high in wood productivity. They comprise an increasingly important renewable resource region in the United States and the World. Timber has been extracted commercially from most of the forest land in this mountain range at least once. Extensive initial clearfellings or successive "high gradings" have been the utilization pattern of much of the private forest ownership. A 100-year period of sporadic perturbation has occurred in a forest-soil system unaccumstomed before to the state called "harvested." Removal of nutrient capital, destruction of lesser vegetation, compaction and displacement of soil, and slash disposal by fire characterizes the harvested state. Lush-green, forest-soil systems have been transformed within a relatively short time to a smoldering, jackstraw pile of logging residue. What was the observable response of these ecosystems to such drastic perturbation?

Revegetation has occurred usually within one to two years (Isaac, 1940); apparently favoring a greater hardwood component than was present in the old-growth conifer forests. Red alder (*Alnus rubra*, Bong.) and bigleaf maple (*Acer macrophyllum*, Pursh) replaced Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) on the more favorable sites. Even more hardwood regeneration was favored by the persistent periodic removal of old-growth conifers or second-growth merchantable Douglas-fir stands.

As Douglas-fir became less prevalent and its stumpage price increased, chemical weeding through selective herbicides appeared on the scene about 25 years ago. In an effort to stop the encroachment of low-utility hardwoods, yet another man-caused perturbation was thus applied to these forest-soil systems. With the advent of herbicides, specific overstory and/or understory stand components could be suppressed or eliminated without physical disturbance to the site, and without injury, hopefully, to the coniferous regeneration. Sophistication of forest management had been advanced immeasurably, in terms of technology. Public safety dictated thorough testing of the toxic nature of these chemicals, but few questions were raised, above the observational level, concerning the indirect ecological impacts of these and other perturbations commonly used in managing natural systems.

OBJECTIVES AND INVESTIGATIONAL APPROACH

The principal objective of this study was to examine the response of the forest-soil system common to the mid-Coast Range of Oregon to management-induced perturbations. Suppression of brush with herbicides, clearcut logging, and slash burning represent the specific disturbances investigated. Water and soil chemistry provided indices of response.

The investigation was conducted at three levels of resolution. Gross responses to perturbation were examined at the watershed level, using water quality data. Within watersheds, differences between disturbed and undisturbed stands were studied with respect to differences in soil solution chemistry. Finally, details of nitrogen mineralization were studied under controlled conditions in the laboratory. The dynamics of nitrate nitrogen production and retention were followed through the various investigational levels, and were the focus of attention throughout.

LITERATURE REVIEW

Perturbation-Response Monitoring by Streamwater and Soil Solution Chemistry

Not until 1958 was a specific study devised to test the response of Oregon's Coast Range forest ecosystems to harvest perturbations. This was the Alsea River Basin Study (Harris and Williams, 1971). Designed primarily from the stream biologist's perspective, this study examined the effects of logging and slash burning on water quality characteristics related to the highly productive fisheries characteristic of the region. In a recent publication by Brown, Gahler, and Marston (1973) the water quality data collected from three monitored watersheds was interpreted from the terrestrial viewpoint. The role of red alder, a nitrogen-fixing tree species, was established in the nitrogen cycle of Coast Range aquatic systems. Streamwater draining alder-dominated lands yielded average nitrate concentrations of 1.0 to 1.2 ppm N while Douglas-fir lands averaged 0.12 to 0.19 ppm N. Nitrogen loss increased three- to five-fold from a Douglas-fir watershed after clearcut logging and slash burning. These altered nitrate concentrations in streamwater were still less than in drainage waters from undisturbed alder lands.

During this same time period, the concept of "small watersheds," representing useful ecological units, gained in refinement and scientific popularity. The "small watershed approach" was made explicit by Bormann and Likens (1967) and utilized in the now well-known Hubbard Brook Study (Likens et al., 1970). The chemical make-up of streamwater (surface flow) draining a monitored watershed was found to give an integrated indication of the forest-soil system's ability to retain or release nutrients. As in any other biological entity the patterns of nutrient flux through a watershed are indicators of "health," if wisely interpreted.

From the Hubbard Brook experiment a first look was gained at a forest-soil system in an apparently "unstable" state. The anion, nitrate (NO_3^-), increased 56-fold in concentration in the streamwater draining a forested watershed subjected to extreme disturbance. A northern hardwood forest community was clearfelled and left in place. All vegetation was suppressed through herbicide treatment for three years, to prevent nutrient uptake. Increased nitrate in streamwater was observed as a result of the rapid decomposition of humic substances and nitrogen mineralization in the exposed soil. Nitrate was rapidly leached from the soil system, emphasizing the importance of vegetation as a retention sink in these forest-soil systems.

Nitrate, being an anion, has considerable mobility in the soil due to the weak anion exchange capacities normally found in temperate soils. Positively-charged cations are attracted and held to the negatively-charged soil micelles common to temperate soils.

Because electrical neutrality must be maintained in precipitation, soil solution, and streamflow, the negatively charged anions must be matched by equivalent cations. Consequently the large migration of nitrate (negative charges) from the disturbed watershed at Hubbard Brook was accompanied by an equally large release of cation nutrients, Ca^{++}, Mg^{++}, and K^+ (Likens, Bormann, and Johnson, 1969). Observations such as these added to the conceptual capabilities required in interpreting water quality data from forested watersheds.

In a subsequent verification study by the Hubbard Brook research team (Pierce et al., 1973), streamwater chemistry data were collected from seven paired areas, comparing conventional clearcuttings with undisturbed controls. Concentrations of nitrate and calcium along with streamwater conductivity were found satisfactory in determining length and degree of response to management-induced disturbances.

McColl and Cole (1968) in the Pacific Northwest made explicit the conceptual mechanisms of cation transport as reported at Hubbard Brook, and by observing lysimetric extracts of soil solution. The role of the mobile anions in transporting equal charges of cations through the soil profile was quantified by McColl and Cole. Tension-plate lysimeters were installed at various soil depths in a stand-level experiment in Puget Sound Douglas-fir forests. They found the bicarbonate anion (HCO_3^-) to be more prevalent as a cation mover than NO_3^-, $SO_4^=$, Cl^-, or P-anions. Essentially no nitrate was detected in soil solution extracted in this manner from glacial outwash soils under Douglas-fir.

Bicarbonate increases in soil solution as a result of respiration by soil microorganisms and increased CO_2 partial pressures in the soil atmosphere. A small portion of the CO_2 is dissolved in soil water and forms HCO_3^-. Clearcut logging, slash burning, and fertilization were found to result in higher bicarbonate concentrations with an equal-charge complement of cations moving in the upper soil profile (McColl, 1972; Grier, 1972). Concentrations decreased with depth. Unfortunately, comparisons between soil and streamwater concentrations were not made due to the small treatment areas employed.

McColl and Cole (1968) represented soil solution concentrations in milliequivalents / liter, an electrochemical equivalence per volume of water basis instead of the traditional mass per volume, milligrams / liter. This representation aids in the interpretation of soil solution and water quality data.

Since the total anions expressed as milliequivalents /liter must equal the total cations in streamwater or soil solution, one may be used to estimate the other. Concentration measurements of the major anions give an indication of their relative importance as cation movers in soil leaching and estimates the total concentration of cations. Increases in nitrate and bicarbonate concentrations have been shown to be good indicators of disturbance response. In the watershed and soil solutions monitoring phases of this investigation, measurements of nitrate and bicarbonate provide the primary indicators of increased nutrient loss.

Soil Nitrogen Mineralization

McColl (1972) used multiple regression and physical models to describe bicarbonate generation in the soil. Little has been done, however, to quantify nitrate production or nitrogen mineralization for western forest soils. Nitrate is not only of considerable importance as a cation mover but represents obviously a soluble form of the major plant nutrient, nitrogen; ammonium (NH_4^+) being the other prevalent form. Only by mineralization of organic soil nitrogen, through microbial ammonification and nitrification, can nitrogen be made available for the developing forest community. It must be remembered that ammonification is the primary process of nitrogen mineralization performed by a non-specific group of microorganisms yielding the cation, NH_4^+. This form of nitrogen can either be immobilized by other microorganisms or higher plants, or undergo nitrification (oxidation) by the two specific autotrophic bacteria *Nitrosomonas* and *Nitrobacter* yielding the oxidized nitrate (NO_3^-) form.

Net nitrogen mineralization rates have been successfully estimated only by some type of *in vitro* incubation study. The confounding influence of uptake by plants can be eliminated in this manner, affording observations on ammonium and nitrate increments in incubation samples over time. Microbial immobilization (uptake and synthesis) however cannot be eliminated; consequently "net" mineralization rates are observed. Incubation studies in general have been primarily aimed at quantifying altered mineralization rates due to additions of soil amendments, such as fertilizers or lime. The present investigation is focused on describing ammonium and nitrate production over the ranges of soil temperature and moisture contents encountered in the Coast Range.

Temperature and moisture are two of the most important environmental variables influencing soil nitrogen mineralization. Temperature and moisture ranges at which ammonification is operative are much wider than the range for nitrification (Robinson, 1957; Justice and Smith, 1962). The optimum constant temperature for both processes is above 25°C and varies with soils (Alexander, 1965; Justice and Smith, 1962; Kai, Ahmad, and Harada, 1969). Fluctuating temperatures reduce nitrification rates below those produced by an average constant temperature (Campbell and Biederbeck, 1972). Shifting temperatures of incubation reveal confounding results. Significantly less nitrification occurs when the incubation temperature is shifted from sub-optimal to optimal than when the temperature was initially optimal and shifted to lower temperatures (Chandra, 1961). Obviously, larger diurnal and seasonal temperature fluctuations and shifts are more characteristic of surface soils on clearcuttings than under developed canopies. The optimum moisture for nitrogen mineralization is equivalent to that held by soil between 0.1 and 0.5 atm tension or in the range commonly termed field capacity (Miller and Johnson, 1964; Reichman, Grunes, and Viets, 1966). Mineralization rates decrease with decreasing moisture. At near-saturated or saturated moisture conditions ammonification is reduced and nitrification processes shifted to denitrification (Tusneem and Patrick, 1971; Meek, Grass, and MacKenzie, 1969).

In a mountainous forest region, such as the Coast Range, soil moisture and temperature are strongly influenced by variations in landform and slope. Steeper slopes are usually well drained and vary considerably in summer soil temperatures, depending on the aspect or principal direction of exposure. Benches or flatter landforms are characteristically slower to drain than slopes, even yielding saturated surface soils during storm periods in the Coast Range and exhibit different temperature regimes than slopes.

Contrary to the absence of nitrate in lysimetric extracts under Douglas-fir in Washington, Bollen and Lu (1968) describe nitrogen mineralization, particularly nitrification, as rapid in coastal alder stands in Oregon. Through soil sampling, higher levels of ammonium and nitrate were observed under red alder compared to adjacent Douglas-fir soils. Nitrification appeared more rapid under alder since nitrate consistently out-weighed ammonium, while under Douglas-fir a more equal ratio of nitrate to ammonium was found.

Upland Watershed Hydrology

The hydrologic conceptualizations employed in this research come from Hewlett and Nutter's (1971) iconical model of streamflow mechanics, termed the "Variable Source Area" concept. Their model contains assumptions, that through field and data observation, appear to be valid in the Coast Range. Infiltration is not a limiting process, therefore the two pathways for precipitation are subsurface flow or stream channel interception. The actual time response, from storm event to discharge pattern, depends on the pathways taken by the subsurface flow; which in turn is dependent upon antecedent conditions in the soil mantle, the duration and intensity of the rainstorm, and the rate of expansion or shrinkage of the channel system. The landform characteristics that influence the storage-discharge relationships of upland watersheds are the depth of the soil mantle, the length of the hillside segments, the slope gradients, and the antecedent distribution of soil water before a storm event. Hewlett and Nutter (1971) view the first order basin as the source area for the downstream river flows. Within a watershed the term "source area" is also attached to that portion of the watershed yielding surface flow, which can expand during storms and shrink at the end of storm activity. Soils adjacent to stream channels or at focal points of subsurface drainage, originating from surrounding slopes, produces soils above saturated moisture conditions resulting in the emergence of streamflow. Implied in this view of the "varying source area" is that they are holding areas for subsurface flow exhibiting higher soil moisture contents than can be found in the soil mantle on higher slope positions.

In the Coast Range such "source areas," exhibiting these drainage characteristics, are commonly found as relatively level benches or depressions resulting from mass-soil-movement events. They represent resistor areas to subsurface flow which can enter the area from up to three contributing slopes. They can be the bottom of a partial bowl-shaped landform or the base of a sloping trough. The depression-type, where channel formation has not yet occurred, are even ponding areas during winter storm periods.

Crucial to the "small watershed approach" is that, enroute to subsurface drainage, rainfall must pass through and be influenced by the forest-soil biology and physical chemistry of the watershed. Traditionally, chemical alteration in rainfall includes the processes of canopy interception; interchange with leaf surfaces; throughfall and stemflow; litter layer and rooting zone percolation. This thesis will also develop the idea of chemical alterations occurring after percolating waters enter subsurface flow during its route to the stream channel.

THE STUDY

The Study Area

Oregon's Coast Range

The geology of the central portion of Oregon's Coast Range is dominated by the Tyee sandstone formation, surrounded by lesser sedimentary formations. A marine deposited sandstone, the Tyee formation exhibits at road cuts a texturally diverse stratigraphy which in turn lends diversity to soil development. Fine textured, platey siltstones range up to massively bedded sandstones, with bedding thicknesses from a few to 30+ feet. Mountain erosion and soil formation are extremely rapid owing to: the large amounts of winter precipitation, 200-270 cm per year; mild temperatures, monthly means ranging 4°-20°C; and the high weatherability characteristic of these sedimentary rocks. Landform dynamics are also rapid, characterized by mass-soil (subsoil)-movement events and creep; naturally high sediment loads are common in streams (Brown, 1973). Stream channels and upland watersheds of the size examined in parts of this study are strongly influenced by, or even the results, of singular or multiple mass-soil-movement events. Strongly undulating topography of benches and varying degrees of slopes result from such unstable subsoil conditions.

Perennial streams strongly dissect the topography. Due to the Mediterranean climate yielding great seasonal imbalances in precipitation, stream discharge varies 100-fold from summer base flows to winter stormflows. Storms sweeping to the east across this low mountain range from September through May produce 20 or more freshets annually on stream hydrographs.

Soils in the Tyee formation are Western Brown Forest Soils (Haplumbrepts) or much less frequently Reddish Brown Lateritic Soils (Haplohumults). Within an upland basin, a mosaic of soil variation is found resulting from source areas, undulating landforms, slippage faces, and slopes. Differences reflect varying surface-subsurface stability, drainage-aeration fluctuations, organic matter accumulation, and their interactions. Colluvium (transported by gravity) forms much of the subsoil of upland basins. Soils of the region are characterized by high surface porosity, 50 to 75% of soil volume (Dyrness, 1969), and high surface as well as subsoil conductivities, up to 100 cm/hour.[1] Moisture holding capacities in surface soil were found to be from 40 to 50% by oven-dry weight for field capacity (1/3 atmosphere tension) and up to 80 to 95% for saturation (Appendix Table 3); suggesting a strong hydrologic buffering capability due to high water

---

[1] Yee, C. 1973. Unpublished research on mass-soil-movement events in Oregon's Coast Range. Graduate Student, Dept. of Forest Engineering, Oregon State Univer., Corvallis, Ore.

holding capacities and common deep profiles. A large soil organic component influences this water holding ability, with over 30% by weight having been reported for alder soils (Franklin et al., 1968). The high porosity and conductivity characteristic of the granular structured surface soils grade into more slowly drained, massive-structured subsoils and water-permeable parent material (colluvium). Due to cracks in the underlying sandstone strata and the obvious permeability of some of the siltstones, completely water-tight watersheds cannot be assumed. Water losses attributable to this route must, however, be a small proportion of the total water budget.

Coast Range stands of red alder, and to a lesser degree Douglas-fir, accumulate large organic nitrogen capitals in the soil, ranging as high as 20,000 kg/ha (Newton, El Hassan, and Zavitkovski, 1968; Franklin et al., 1968). The accumulation is not only a product of the nitrogen fixing capabilities of red alder's root symbiont which adds up to 300 kg/ha/yr to the soil capital through litterfall and root exudation (Newton, El Hassan, and Zavitkovski, 1968), but also depends on the efficiency of the forest-soil system in retaining solubilized nitrogen forms, primarily nitrate.

Besides the Douglas-fir and red alder that dominate the vegetation, several understory species characterize the Coast Range ecosystems and contribute significantly in the mineral cycling process. Salmonberry (Rubus spectabilis, Pursh), growing to heights of 15 ft and exhibiting foliar nitrogen contents of 2%, accompanies red alder, becoming usually abundant after alder stands reach 25 years (Newton, El Hassan, and Zavitkovski, 1968; Henderson, 1970). This coincides with the period of maximum nitrogen and litter accumulation under red alder (Zavitkovski and Newton, 1969). Smirnova and Sorogovets recognized other members of the genus Rubus as nitrophyllous (as cited by Henderson, 1970). Both Newton et al. and Henderson state that salmonberry will outlast and dominate red alder sites for a considerable time after the alder starts deteriorating, a phenomenon which commonly occurs after 80 years. In the usual absence of shade-tolerant forest tree regeneration, like Sitka spruce or western hemlock, the succession of red alder to salmonberry exemplifies succession from a tree dominant to a shrub dominant. This gives some indication of the difficult "brush" problems facing tree growers in the Coast Range. Salmonberry as well as two other understory species, vine maple (Acer circinatum, Pursh) and sword fern (Polystichum munitum, (Kaulf.) Presl.) comprise most of the residual vegetation after clearcut logging and apparently persist until the next tree cover develops.

These communities are of major interest here relative to their ability to function as nutrient sinks. Their vigor, and ability to insert themselves to the exclusion of other species, speaks to their tendency to leave no niche unfilled, or nutrient unclaimed, thus their connection with this study.

Study Site Selection

In the selection of study sites, public and private organizations involved in managing forested lands in Oregon's Coast Range were contacted. Over 20 possible study sites, representing conventional hardwood-to-conifer conversion operations, were visited and evaluated using the following criteria:

1) Red alder had to predominate on the area before treatment, with the stand age being 15 years or older.
2) Since all sites represented some type of red alder suppression or elimination as a stand component, herbicide spraying or logging had to have occurred within six months prior to initiation of sampling.
3) Definable watersheds, suitable for monitoring, had to be present on the disturbed sites.
4) Access had to be possible during winter storm periods.

Three sites were selected that met these criteria; the Brush Creek site, the Depot Creek Site, and the Drift Creek Site. The greatest straight-line distance between sites was 40 km and the shortest distance, 22 km. They are 23, 18, and 13 km respectively from the Alsea River Basin Study watersheds. All three were on marine deposited sedimentary rock substrata and had similar soils. Differences were in landform and distance from the ocean.

Study Sites and Watershed Descriptions

At each of the three study sites, four upland watersheds were selected, two disturbed and two control, using the following criteria:

1) All watersheds must have supported a significant red alder component. This was to insure a high nitrogen capital in the soil, hence for maximum opportunity to observe any nutrient-release response due to increased nitrification.
2) The area of disturbance had to cover most of the watershed, preferably 100%.
3) Control watersheds had to be similar in size and aspect, and devoid of recent disturbance.
4) The area of treatment had to encompass at least two upland watersheds in order to gain an estimate of within treatment variation.

Duplication of both disturbed and control watersheds within areas was necessary because there had not been a pre-treatment calibration period. Two additional watersheds, D9 and Big Alder Source Area, were sampled at the Brush Creek Site, to add to sampling intensity in a short time frame. Appendix Table 1 presents the general watershed characteristics and Table 1 the soil nitrogen descriptions. Area determinations and cover percentages of the 14 watersheds were found using aerial photographs with ground controls and perimeter checks, then applying a polar planimeter.

Table 1. Total nitrogen and pH of soil samples[1] from the upper 15 cm collected in May and June, two years after disturbance; along with soil series.

Watershed	Total Nitrogen[2] (%)	pH[2, 3]	Soil Series
BT1 and BT2	0.25 (0.43-0.01)	4.9 (5.2-4.7)	Bohannon
BC1	0.42 (0.58-0.30)	5.1 (5.4-4.8)	"
BC2	0.40 (0.54-0.27)	5.2 (5.6-4.3)	"
ST1 and ST2	0.59 (0.78-0.50)	4.9 (5.3-4.8)	Slickrock
SC1 and SC2	0.69 (0.82-0.59)	4.4 (4.6-4.2)	"
HT1 and HT2	0.62 (0.98-0.45)	4.6 (4.9-4.3)	Bohannon
HC1 and HC2	0.60 (1.3-0.12)	4.4 (4.8-4.0)	"

[1] Five subsamples were combined per sample.

[2] Average values of five samples (25 subsamples) and maximum and minimum values.

[3] pH of a 1:2 soil to water mixture.

Brush Creek Site. The selective herbicide treatments applied to the two Brush Creek watersheds, BT1 and BT2, represent a progressive conversion attempt on a mature but heterogeneous, red alder stand having a scattered Douglas-fir component. The alder ranged from 30 to 80 years in age, in patches. Previous herbicide treatments in 1952, 1968, and 1970 had been confined to the lower portions of the watersheds and had merely suppressed the alder. The treatment in May, 1971 (before stream sampling) had been successful in a total alder kill and then the following treatments in April and August, 1972 (during the sampling period) killed much of the shrubby understory of salmonberry and vine maple. Grasses, ground moss mat, and herbaceous cover increased after treatment, preventing the occurrence of bare soil. An all-weather road runs midslope across both treated catchments and old logging trails are numerous. The two control watersheds for Brush Creek Site, BC1 and BC2, are within 5 km of the treated site. The features of these four watersheds are quite different (see Appendix Table 1).

Additions to the Brush Creek Site. There was a possibility that the watersheds selected on the north slopes would not display a representative range in soil temperature, and that adequate opportunities would not exist for studying disturbed and undisturbed stand conditions within watersheds. D9 and Big Alder Source Area were added to the sample scheme to correct these deficiencies.

D9 and Big Alder streams drain the south slopes of the same ridge that is drained on the north by BT1 and BT2. Only the well-defined upper source area of Big Alder was monitored. Disturbance of the D9 Watershed involved clearcutting the older alder and Douglas-fir from the interior portion of the drainage, leaving a younger Douglas-fir stand on the ridges. Logging operations from January to June of 1973 involved tractor-yarding of logs on 45°+ slopes with several skid trails crossing the stream channel. Streamwater sampling started just before completion of the logging. Two subsequent treatments with herbicides followed logging.

D9 drainage afforded an opportunity to study soil solutions as a function of cover type within watersheds. Tension-cup lysimeters were installed at three soil depths at the base of two nearly identical, 10° to 15° slopes. One lysimeter installation site had been logged of 80-year old alder and Douglas-fir and the control installation was under a residual stand of red alder and cherry (Prunus emarginata, Douglas) having 12" DBH and being of comparable age. Even-aged Douglas-fir stands occupied the ridges 10 to 20 meters up from both installations. The major difference between the two sites was presence or absence of tree cover, the principal test variable planned for this experiment. Slopes on D9 Watershed vary from flat on a predominant bench up to 60° next to the deeply incised stream channel.

Big Alder Source Area had been subjected to several previous loggings, the final phases of which ended at the start of monitoring. Immediately above the weir emplacement, alder slashing resulted in large amounts of debris on the ground and across the stream. Treatment with herbicides on a majority of the upper basin coincided with this. Subsurface drainage from an upper flat basin to a lower bench dominated with grasses and sedge characterizes this source area. Streamflow emerges immediately above the sampling point.

Depot Creek Site. The Depot Creek Site afforded observations on four watersheds very similar in physiogonomy and stand composition, characterized by gently sloping, undulating topography. A pattern ot depressions and benches is prevalent on the upper portions of these watersheds. Depressions were found to contain standing water during winter storm periods. Disturbance on ST1 and ST2 amounted to pre-logging treatment with herbicides, alder being the target, followed by removal of both merchantable Douglas-fir and alder, Logging residues were minimal due to the completeness of harvest. Sixty percent of ST2 was logged, excluding disturbance on a major source area. Dead alder too small for harvest was left along the stream channels. Both treated and control watersheds are located on the Toledo geologic formation on the outskirts of the Tyee sandstone formation. The Toledo formation is also a marine deposited sandstone but contains more shales.

Drift Creek Site. The Drift Creek Site is located on the NE slope of a mountain ridge overlooking Alsea Bay to the west. It is the first relief confronting easterly moving storm fronts from the Pacific Ocean. Disturbance of HT1 and HT2 involved clearcut logging of a mature Douglas-fir and red alder stand. Considerable logging residue, especially unmerchantable alder, remained after harvest. The unit was herbicide treated primarily to desiccate the remaining vine maple and salmonberry understory, and was control-burned in the fall after harvest. Since the lower portions of the watersheds represented powerline rights-of-way, grass seed with an all-purpose fertilizer was applied as a 50-meter belt across both drainages. This influenced less than 10% of both areas but the resulting grass comprised the preponderance of vegetations on these areas two years after disturbance. Both watersheds still remain in a grass-herb vegetational state three years after disturbance.

HT1 closely matches HC2 and HT2 matches HC1 in regards to watershed features, which have influence on subsurface drainage. HT1 and HC2 have well-developed upper benches and are larger in size than HT2 and HC1 which are steep, feather-shaped drainages with eroding faces where streams emerge. Both HT2 and HC1 carry heavy sediment loads evident by the constant buildup behind weir gates. The same stand of timber occupied both cleared and control watersheds, with some variation in composition.

Data Collection

Field Investigation

Watershed Monitoring. Discharge and selected dissolved solids were monitored from each watershed. At the mouth of each watershed, plywood weir gates were driven into the alluvium on the sides and bottoms of the channels. Weirs on disturbed and control streams were emplaced similarly. All were 60° V-notch. Weir sites were selected so that a water impoundment area was created behind the gates so that streamflow did not influence discharge through the notch. By measuring stage, height of water flowing through the notch, surface flow was measured at discrete time intervals. During peak stormflows when weirs were inoperable, a current meter was employed at appropriate locations to determine stream discharge. Since all watersheds were side-slope drainages, upland in nature, weirs were located at the base of the slope before sampled streams entered bottomland drainages. Subchannel flow was not included due to the shallow weir emplacement procedure; it was assumed to be fairly constant throughout the sampling period and to account for little within-treatment variation.

Discharge determinations were not obtained specifically to gain a yearly water budget, but were used in conjunction with selected water quality data to observe concentrations relative to flow rate.

Fine resolution estimates of discharge and selected nutrients were afforded for the Coast Range through the Alsea River Basin Study (Brown, Gahler, and Marston, 1973). Because concentration variation of selected anions, over a large area, was under investigation, extensive sampling could be used to generalize regionally and the anion indices used to estimate cation loss.

Water samples and discharge measurements were gathered biweekly, with monthly sampling during summer low flows, for approximately two water years following disturbance. The sampling period extended from September, 1971, to November, 1973. D9 and Big Alder were sampled from April, 1972 to November, 1973, at times on a weekly basis. The main source area on D9 was also monitored during the spring of 1973 when surface flow was present in the intermittent channel. Highly contrasting amounts of precipitation characterized the two sampling years; above normal in 1971-72 and well below normal in 1972-73.

Soil Solution Monitoring. Tension-cup lysimeters were installed at two locations on D9 Watershed in January of 1973 following the clearcut logging and herbicide treatment of the previous summer. Their purpose was to determine within-watershed differences in soil solution resulting from the removal of the forest stand. The lysimeters consisted of ceramic cups (6 cm in diameter) attached to PVC tubing with epoxy. Assembly and installation was performed according to Parizek and Lane (1970).

One installation was established in the clearcut and one under a residual stand, 150 m apart. At the two installation sites, lysimeters were emplaced at 10, 65, and 130 cm of soil depth. Wooden platforms were employed during installation and collection to minimize disturbance of the immediate area.

Soil profiles encountered while placing the lysimeters were similar with typical dark brown, low-density, crumb structure at the surface containing high organic matter (0-35 cm); grading to a light yellow, subangular blocky structure with low organic matter (35-100 cm); grading further to light yellow, higher density, massive structured, colluvial subsoil (100 cm plus). Textures graded from a silty loam at the surface which is highly structured to a silty clay loam parent material mixed with stones. The depth of organic matter influence extended down to 25 cm on the disturbed site and to 45 cm under the residual stand. This was considered evidence that the preponderance of both nitrogen mineralization and soil respiration occurs above the 45-cm depth. The majority of roots occur within these upper depths, although structural roots penetrate into the water-permeable colluvium.

Soil solutions were collected weekly with an extraction vacuum of 0.8 atm placed on the lysimeters between collecting days. Soil depths with high moisture contents would fill the reservoir cup of the lysimeter (500 ml capacity) within a day after evacuation while cups in drier zones would collect soil solution samples at various times during the weekly interval, presumably during wetting-front movement following rains. It should be noted that 0.8 atm of suction withdraws soil water past the 0.3 atm commonly considered as field capacity. Water moving by gravity and ambient water are sampled with this procedure, along with the anion constituents. Soil samples of the upper 10 cm were also collected and analyzed for total nitrogen, nitrate and ammonium nitrogen, as well as moisture content and pH. At both installations soil temperatures were recorded continuously. Precipitation was gauged and collected weekly.

Water Analyses. Streamwater and soil solution extracts were analyzed using the same procedures taken from Standard Methods for the Analysis of Water and Waste-Water (American Public Health Assoc., 1971). Initially, analyses on streamwater samples included only specific conductance and nitrate. Specific conductance was determined with a conductivity cell capable of measuring μmhos/cm. Samples were placed in a water bath at 25°C. For nitrate determinations the brucine method was used.

Bicarbonate analyses were initiated in May of 1972, using potentiometric titration with weak acid to a 4.5 pH end-point. Nitrite determinations of initially collected samples found less than 50 μg/liter in both streamwater and soil solution and were not continued. Selected samples were analyzed for chloride using the argentometric method.

After collection streamwater samples were sealed and stored at 3°C until analyzed. Changes in nitrate concentrations at this temperature were found to be within the error of analysis for storage periods up to a year. Nitrate analyses were performed within a month of collection. Specific conductance and bicarbonate analyses were most frequently performed the night following that day's collection. Filtration of the samples was not required since it was not found to increase accuracy.

Cations, Ca^{++}, Mg^{++}, Na^{+}, and K^{+} were determined in streamwater, using standard atomic adsorption techniques. Analyses for cations were performed on composite samples. Three randomly-selected sample aliquots were mixed to comprise one composite. The sample aliquots were selected from within predetermined collection periods. The five periods that were identified and sampled during the first year after disturbance closely represent the five various phases of the yearly hydrograph; fall charge-up, winter stormflows, spring draw down, summer base flows, and fall charge up again. Even though some of these samples had been stored for up to two years before cation analyses, all samples within a collection period had received the same storage treatment at 3°C. The purpose of these analyses was to gain insight into the relative concentrations of the prevalent cations in the surface waters examined.

Specific conductance can be used to estimate total ionic concentrations of anions or cations in streamwater and soil solutions (Jackson, 1958; Hem, 1959; Ponnamperuma, Tianco, and Loy, 1966; Tanji and Biggar, 1972). The scope of applicability in using such regression relationships is limited to a selected locale having relative concentrations of ionic constituents in similar proportions. Such a regression for specific conductance and total anions was derived using water quality data from Oregon's Department of Environmental Quality[2], whose task it is to monitor major rivers in Oregon. Analyses included the major cations and anions found in the principal waterways draining the Tyee sandstone formation. All available data were employed, excluding points which did not meet predetermined criteria for cation-anion balance. Both cations and anions were converted to milliequivalents/liter, so that the sum of the cations had to match the sum of anions within certain limits.

Using a least squares fit on 46 points, the initially derived relationship was $Y = .0615 + .00804\ K$, where Y equals anion concentration in meq/liter and K equals specific conductance in µmhos/cm. The correlation coefficient for this regression equaled .88 with a mean square residual of .00344. To be physically feasible the line must go through zero, consequently with this modification the final

---

[2] Data furnished by Dr. Alan Hose, Chief Chemist in the Water Quality Control Laboratory, Dept. of Environmental Quality, Portland, Oregon.

relationship was $Y = .00888\ K$. The mean square of the residual changed to .00365.

In an attempt to verify this regression model for my specific upland streams, the sum of the two most prevalent anions, nitrate and bicarbonate, were regressed against specific conductance, using 333 points. If other anions are constant, the regression line using the sum of nitrate and bicarbonate should parallel the total anion regression line. It was $Y = -0.1988 + .00891\ K$, with an $R^2 = .86$. The negative y-intercept of .1988 should and does approximate the amount of anions (principally chloride) not accounted for by using only the sum of nitrate and bicarbonate. And the slope of .00891 closely approximates the .00888 slope found using the other independently derived data. The other most prevalent anion found in these waters, chloride, appears to remain fairly constant throughout the range of specific conductance, confirming the validity of the above test. In the Department of Environmental Quality data and Alsea River Basin Study data chloride ranged consistently from .1 to .2 meq/liter. Consequently, total anion concentrations were estimable using the derived regression relationship for all study watersheds. Unfortunately, the derived regression equation was found unsuitable for predicting total anions in soil solution extracts after a statistical comparison of slope coefficients.

Laboratory Investigation

Incubation Procedure. Soils were incubated under controlled conditions to evaluate the role of cover type, temperature and moisture content on the mineralization rates of soil nitrogen. The incubation procedure was a result of screening many incubation techniques commonly employed, and assembling the most favorable techniques in an effort to simulate field conditions. Duplicate incubation series were run for red alder and Douglas-fir occupied soils.

Equal amounts of soil were collected in May from the upper 15 cm under five pure red alder stands and five pure Douglas-fir stands, and composited by species. Three pairs of the sampled stands were adjacent, and all lay in the Tyee sandstone formation region. Soil types were the same. Soils from the lysimeter sites under red alder and adjacent Douglas-fir at the D9 Watershed were included; and a subsample was kept separate to compare with soils collected from the same site the previous October and stored at 4°C during the interim.

Soils were air dried and carefully screened (<4 mm) leaving the majority of peds intact. All soils exhibited a near-shot structure with the preponderance of peds being under 4 mm. Air dry moisture content and ammonium and nitrate levels were determined on triplicate subsamples. General chemical properties are presented in Appendix Table 2. Moisture holding capacities at 0, 1/3, 2, and

15 atm tension were determined on pressure extraction plates on five replications. These will be referred to respectively as saturation, field capacity, "mid," and wilting point (Appendix Table 3). Air dried soils were stored at 4°C during these determinations in sealed polyethylene bags. Oven-dry weights (at 110°C) were also determined since this will be the basis of reported values.

The experimental design entails duplicate samples of red alder and Douglas-fir soils being subjected to 16 combinations of four moisture contents (saturation, field capacity, "mid," and wilting point) and four temperatures (7°, 14°, 21°, and 28°C). Each set therefore involved 32 incubation samples for red alder and for Douglas-fir soils. Three such sets were established, to be withdrawn one at a time from the incubation chambers at time intervals of 15, 30, and 45 days. Appropriate amounts of distilled water were added uniformly with an atomizer while mixing to yield uniform mixtures of the four moisture contents. Styrafoam coffee cups with lids were used as containers with 40 g (oven-dry basis) incubation samples. A 1-mm hole in the lid, along with adequate air volume within the cup, allowed water loss and CO_2 interchange. Carbon dioxide buildup has been demonstrated to suppress nitrification (Bremner and Douglas, 1971). Water losses were compensated by addition every 14 days. N-Serve, a commercial nitrification inhibitor, was applied at the end of incubation, and allowed to stand overnight at 3°C. Samples were then dried at 60°C to stop further microbial activity, and stored at 3°C until analyzed.

Extractable ammonium and nitrate nitrogen were determined on the same 40-g sample with Bremner and Kenney's technique (1966). Ammonium production was calculated from the formula:

NH_4-N produced = (final NH_4-N - initial NH_4-N) + (final NO_3-N - initial NO_3-N). This takes into account that any nitrate produced within an incubation period first had to be ammonified. For example, a sample having initial concentrations of 20 ppm N, NH_4 and 10 ppm N, NO_3; and after 15 days incubation show final concentrations of 50 and 100 ppm N, respectively; then during the incubation period 120 ppm N, NH_4, and 90 ppm N, NO_3, are produced.

RESULTS AND DISCUSSION

Watershed Response to Perturbation

Patterns of anion concentrations in streamwater, as presented in Figures 1 to 4 along with yearly loss estimates, Table 2, provide the basis for judging watershed responses to the perturbations examined. Since the units in Figures 1 to 4 are milliequivalents /liter, total anion concentrations also reflect total cations. These graphical representations of the relative amounts of the biologically responsive anions affords a critical inspection and comparison of treatment and site effects. Emphasis is on concentration patterns as they vary due to discharge and/or treatment, but specific values can be observed. Bicarbonate concentrations lie between those of nitrate (computer drawn asterisks) and the sum of nitrate and bicarbonate, indicated by plus signs (+). Other anion concentrations estimated between the plus (+) and the total anion concentration, the triangle (▶), are predominantly chloride; along with minor amounts of other common anions such as sulfate and phosphates. Since this procedure estimates the concentration of these less prevalent anions, they will collectively be referred to as "non-measured anions." The biweekly measured hydrographs that accompany the concentration data distort winter storm patterns, but yield actual indications of discharge variation.

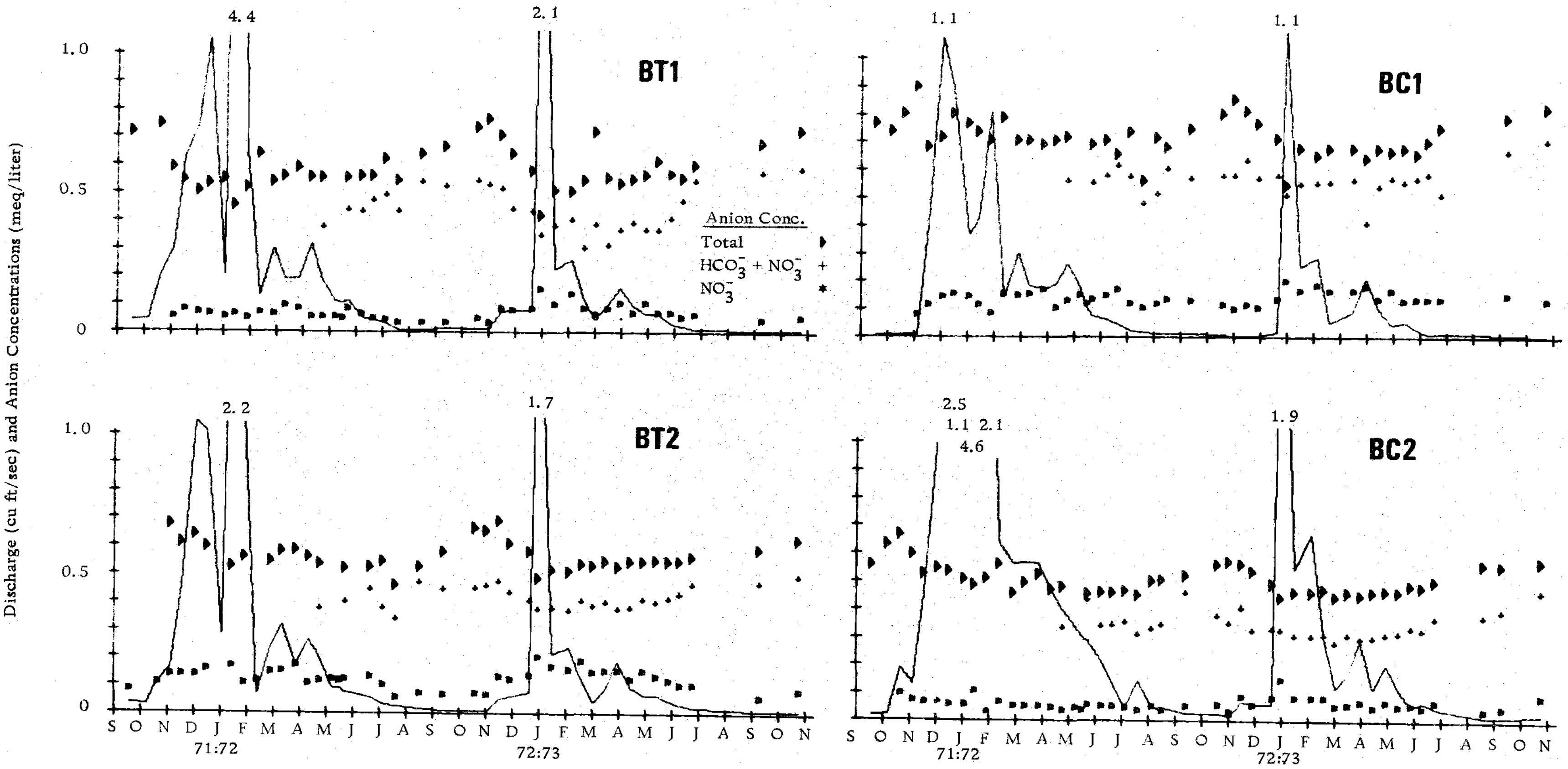


Figure 1. Brush Creek Site. BT1 and BT2 were treated with phenoxy herbicides in May '71 (3/4 watersheds), April '72 (entire watersheds), and August '72 (1/2 watersheds). BC1 and BC2 were untreated controls. Solid line represents biweekly measured discharge (cu ft/sec) and points represent anion concentrations in stream water (meq/liter).

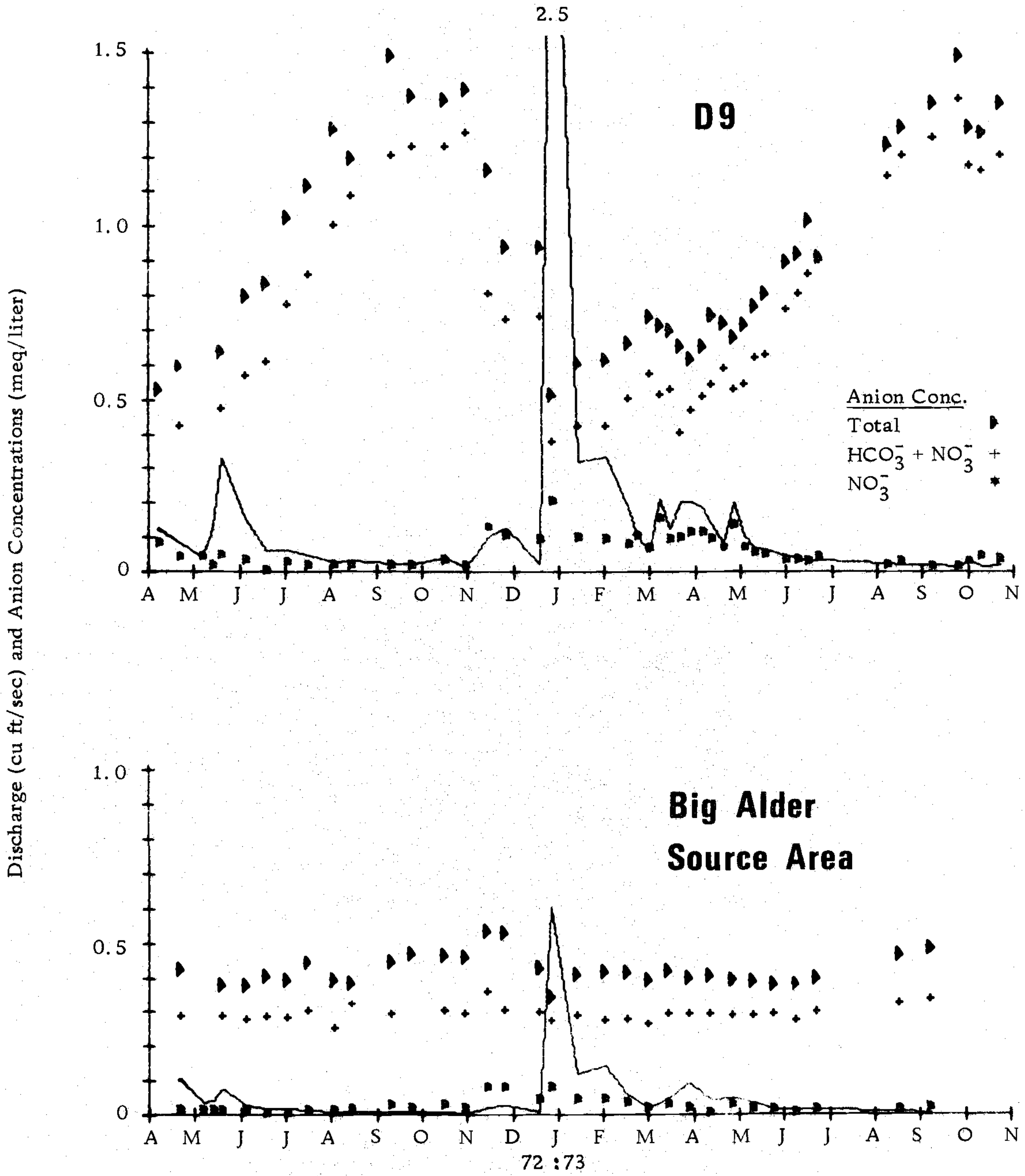


Figure 2. Brush Creek Site. D9 Watershed was 60% clearcut logged during January to June '72 (interior portion) and the logged area treated with phenoxy herbicides in April '72 (1/2 area) and in August '72 (entire area). Big Alder Source Area was thinned of Douglas-fir (1/4 area) and partially clearcut logged (1/3 area) during January to April '72; and treated with herbicide in August '72 (2/3 area). Solid line represents biweekly measured discharge (cu ft/sec) and points represent anion concentrations in stream water (meq/liter).

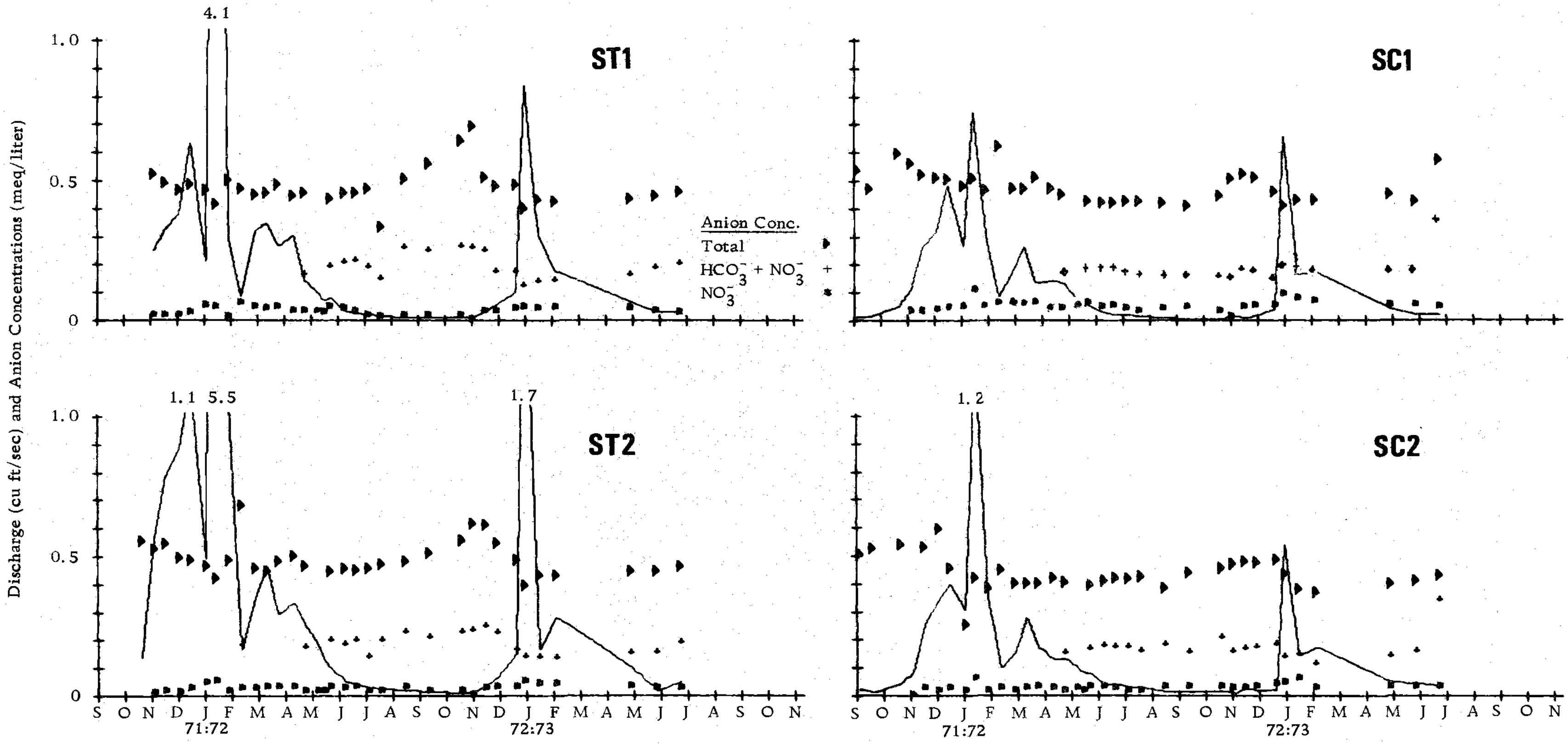


Figure 3. Depot Creek Site. ST1 and ST2 were pre-harvest treated with phenoxy herbicides spring '71 and clearcut logged during the summer '71 (ST1, entire watershed; ST2, 60% watershed). SC1 and SC2 were undisturbed controls. Solid line represents biweekly measured discharge (cu ft/sec) and points represent anion concentrations in stream water (meq/liter).

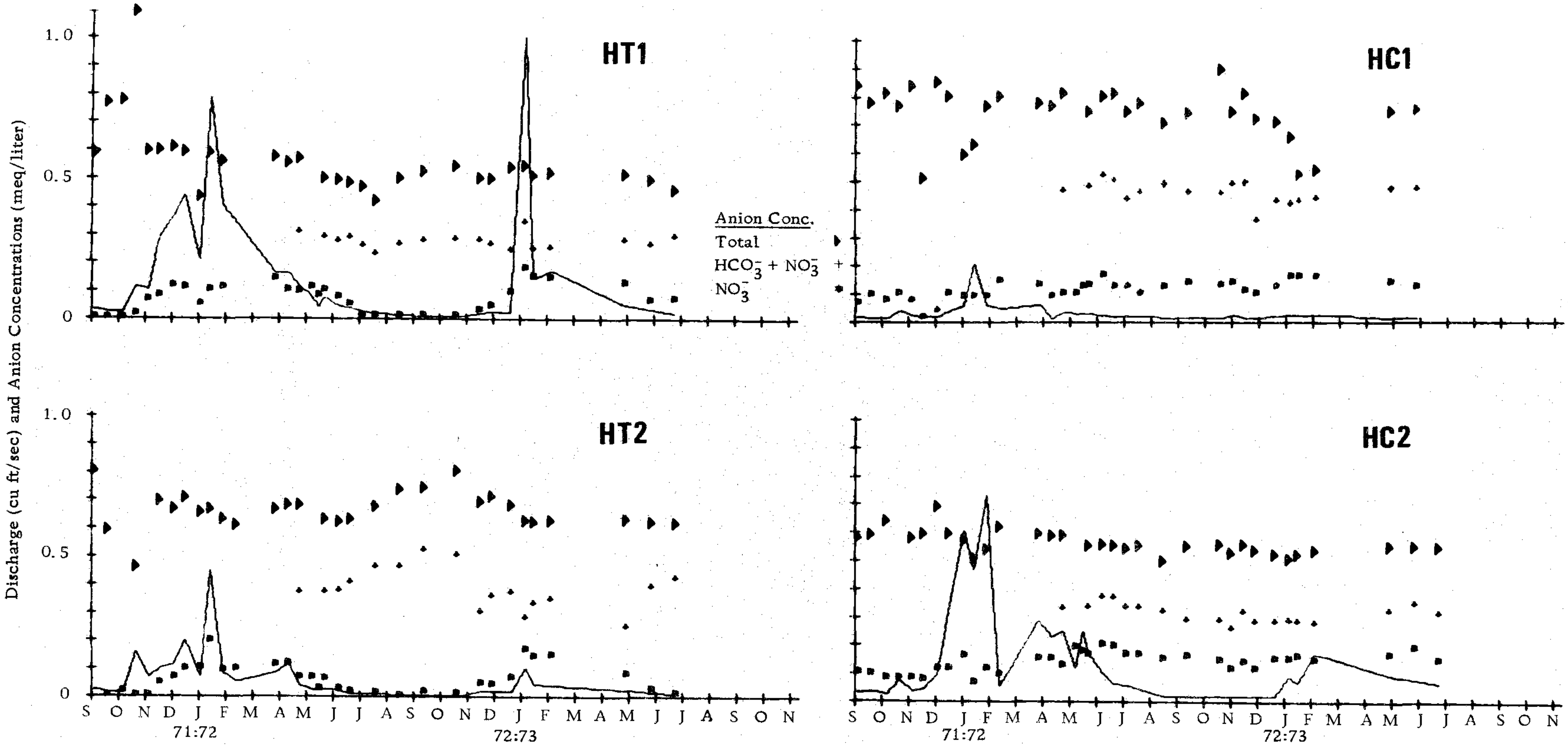


Figure 4. Drift Creek Site. HT1 and HT2 were clearcut logged during the winter '71, herbicide treated in the spring '71, and logging slash burned on September 16, '71. HC1 and HC2 were undisturbed controls. HT1 matches HC2 and HT2 matches HC1 in regards to size and watershed physiognomy. Solid line represents biweekly measured discharge (cu ft/sec) and points represent anion concentrations in stream water (meq/liter).

Table 2 reveals that variation in nitrate and total anion loss is a result more of innate watershed differences than of treatment. This is also apparent from the average concentrations (of all samples) presented in Appendix Table 4. The values in Table 2 were calculated by direct integration of the biweekly measured discharge and concentration data. When this sampling method was applied to the continuous recorded hydrograph of the smallest watershed monitored in the Alsea River Basin Study, a 20% underestimate of yearly water loss was found. Since winter storm peaks can be missed by periodic discharge measurements, the values in Table 2 are presumably underestimates. These biases are probably consistent among treatments, however, because all were recorded by the same procedure. Loss differences shown in Table 2 are evident as concentration and discharge differences in Figures 1-4.

Consistencies apparent in the chemical flux characteristics of these watersheds are: (1) total anion concentrations are relatively constant throughout the year, even with 100-fold fluctuations in discharge due to complementary changes with season in bicarbonate and nitrate concentrations; (2) bicarbonate is the dominant anion with highest concentrations in late summer and lowest during winter storms; (3) nitrate complements bicarbonate concentrations by yielding lowest concentrations during summer base flows and highest during winter flushings. Low concentrations of nitrate during summer appear more pronounced on treated watersheds.

Table 2. Discharge and nutrient loss from both disturbed and undisturbed upland watersheds in Oregon's Coast Range.

Watershed	Area (ha)	Yearly Loss			Yearly Loss per Hectare		
		Discharge (m^3)	Total Anions (equivalent)	Nitrate Nitrogen (kg)	Discharge (m^3)	Total Anions (equivalent)	Nitrate Nitrogen (kg)
				Herbicide			
BT1	10.2	307,823	153,680	278	30,126	15,111	27
BT2	9.3	303,983	182,841	619	32,828	19,745	67
				Undisturbed Control			
BC1	4.8	188,345	136,246	353	39,320	28,443	74
BC2	29.1	551,464	276,088	501	18,970	9,497	17
				Partial Clearcutting & Herbicide			
D9[1]	15.9	163,619	105,915	330	10,290	6,661	21
Big Alder	6.2	45,569	17,425	33	7,373	2,820	5
				Herbicide & Clearcutting			
ST1	12.5	250,447	109,599	151	20,020	8,761	12
ST2	15.5	395,451	178,589	225	25,431	11,485	15
				Undisturbed Control			
SC1	6.2	115,754	56,497	107	18,640	9,098	17
SC2	5.4	136,881	57,277	70	25,208	10,548	13

(Continued on next page)

Table 2. (Continued)

Watershed	Area (ha)	Yearly Loss Discharge (m^3)	Yearly Loss Total Anions (equivalent)	Yearly Loss Nitrate Nitrogen (kg)	Yearly Loss per Hectare Discharge (m^3)	Yearly Loss per Hectare Total Anions (equivalent)	Yearly Loss per Hectare Nitrate Nitrogen (kg)
			Clearcutting, Herbicide, & Slash Burning				
HT1	8.5	134,813	76,232	204	15,860	8,968	24
HT2	1.9	50,895	33,824	87	27,511	18,283	47
			Undisturbed Control				
HC1	1.2	30,392	21,684	49	25,327	18,070	41
HC2	10.3	142,153	80,825	278	13,734	7,809	27

---

[1] D9 and Big Alder losses from 6/1/72 to 5/31/73 and others from 11/15/71 to 11/14/72, time period is first full sampling year after disturbance.

Chloride in randomly checked samples measured 0.10 to 0.25 meq/liter making it as prevalent as nitrate in these drainage waters. Chloride may account for 41% by weight of total dissolved solids in rainfall falling on coastal slopes in Oregon (Tarrant *et al.*, 1968). Concentrations of chloride varied from 0.1 to 0.2 meq/liter in the watersheds monitored on the Alsea River Basin Study.[3] Coastal streams in central California draining alder lands contained relatively constant chloride also, 0.72 to 0.86 meq/liter, with slight increases during winter (Baldwin, 1971). Sixty percent of the total Cl^- leaving the California basins, also underlain by marine-deposited sedimentary rocks, was atmospheric in origin. A similar pattern, as reported by Baldwin, of decreasing concentrations of chloride with increasing distance from the ocean appears evident (though not quantified) in Figures 1 to 4. Depot Creek watersheds, at 10 km from the ocean, shows the non-measured anion components (between + and ▶) approximating 0.3 meq/liter while at 32 km from the ocean, Brush Creek watersheds show consistent values closer to 0.2 meq/liter.

By examining the patterns of anion migration from disturbed vs. undisturbed watersheds, it is apparent that only the southfacing watershed, D9, responded significantly to treatment with prolonged increased bicarbonate concentrations during low-flow periods. Due to

---

[3] Unpublished data collected by the Environmental Protection Agency.

low summer discharge, total anion loss per hectare did not increase within the limits of detection for the year following disturbance (Table 2). Concentrations of bicarbonate ranged from 0.32 meq/liter (19 ppm) during winter storms to 1.34 meq/liter (82 ppm) during September of the second year following clearcut logging and herbicide treatment. Less drastic increases in bicarbonate due to disturbance are also evident in Figures 1, 3, and 4 as summer humps in concentration on west- and north-facing watersheds. Low concentrations of nitrate appear in the summer on treated watersheds, tending to nullify the observed increased bicarbonate. This results in little increased loss.

High total anion peaks on HT1 at the time of slash burning are interpreted as increased bicarbonate. Fredriksen (1971) reported similar high bicarbonate spikes immediately following slash disposal in Oregon's Cascade Mountains. Grier (1972) reported increases of bicarbonate concentration in soil solution after fire, on forested lands in Washington.

In an effort to estimate the possible duration of abnormally high bicarbonate concentrations from D9 Watershed, additional stream samples were collected from the clearcut logged watershed, Needle Branch, monitored in the Alsea River Basin Study. These samples were collected six years after disturbance. Although bicarbonate was not determined in that study, increased bicarbonate was indicated by the increase in specific conductance. Needle Branch samples collected in October, when concentrations were highest in D9 Creek, showed concentrations from the six-year-old clearcutting to be comparable to those of undisturbed watersheds. Since both are south-facing watersheds, they are assumed to have similar patterns of bicarbonate response following clearcutting.

Corresponding increases in cation concentration in base flow from D9 were in order; sodium (Na) was the most accentuated, calcium (Ca) and magnesium (Mg) were next, and possibly slight increases occurred in potassium (K) (see Table 3, under D9, 7/31/72 to 10/26/72). Of the cations, sodium is the most concentrated in the streams studied. Calcium and magnesium were about equally concentrated and potassium was least (Table 3).

The combination of factors causing increased bicarbonate as well as variation in nitrate loss was studied further in D9 Creek. Exposure, as it influences soil temperature, and watershed features, as they influence subsurface flow, appear to be significant variables.

Additional samples were collected and analyzed during summer base flow periods from watersheds adjacent to D9 (Table 4) and from within the D9 Watershed at intervals along the prinicipal stream (Table 5). From Table 4, the enhancement of the exposure effect due to north or south orientation, and by increased exposure resulting from clearcut logging of D9, accentuated the bicarbonate anion

Table 3 . Cation concentrations (meq/liter) of composite stream water samples collected during specified periods: 11/2 to 1/25, fall charge-up; 1/25 to 4/27, winter stormflow; 4/27 to 7/31, spring drawdown; and 7/31 to 10/26, summer baseflow.

Sampling Period		Herbicide		Control		Partial Clearcutting & Herbicide		Herbicide & Clearcutting		Controls		Clearcutting, Herbicide & Slash Burning		Controls	
From	To	BT1	BT2	BC1	BC2	D9	Alder	ST1	ST2	SC1	SC2	HT1	HT2	HC1	HC2
						Na (meq/liter)		Combining wt = 23[1]							
11/ 2/71	1/26/72	.62	.64	.80	.62	-	-	.61	.62	.59	.52	.69	.72	.77	.67
1/26/72	4/27/72	.63	.54	.67	.59	-	-	.54	.67	.71	.53	.62	.76	.76	.64
4/27/72	7/31/72	.45	.42	.46	.40	.64	.63	.45	.44	.42	.40	.51	.53	.59	.45
7/31/72	10/26/72	.49	.45	.47	.42	.92	.34	.55	.51	.42	.44	.45	.62	.59	.45
10/26/72	1/26/73	.45	.42	.45	.40	.53	.37	.32	.41	.42	.42	.44	.51	.54	.45
1/26/73	4/27/73	-	-	-	-	.49	.37	-	-	-	-	-	-	-	-
4/27/73	7/31/73	-	-	-	-	.63	.37	-	-	-	-	-	-	-	-
						Ca (meq/liter)		Combining wt = 40							
11/ 2/71	1/26/72	.05	.07	.09	.04	-	-	.02	.02	.03	.02	.03	.05	.08	.04
1/26/72	4/27/72	.06	.07	.09	.05	-	-	.03	.03	.03	.03	.04	.05	.07	.04
4/27/72	7/31/72	.11	.09	.13	.09	.14	.06	.04	.05	.04	.04	.06	.08	.09	.06
7/31/72	10/26/72	.14	.13	.15	.10	.21	.07	.05	.06	.05	.05	.07	.12	.10	.06
10/26/72	1/26/73	.11	.10	.14	.09	.12	.08	.05	.05	.05	.06	.06	.09	.10	.06
1/26/73	4/27/73	-	-	-	-	.12	.01	-	-	-	-	-	-	-	-
4/27/73	7/31/73	-	-	-	-	.15	.08	-	-	-	-	-	-	-	-
						Mg (meq/liter)		Combining wt = 24							
11/ 2/71	1/26/72	.05	.07	.09	.04	-	-	.03	.03	.03	.02	.04	.06	.09	.05
1/26/72	4/27/72	.06	.07	.09	.05	-	-	.04	.03	.03	.03	.06	.05	.08	.06
4/27/72	7/31/72	.10	.09	.12	.07	.17	.06	.05	.05	.04	.04	.09	.10	.11	.09
7/31/72	10/26/72	.12	.11	.16	.09	.24	.07	.07	.07	.04	.05	.10	.15	.11	.09
10/26/72	1/26/73	.10	.09	.12	.09	.14	.08	.06	.05	.05	.06	.10	.11	.11	.09
1/26/73	4/27/73	-	-	-	-	.13	.06	-	-	-	-	-	-	-	-
4/27/73	7/31/73	-	-	-	-	.17	.06	-	-	-	-	-	-	-	-

(Continued on next page)

Table 3 . (Continued)

Sampling Period		Herbicide		Control		Partial Clearcutting & Herbicide		Herbicide & Clearcutting		Controls		Clearcutting, Herbicide & Slash Burning		Controls	
From	To	BT1	BT2	BC1	BC2	D9	Alder	ST1	ST2	SC1	SC2	HT1	HT2	HC1	HC2
							_K_ (meq/liter)	Combining wt = 39							
11/ 2/71	1/26/72	.02	.02	.01	.02	-	-	.02	.03	.02	.02	.03	.03	.03	.02
1/26/72	4/27/72	.02	.02	.02	.04	-	-	.02	.02	.03	.02	.05	.04	.03	.02
4/27/72	7/31/72	.03	.03	.02	.03	.04	.04	.02	.02	.02	.02	.04	.03	.03	.03
7/21/72	10/26/72	.05	.06	.02	.03	.05	.04	.03	.03	.02	.02	.04	.04	.04	.03
10/26/72	1/26/73	.04	.03	.02	.03	.04	.05	.03	.03	.02	.02	.03	.04	.04	.03
1/26/73	4/27/73	-	-	-	-	.03	.03	-	-	-	-	-	-	-	-
4/27/73	7/31/73	-	-	-	-	.04	.02	-	-	-	-	-	-	-	-

[1] (meq/liter) x (combining weight) = ppm; combining weight = $\frac{\text{Atomic wt}}{\text{Valence}}$

Table 4. Bicarbonate concentrations (meq/liter) during summer base flow period from adjacent watersheds having contrasting exposures, at the Brush Creek Site.

Collection date	South Exposure			North Exposure		
	Clearcut	Undisturbed		Herbicide		Undisturbed
	D9	1	2	BT1	BT2	BC2[1]
6/15	0.88	-	-	0.49	0.36	0.30
7/31	1.13	0.91	-	-	-	-
8/9	1.19	0.74	0.62	-	-	0.33
8/29	1.25	0.85	0.64	0.53	0.42	0.35
9/15	1.37	0.71	0.48	-	-	-
9/22	1.13	0.73	0.56	-	-	-
10/14	1.18	0.73	-	0.53	0.42	0.37

[1] BC2 is 5 km from Brush Creek Site. Other watersheds share common boundaries.

Table 5. Concentrations of nitrate, bicarbonate, and total anions at sampling points up from the weir emplacement into the D9 Watershed during summer base flow.

Distance from weir (m)	NO_3		HCO_3		Total Anions
	(ppm N)	(meq/liter)	(ppm)	(meq/liter)	(meq/liter)
at weir	0.2	0.014	76	1.2	1.3
45	0.2	0.014	78	1.3	1.4
110	0.3	0.021	100	1.6	1.7
--[1]					
150	0.6	0.036	73	1.2	1.3

---

[1] Three laterally-positioned source areas contribute significant subsurface flow at this point, approximately 115 m from weir.

migration. Yearly solar radiation input differences between north and south aspects for this latitude and on 45° slopes are four-fold greater for south aspects (Buffo, Fritschen, and Murphy, 1972). McColl (1972) reported increased temperature in the forest floor resulted in increased bicarbonate production in soil solution.

From Table 5, significant alterations in streamwater concentrations, during summer low flows, occur at a point 115 m from the weir where significant subsurface flow enters the principal channel from laterally positioned source areas. The contributions from the lateral source areas are lower in nitrate, as indicated by dilution of main channel streamwater yielding lower nitrate; and equal or higher in bicarbonate concentrations. Bicarbonate further downstream from this confluence probably reflects the trend of CO_2-HCO_3 levels to a lower equilibrium with ambient air CO_2 partial pressures. CO_2 in soil solution is higher due to higher partial pressures attributable to soil respiration, and to increased solubility of the gas at lower subsoil temperatures. Apparently, lower HCO_3 concentrations result when subsurface flow emerges as streamflow, because of lower atmospheric partial pressures of CO_2 and warmer temperatures in exposed streams.

Watershed physiognomy influences nitrate loss as exemplified by Tables 5 and 6. Highest nitrate losses come from the steeper upper portion of D9 and the steeper watersheds ($> 30°$ slopes)

Table 6. Nitrate concentrations (ppm N) in streamwater draining level source areas vs. steep watersheds at the Brush Creek Site.

Sampling date	Level		Steep	
	Big Alder Source Area	D9 Source Area	D9	BC1
3/9	0.4	0.5	1.3	2.3
3/23	0.3	0.6	1.6	2.5
4/6	0.1	0.3	1.3	1.9
4/20	0.4	0.7	1.9	2.3
5/4	0.2	0.5	0.8	1.8

characterized by the lack of level source areas, e.g., BT2, BC1, HT2, and HC1 (Table 2). Corresponding higher cation concentrations (Na, Ca, and Mg) are most evident from the steeper Drift Creek Watersheds, HT2 and HC1, compared to the benched watersheds, HT1 and HC2 (Table 3). The correlation between high nitrate loss and steepness of slope, as it influences soil drainage, is further examined through lysimeter and incubation results.

Local Response to Perturbation

Nitrate concentration decreased with increasing profile depth in soil solution extracted from both the clearcutting and residual stand (Figure 5). Differences in concentration at the 10 cm depth appear to reflect differences in vegetation uptake or diminishing free water available for extraction on the clearcutting. A sparse grass-herb

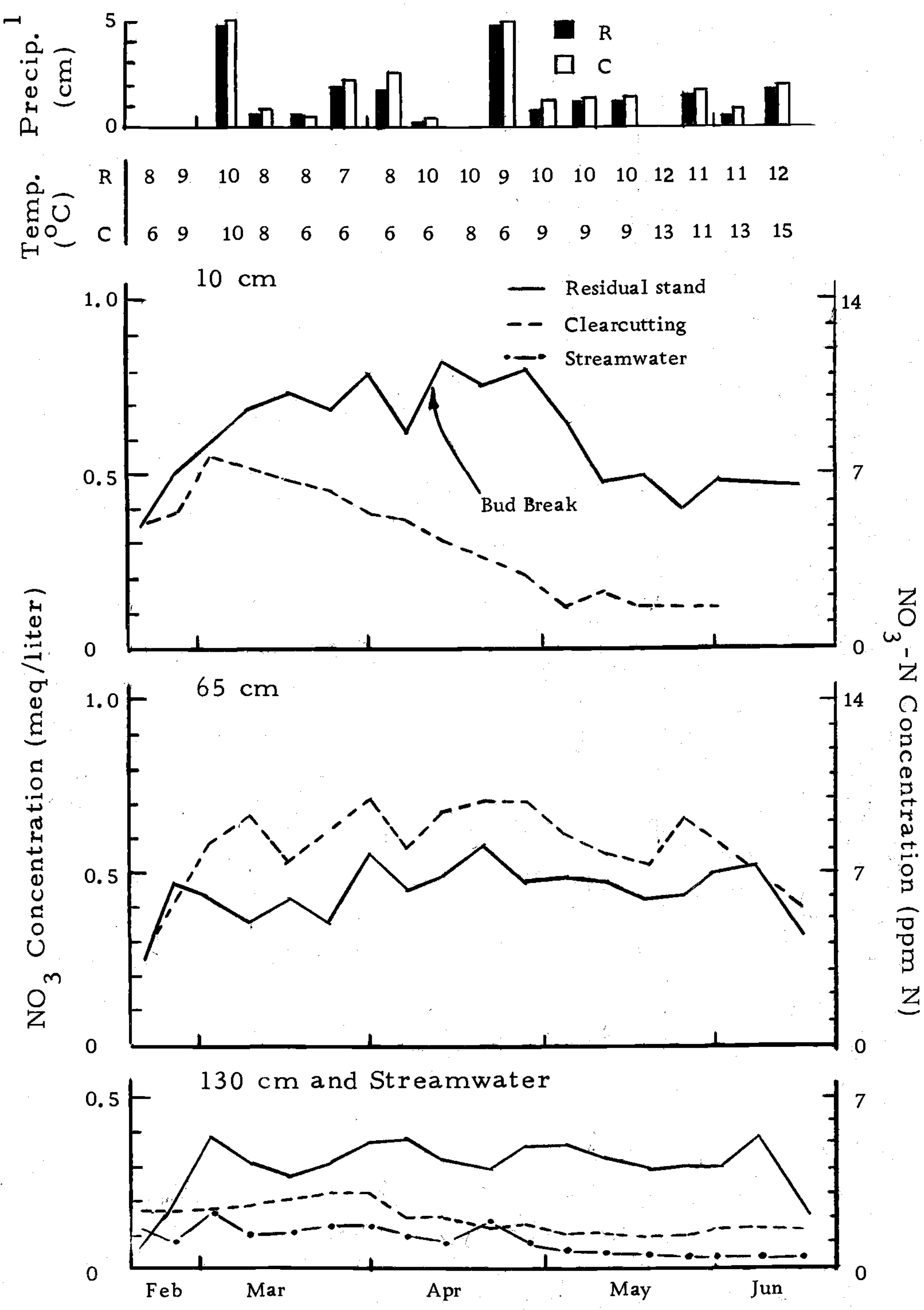


Figure 5. Nitrate concentrations in soil solution extracts and streamwater collected from D9 watershed. Soil solution collected by tension-cup lysimeters from three profile depths under a residual alder stand (R) vs a clearcutting (C) with herbicide treatment. Weekly precipitation and weekly mean temperature at 10 cm depth.

[1] Nitrate conc. in precipitation on both areas <.029 meq/liter or 0.4 ppm N.

community was present on the clearcutting slope, as contrasted with the residual red alder and cherry stand immediately around the other lysimeter installation. Plants were carefully cleared from within one meter of the clearcutting installation during mid-April, a procedure that apparently did not influence the nitrate decline at 10 cm. Bud break of the alder, cherry, and vine maple about April 10, with full canopy development by May 18, coincides with decreased nitrate on the vegetated site. The declines at the 10-cm depth are not fully reflected in concentrations at the 65- and 100-cm depths.

Streamwater concentrations of the D9 Watershed (60% clearcut logged) are included in Figures 5-7 for comparisons of trends. The hydrologic relationships between concentrations in the profile and streamwater are poorly understood. Streamwater concentrations alone do not reflect rates of loss, because stream discharge was decreasing during this sampling period. Concentrations of nitrate in streamwater were consistently lower than in soil solutions during this spring sampling period. Nitrate levels at 130-cm depth on the clearcut site approximated streamwater concentrations but remained 0.1 meq/liter higher except during two storms in early March and late April when the concentrations were equal. Absence of major storm activity during the five-month sampling period resulted in an average rainfall deficit of 23 cm in the Coast Range. Summer streamflow may therefore have had an unusually high ratio of deep seepage origin.

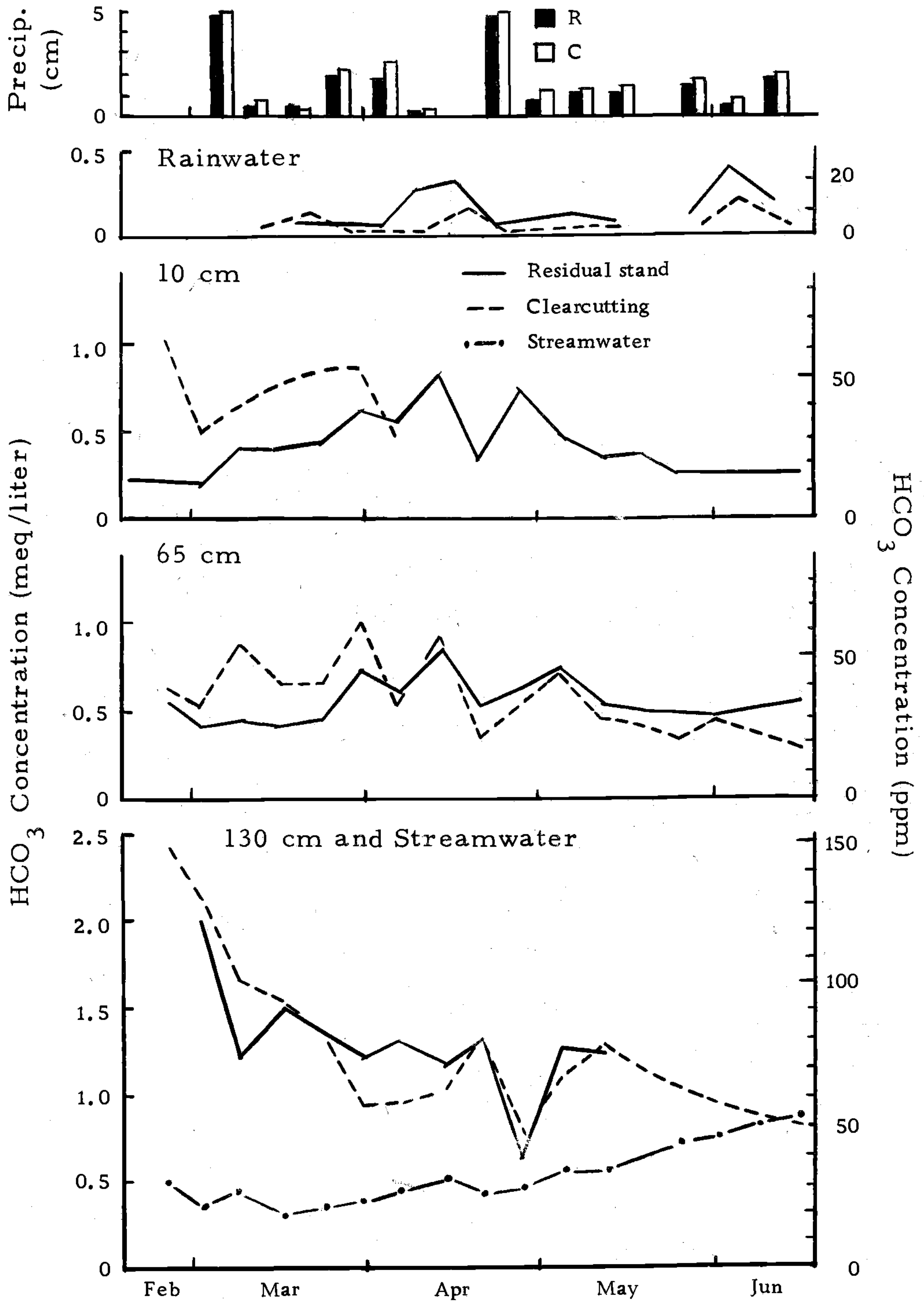


Figure 6. Bicarbonate concentration in soil solution extracts, rainwater, and streamwater collected from D9 watershed. Soil solutions collected by tension-cup lysimeters from three profile depths under a residual alder stand (R) vs a clearcutting (C) with herbicide treatment.

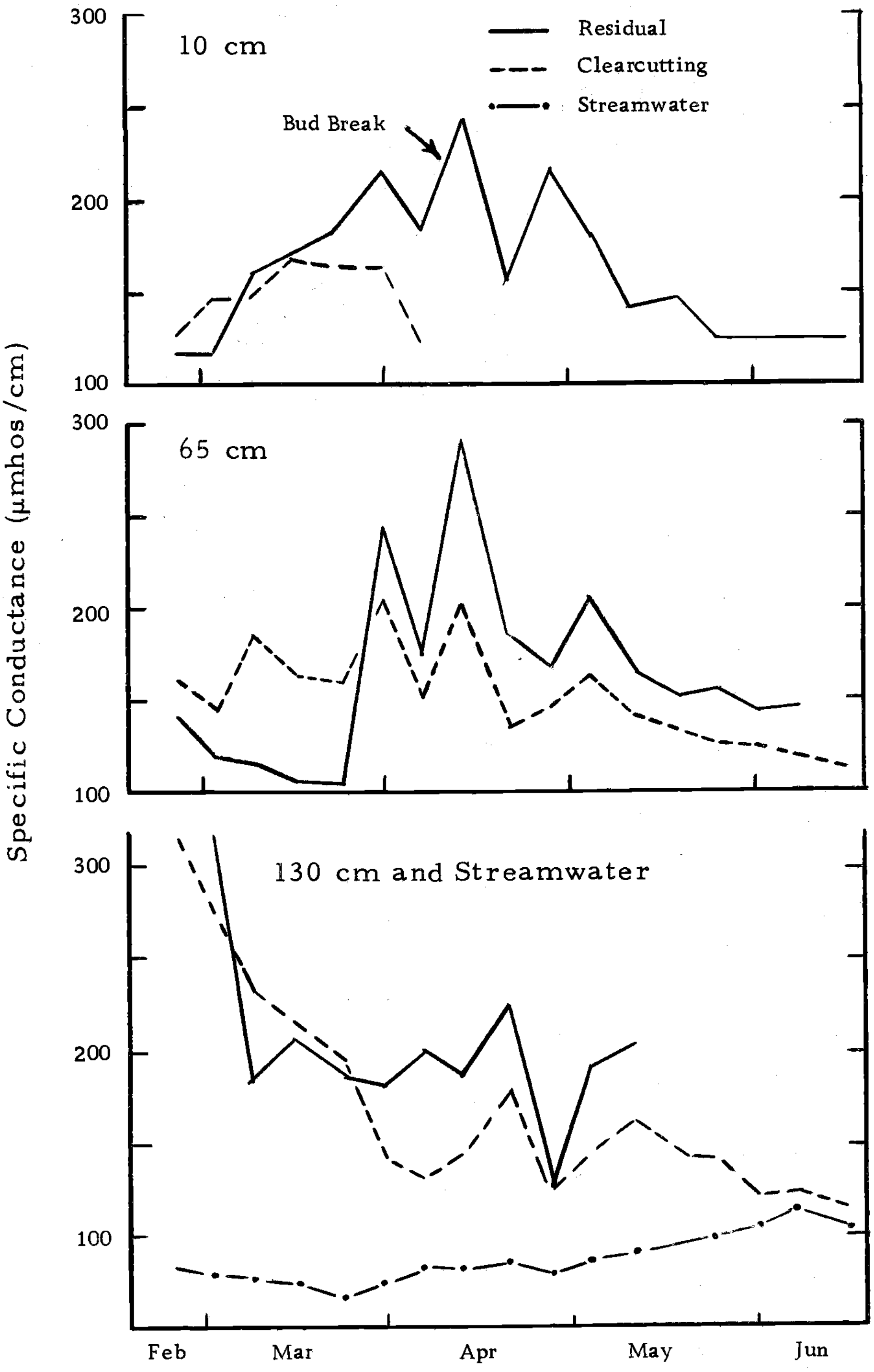


Figure 7. Specific conductance of soil solution extracted from three depths and of streamwater collected from D9 watershed.

Decreasing nitrate with increasing profile depth has also been noted and carefully studied by Meek et al. (1969, 1970) in agricultural soils in California. By controlling water table heights in pit lysimeters they observed disappearance of nitrate at soil depths approaching and into the submerged zone. Concentrations of 16 ppm nitrate down to a depth of 180 cm disappeared and were not recovered in the leachate after a week. This demonstrates the capacity of such conversion systems. Redox potential in the soil decreased with depth similar to nitrate concentrations. A laboratory study found increased conversion of nitrate to N_2 gas in incubated soils at moisture contents above 41%. Such a relation is probable on the upland forest-soil systems studied. Probable wherever anaerobic conditions are prevalent, but not where excessive drainage occurs.

No direct moisture determinations were made at the lower profile depths, but moisture contents above field capacity, approaching saturation, are assumed for the following reasons. Maximum quantities of extractable water were yielded from both sites at the 130-cm depths during weekly extraction periods up until mid-May. During winter and spring conditions, 250 ml of soil solution could be extracted within an hour at the 130-cm depth compared to 10 ml from the 10-cm depth when surface soils were at field capacity. Soils were commonly submerged in source areas, including the major source area of D9 during storm periods. Saturated soils are also common adjacent to stream channels during the same period.

Patterns of nitrate distribution at the lower profile levels reflect only minor differences in concentration resulting from the presence or absence of tree uptake.

Bicarbonate concentrations increased with greater depth in the profile in a pattern opposite that of nitrate (Figure 6). This is presumably due to increased CO_2 partial pressures with increasing depth. Boynton and Compton (1944) showed that in deeper horizons during winter, oxygen may be almost completely replaced with CO_2. The effect was more pronounced in finer textured soils, such as found in the Coast Range. Decreased O_2 must result in lower redox potentials in the lower profile. Bicarbonate distributions in the profile show even less responsiveness to presence or absence of forest vegetation than nitrate.

Specific conductance of the soil solution is more variable between the two sites, than is bicarbonate concentration, at least in the upper part of the soil profile (Figure 7). Soil solutions are ionically more concentrated and abundant under the residual stand at 10 cm than in the open. Adequate amounts of soil solution could not be collected from the cleared site at 10 cm, to measure specific conductance and bicarbonate, after the first week in April. Total concentration was higher and more variable at 65 cm under the residual stand than in the open, but both are similar at 130 cm. Streamwater from the entire watershed is lower in total concentration than was in soil solution on this 10-15° slope. It is noteworthy that these two lysimeter sites sample only one of the many within-watershed drainage conditions. The slopes on the D9 Watershed range from 60° to flat, suggesting the presence of more rapidly drained and more slowly drained conditions, than were sampled.

Soil sampling from the upper 10 cm presents another view of the two contrasting lysimeter installation sites (Figure 8). Composites of three or more randomly collected subsamples afforded estimates of soil nitrogen components, pH, and soil moisture in the upper 10 cm. Total nitrogen capital for both sites averaged 0.47% (air-dry weight) with notable increases to 0.51% after leaf fall under the residual stand. No change in total nitrogen was observed with respect to season on the clearcutting. Surface soil moisture decreased more quickly during the spring on the clearcutting than in the stand. The consistently lower pH on the clearcutting can hold significance for nitrogen mineralization processes which are known to be strongly pH dependent (Alexander, 1965). Rainfall pH, when collected under the stand, varied from pH 4.2 to 7.2 but averaged close to six for both sites. Higher pH values reflect higher bicarbonate concentrations, possibly resulting from microbial activity in raingauges. Soil solution from the 10-cm depth was consistently above pH 7, and was 0.1 to 0.6 pH unit higher on the clearcutting than in the hardwood stand. At 65 cm and below pH decreased and was always lower on the clearcutting.

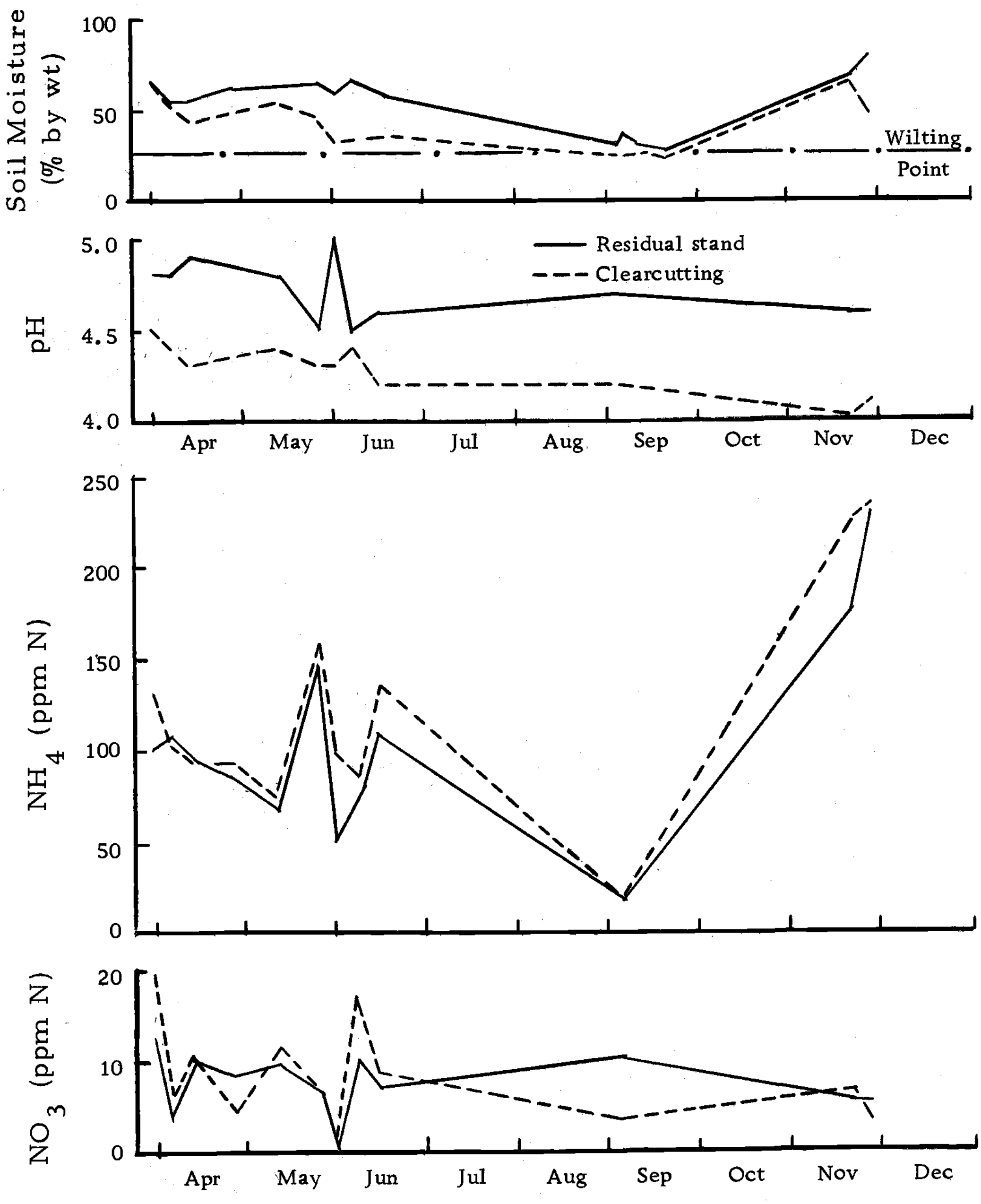


Figure 8. Soluble nitrogen, pH, and moisture content of the upper 10 cm of soil under a residual alder stand vs a clearcutting on D9 watershed.

Ammonium is the prevalent form of soluble nitrogen on both sites, usually exceeding nitrate by a factor of 10 or more. Bollen and Lu (1968) found the opposite in a coastal pure alder stand, with nitrate in soil being consistently higher than ammonium.

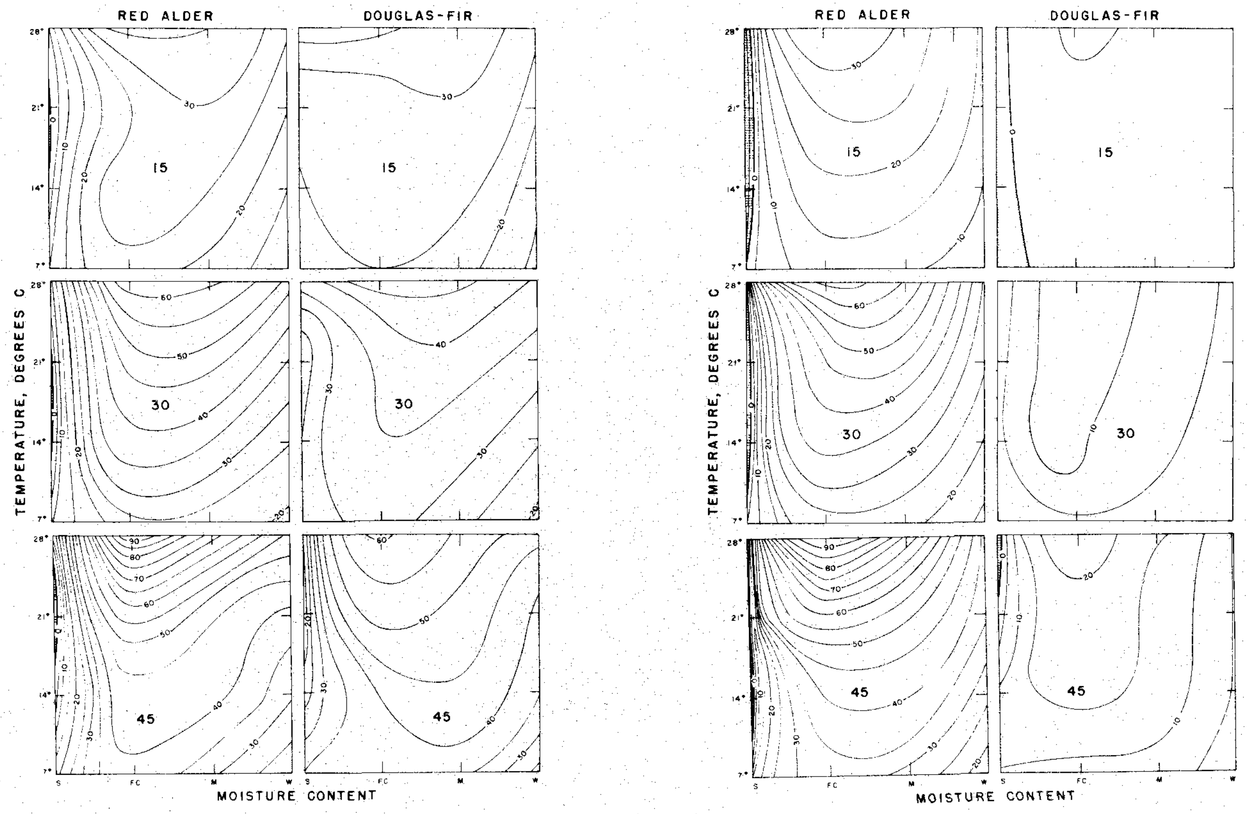
High levels of nitrate are found by soil analysis than are indicated by nitrate concentrations in soil solutions collected at 10 cm. Extractable soil solution is less concentrated than soil water held closer to the exchange sites. This is an indication that nitrate fits into the general pattern wherein soil solutions tend to give up solutes to surfaces, an anion exchange phenomenon. This system is likely to be involved in the retention of supposedly mobile nitrate in leaching situations. Adsorption of the sulfate anion in Oregon soils has been demonstrated to vary considerably depending on the specific cation with which it is associated and soil pH (Chao, Harward, and Fang, 1963). Soil pH had the greater influence, with adsorption decreasing as neutrality was approached. Soils at pH 4 showed the maximum adsorption, eight times that at pH 7. Russell and Prescott (1916-1917) listed the ability of soil colloids to adsorb anions in the following decreasing order: PO_4, SO_4, Cl, and NO_3.

Ammonium concentrations show more oscillation through the year with a summer low and late-fall high. Nitrate remained more constant except for an apparent spring low, possibly due to high uptake demands. Again, little difference is evident between the forested vs. the devegetated sites in regard to nitrogen mineralization, except for the slightly higher ammonium and late-spring nitrate concentrations on the clearcutting.

Soluble Nitrogen Generation

Incubation experiments produced consistent patterns of nitrate and ammonium production over three separate time frames. Vertically-viewed response surfaces (or isograms) depict the interactions among soil moisture and temperature in yielding various rates of ammonification and nitrification (Figure 9). The iso-lines connecting points of equal ammonium and nitrate production can be viewed as contour lines of the response surface. These surfaces were hand drawn from the 16 points (32 observations) per surface from the incubation study. In the construction of each surface eight curves were drawn, one for each temperature and moisture content. Curves were drawn through the data points using the simplest of possible functional relationships. Then the eight curves were assembled into one response surface using precise measurements to locate points of equal production. With this method of representation the full relationship can be viewed and compared at different levels of interest. Minimal interpretation is required after adjusting to the representational mode.

Ammonification and nitrification rates are highest at field



Ammonium Production (ppm N)

Nitrate Production (ppm N)

Figure 9. Ammonium and nitrate nitrogen produced in soils occupied by red alder and Douglas-fir after 15, 30, and 45 days of incubation. Lines connect points of equal production and shaded areas below zero indicate regions of ammonium immobilization or nitrate reduction. Ammonium production calculated using the formula; (Final NH_4-N - Initial NH_4-N) + (Final NO_3-N - Initial NO_3-N).

capacity and at 28°C. Saturated conditions of soil moisture resulted in either extremely slow rates of mineralization or in ammonium immobilization and denitrification (below zero on surfaces). Denitrification was evident with both soils but was more pronounced, and occurred at a wider temperature range, in alder soils. Denitrification, instead of nitrate immobilization, is assumed due to the preponderance of evidence collected over the last 75 years documenting this phenomena at saturated soil conditions (Broadbent and Clark, 1965). Enzymatic denitrification is a biological process accomplished by facultatively anerobic bacteria capable of using nitrate as a hydrogen acceptor, in place of oxygen. N_2 or N_2O gas evolution is the end-product of this process. Small ammonium increments are evident in saturated alder soil between 14-28°C.

Black (1957) summarized several incubation studies and concluded that the production of nitrate in soil requires the presence of free oxygen. He also stated that the effect of aeration on nitrate production usually reflects the effect of aeration on the transformation from organic nitrogen to ammonium nitrogen, and not on the ammonium to nitrate transformation. This does not appear to be the case at least in Douglas-fir soils since ammonification occurs, but not nitrification, at 28°C and saturation.

Denitrification was evident at 14°C but not at 7°C in saturated alder soils. Even though there is only a 15% decrease in saturation values of dissolved oxygen in water from 7° to 14°C (American Public Health Association, 1971) this is enough to apparently influence differences in mineralization processes by microorganisms. The oxygen status appears more critical than temperature since net mineralization is greater at 7° than at 14°.

Surface soil temperature and moisture conditions recorded at the lysimeter study sites, on a south aspect, are presented in Figure 10 to give some indication of actual operating regions on the response surfaces. Differences and variation should be accentuated on a south aspect and due to the abnormally dry spring conditions during this observation period. It should be noted that winter and spring moisture contents are above field capacity (1/3 atm), tending to saturation in the upper 10 cm. Higher moisture contents are assumed at greater depths. Decreasing nitrate concentrations with increasing depth found in the lysimeter study, during the spring, appear to be a result of the denitrification observed in the incubation study at near saturated conditions.

Hallin (1967) found similar temperature and moisture conditions in soils down to 90 cm on a north-facing clearcutting compared to an adjacent undisturbed Douglas-fir stand in south-central Oregon. Ammonification appears equal for alder and Douglas-fir soils between field capacity and "mid" (2 atm) moisture contents and 7° to

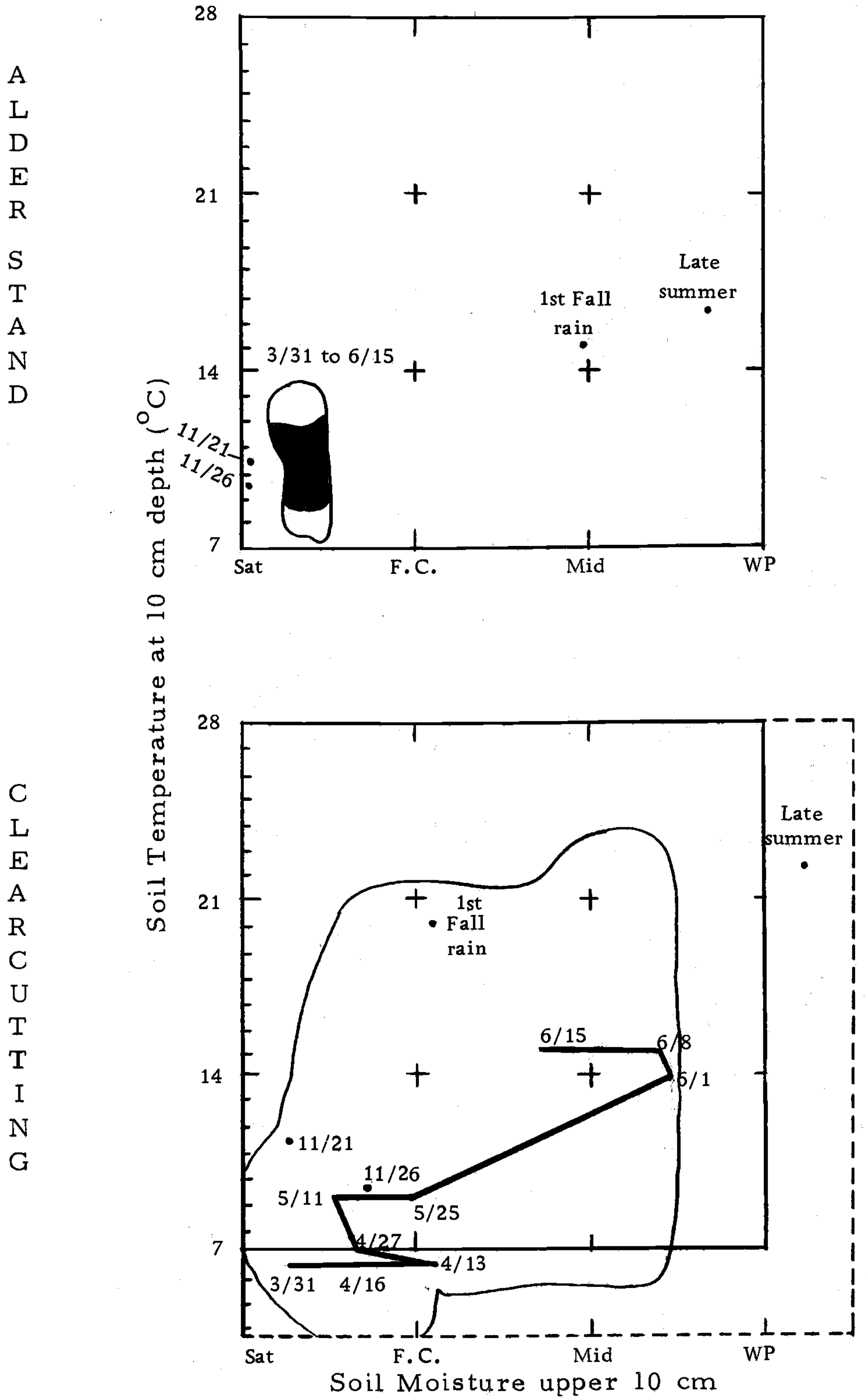


Figure 10. Surface soil temperature-moisture regimes on a south aspect under a red alder stand vs clearcutting. The dark area and line indicate mean values and the enclosed region is the area of diurnal variation.

21 °C; suggesting that near equal amounts of soluble nitrogen are afforded the two species if comparable conditions of temperature and moisture are present in the soil. This probably encompasses much of the growing season conditions under developed stands and possibly on north-facing clearcuttings. Nitrification is minimal in Douglas-fir soils in this same temperature-moisture region. These findings may aid in understanding the small degree of increase in ammonium and nitrate losses in streamwater found by Fredriksen (1970) and Brown _et_ _al_. (1972) draining clearcut logged Douglas-fir stands.

Nitrification of the ammonified nitrogen is almost complete in red alder soils, as pointed out by the similarities in the ammonium and nitrate response surfaces at 45 days and as presented in Figure 11. While nitrification under Douglas-fir appears to transform only a small portion of the available ammonium (Figure 12), alder soils show nitrification rates being limited by ammonification rates. At adequate moisture and high temperatures both ammonification and nitrification are rapid in alder soils. Lower temperatures reveal a leveling-off of the mineralization rates indicating the increased presence of a limiting factor.

Red alder seedlings show a negative response to high levels of nitrate fertilization in regard to nodulation and growth (Zavitkovski and Newton, 1968). This presents an anomaly, since nitrate is found at high concentrations under alder (Bollen and Lu, 1968), which has

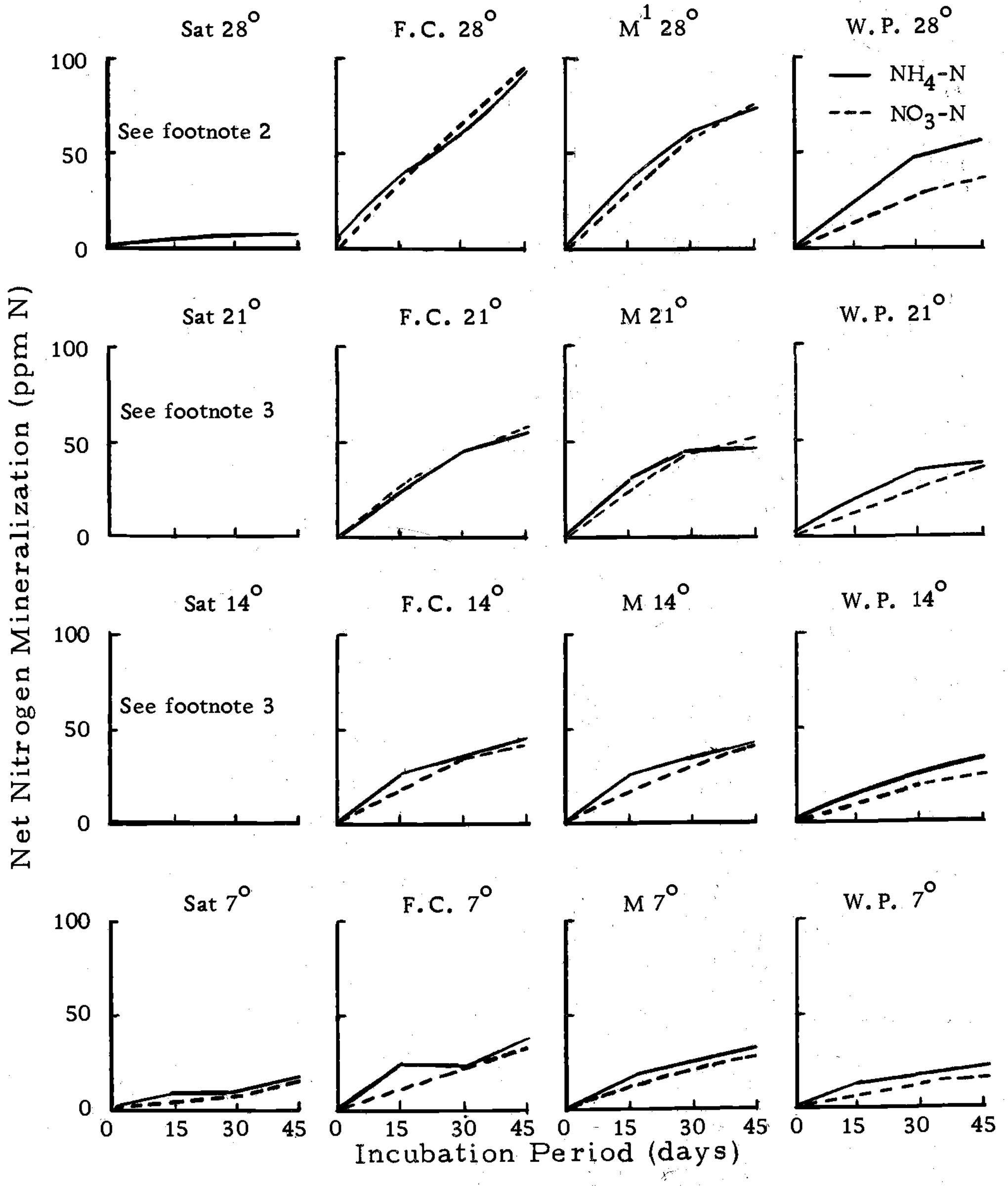


Figure 11. Ammonium and nitrate production in red alder occupied soils at various moisture and temperature combinations over 45 days of incubation. Ammonium production calculated at each point using the formula: (Final NH_4-N - Initial NH_4-N) + (Final NO_3-N - Initial NO_3-N).

[1] M = soil moisture content at 2 atm tension

[2] Nitrate initially in the sample at the start of incubation apparently reduced

[3] Nitrate initially in the samples apparently reduced and no ammonium production occurred

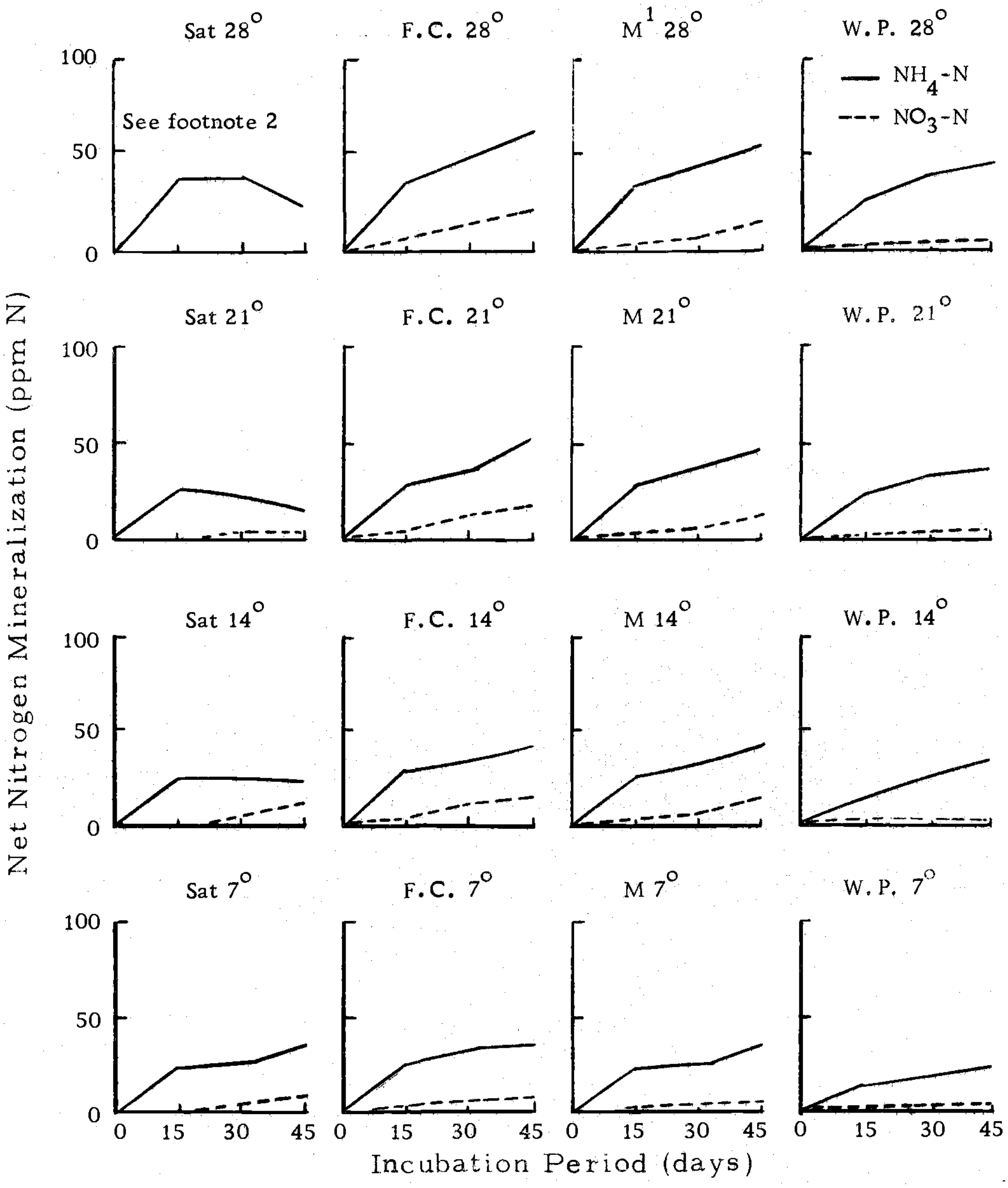


Figure 12. Ammonium and nitrate production in Douglas-fir occupied soils at various moisture and temperature combinations, over 45 days incubation. Ammonium production was calculated at each point using the formula: (Final NH_4-N - Initial NH_4-N) + (Final NO_3-N - Initial NO_3-N).

[1] M = soil moisture content at 2 atm tension

[2] Nitrate initially in the samples apparently reduced or immobilized

nitrogen-fixing capabilities. A nitrate fertilization trial using salmonberry, a companion species in mature red alder, showed significant increases in foliar contents of nitrogen with fertilization, 2.8% vs. unfertilized, 2.2%. The high nitrogen contents alone reflect the capability of this species as a sink for mineral nitrogen such as nitrate.

Ammonification and nitrification rates are twice as rapid in soils collected in May compared to soils collected in October and incubated under equal conditions (Table 7). Soils collected in May had higher percentages of organic matter and total N (Appendix Table 2) which probably accounts for the higher moisture holding capacity (Appendix Table 3). Douglas-fir and red alder soils treated with root washings from noduled alder roots showed similar mineralization rates as untreated controls (Table 8). Moore and Waid (1971) observed substantial decreases in nitrification due to treatment of soils with root washings of agricultural plants.

Table 7. Ammonium and nitrate nitrogen production of soils collected from the same red alder stand in May and in October. Both soils incubated at field capacity and at 7° and 21°C for 45 days.

Collection month	NH_4 (ppm N)	NO_3 (ppm N)
7°C		
May	117	72
October	34	31
21°C		
May	177	171
October	64	76

Table 8. Ammonium and nitrate nitrogen production in red alder and Douglas-fir occupied soils treated with washings from red alder roots bearing nodules. Incubation performed at field capacity and 14°C for 45 days.

Soils	NH_4 (ppm N)	NO_3 (ppm N)
With root washings		
red alder	44	46
Douglas-fir	39	16
Without root washings		
red alder	42	45
Douglas-fir	39	15

CONCLUSIONS

1. The forest-soil system in the mid-Coast Range of Oregon appears chemically stable under management-induced perturbations. Herbicide suppression of woody vegetation, clearcut logging and slash burning produced similar effects to no treatment, with little apparent increased loss in nutrient capital after such disturbances. Tree removal does not appear to significantly alter retention of dissolved nutrients within the soil profile or to affect nutrients in streamwater from clearcuttings.

   Accelerated loss of minor essential nutrients does not appear likely since the abundant sodium cation responds the greatest to increased anion loss. Loss of essential anions such as phosphorus (PO_4) did not increase with clearcutting and slash burning, as found in the Alsea River Basin Study. Non-measured anions, i.e., Cl, SO_4 and PO_4, did not appear to be influenced by disturbance in this current study.

2. Bicarbonate is the prevalent cation mover in these forest-soil systems. Exposure as a result of aspect or clearcutting influences bicarbonate concentrations in streamwater during base flow periods. Increased bicarbonate in streamwater resulting from increased exposure due to disturbance does not appear to appreciably alter yearly loss of total anions or

cations. In soil solution extracts collected during spring to summer, differences were small in the distribution of bicarbonate through the profile after clearcutting. Since bicarbonate increases in summer base flow, its origin must be in moist areas capable of high soil respiration such as source areas or adjacent to stream channels.

3. Nitrate concentration complements bicarbonate by being highest in the winter and lowest during summer base flows. The balancing effects of these two anions yield streamwater from upland watersheds having consistent total ionic strength the year round.

4. Dominant tree cover strongly influences the quality of nitrogen mineralization in the soils it occupies. Nitrification rapidly transforms ammonium to nitrate in red alder occupied soils, while transformations under Douglas-fir appear proportional to the ammonium present.

5. Nitrate in soil solution decreased in concentration with increased soil depth during high soil moisture conditions. Streamwater draining source areas (slowly draining areas) was consistently lower in nitrate concentrations than drainage water from steeper landforms. Slope and landform strongly influence drainage and therefore soil moisture conditions in the soil profile and in subsurface flow impounding areas, such as source areas.

Denitrification at near-saturated or saturated moisture conditions appears to be a critical process in nutrient retention in these high-nitrogen forests.

It is hypothesized from the findings of this research that nutrient loss in general is more a function of climatic and watershed features that influence temperature, drainage patterns, and resident-time of subsurface flow than of the several types of disturbance investigated.

BIBLIOGRAPHY

Alexander, M. 1965. Nitrification. In: Soil Nitrogen (W. V. Bartholomew and F. E. Clark, eds.). Agronomy 10. American Society Agronomy Inc., Madison, Wisconsin. p. 307-343.

American Public Health Association, Inc. 1971. Standard methods for the analysis of water and waste-water, 13th ed. Washington, D. C. 874 p.

Baldwin, A. D. 1971. Contribution of atmospheric chloride in water from selected coastal streams of Central California. Water Resources Research 7(4): 1007-1012.

Black, C. A. 1957. Nitrogen. In: Soil-plant Relationships. John Wiley and Sons, Inc., New York. 332 p.

Bollen, W. B. and K. C. Lu. 1968. Nitrogen transformations in soils beneath red alder and conifers. In: Biology of Alder (J. M. Trappe et al., eds.). Portland, U. S. Pacific Northwest Forest and Range Experiment Station. p. 141-148.

Bormann, F. H. and G. E. Likens. 1967. Nutrient cycling. Science 155(3761):424-429.

Boynton, D. and O. C. Compton. 1966. Normal seasonal changes of oxygen and carbon dioxide percentages in gas from the larger pores of three orchard soils. Soil Science 57: 107-117.

Bremner, J. M. and D. R. Kenney. 1966. Determination of isotope-ratio analysis of different forms of nitrogen in soils. 3. Soil Science Society of America Proceedings 30:577-582.

Bremner, J. M. and L. A. Douglas. 1971. Use of plastic films for aeration in soil incubation experiments. Soil Biology and Biochemistry 3:289-296.

Broadbent, F. E. and F. E. Clark. 1965. Denitrification. In: Soil Nitrogen (W. V. Bartholomew and F. E. Clark, eds.). American Society of Agronomy series no. 10, Madison, Wisconsin. p. 344-359.

Brown, G. W. 1972. Logging and water quality in the Pacific Northwest. In: Proceedings of the National Symposium on Watersheds in Transition, 1972. American Water Resources Association Proceedings series 14. p. 330-334.

Brown, G. W., A. R. Gahler, and R. B. Marston. 1973. Nutrient losses after clear-cut logging and slash burning in Oregon Coast Range. Water Resources Research 9(5): 1450-1453.

Buffo, J., L. Fritschen, and J. Murphy. 1972. Direct solar radiation on various slopes from 0° to 60° north latitude. USDA Forest Service Research Paper. PNW-142. Pacific NW Forest and Range Experiment Station, Portland, Oregon. 74 p.

Campbell, C. A., V. O. Biederbeck, and F. C. Warder. 1971. Influence of simulated fall and spring conditions on the soil system. II. Effect on soil nitrogen. Soil Science Society of America Proceedings 35:480-483.

Campbell, C. A. and V. O. Biederbeck. 1972. Influence of fluctuating temperatures and constant soil moistures on nitrogen changes in amended and unamended loam. Canadian Journal of Soil Science 52:323-336.

Chandra, P. 1961. Note on the effect of shifting temperatures on nitrification in a loam soil. Canadian Journal of Soil Science 41:314-315.

Chao, T. T., M. E. Harward, and S. C. Fang. 1963. Cationic effects on sulfate adsorption by soils. Soil Science Society of America Proceedings 27:35-38.

Franklin, J. F., C. T. Dyrness, D. G. Moore, and R. F. Tarrant. 1968. Chemical soil properties under coastal Oregon stands of alder and conifers. In: Biology of Alder (J. M. Trappe et al., eds.). Portland, U. S. Pacific Northwest Forest and Range Experiment Station. p. 73-84.

Fredriksen, R. L. 1971. Comparative water quality--natural and disturbed streams following logging and slash burning. In: Proceedings of symposium on forest land uses and stream environment. Corvallis, Oregon State University Press. p. 125-138.

Grier, C. C. 1972. Effects of fire on the movement and distribution of elements within a forest ecosystem. Ph. D. thesis, Seattle, University of Washington. 182 numb. leaves.

Hallin, W. E. 1967. Soil-moisture and temperature trends in cutover and adjacent old-growth Douglas-fir timber. USDA Forest Service Research Paper. PNW-56. Pacific NW Forest and Range Experiment Station, Portland, Oregon. 11 p.

Harris, D. D. and R. C. Williams. 1971. Streamflow, sediment-transport, and water-temperature characteristics of three small watersheds in the Alsea River Basin, Oregon. Geological Survey Circular 642. 21 p.

Hem, J. D. 1959. Study and interpretation of the chemical characteristics of natural water. U. S. Geological Survey, Water-Supply Paper 1473. 269 p.

Henderson, J. 1970. Biomass and composition of the understory vegetation in some Alnus rubra stands in western Oregon. M. S. thesis, Corvallis, Oregon State University. 64 numb. leaves.

Hewlett, J. D. and W. L. Nutter. 1971. The varying source area of streamflow from upland basins. In: Symposium on Interdisciplinary Aspects of Watershed Management, Bozeman, Montana State University, 1970.

Isaac, L. A. 1940. Vegetation succession following logging in the Douglas-fir region with special reference to fire. Journal of Forestry 38:716-721.

Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall, Englewood Cliffs, N. J. 498 p.

Justice, J. K. and R. L. Smith. 1962. Nitrification of ammonium sulphate in a calcareous soil as influenced by combinations of moisture, temperature and levels of added nitrogen. Soil Science Society of America Proceedings 26:246-250.

Kai, H., Z. Ahmad, and T. Harada. 1969. Factors affecting immobilization and release of nitrogen in soil and chemical characteristics of nitrogen newly immobilized. 1. Effect of temperature on immobilization and release of N in soil. Soil Science and Plant Nutrition 15:207-213.

Likens, G. E., F. H. Bormann, and N. M. Johnson. 1969. Nitrification: importance to nutrient losses from a cutover forested ecosystem. Science 163(3872):1205-1206.

Likens, G. E., F. H. Bormann, N. M. Johnson, D. W. Fisher, and R. S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed ecosystem. Ecological Monographs 40:23-47.

McColl, J. G. and D. W. Cole. 1968. A mechanism of cation transport in a forest soil. Northwest Science 42(4):134-140.

McColl, J. G. 1972. Dynamics of ion transport during moisture flow from a Douglas-fir forest floor. Soil Science Society of America Proceedings 36(4):668-674.

Meek, B. D., L. B. Grass, and A. J. MacKenzie. 1969. Applied nitrogen loss in relation to oxygen status of soils. Soil Science Society of America Proceedings 33:575-578.

Meek, B. D., L. B. Grass, L. S. Willardson, and A. J. MacKenzie. 1970. Nitrate transformations in a column with a controlled water table. Soil Science Society of America Proceedings 34:235-239.

Miller, R. D. and D. D. Johnson. 1964. The effect of soil moisture tension on carbon dioxide evolution, nitrification and nitrogen mineralization. Soil Science Society of America Proceedings 28:644-647.

Moore, D. R. E. and J. S. Waid. 1971. The influence of washings of living roots on nitrification. Soil Biology and Biochemistry 3:69-83.

Newton, M., B. A. El Hassan, and J. Zavitkovski. 1968. Role of red alder in western Oregon succession. In: Biology of Alder (J. M. Trappe _et al._, eds.). Portland, U. S. Pacific Northwest Forest and Range Experiment Station. p. 73-84.

Parizek, R. R. and B. E. Lane. 1970. Soil-water sampling using pan and deep pressure-vacuum lysimeters. Journal of Hydrology 11:1-21.

Pierce, R. S., C. W. Martin, C. C. Reeves, G. E. Likens, and F. H. Bormann. 1973. Nutrient loss from clear cuttings in New Hampshire. In: Proceedings of the National Symposium on Watersheds in Transition, 1972. American Water Resources Association Proceedings series 14. p. 285-295.

Ponnamperuma, F. N., E. M. Tianco, and T. A. Loy. 1966. Ionic strength of the solutions of flooded soils and other aqueous solutions from specific conductance. Soil Science 102:408-413.

Reichman, G. A., D. L. Grunes, and F. G. Viets, Jr. 1966. Effects of soil moisture on ammonification and nitrification in two Northern Plains soils. Soil Science Society of America Proceedings 30:363-366.

Robinson, J. B. D. 1957. The critical relationship between soil moisture content in the region of wilting point and the mineralization of natural soil nitrogen. Journal of Agricultural Science 49:100-105.

Russell, J. R. and J. A. Prescott. 1916-1917. The reaction between dilute acids and the phosphorus compounds of the soil. Journal of Agricultural Science 8:65-110.

Tanji, K. K. and J. W. Biggar. 1972. Specific conductance model for natural waters and soil solutions of limited salinity levels. Water Resources Research 8(1):145-153.

Tarrant, R. F., K. C. Lu, W. B. Bollen, and C. S. Chen. 1968. Nutrient cycling by throughfall and stemflow precipitation in three coastal Oregon forest types. USDA Forest Service Research Paper PNW-54. 7 p. Pacific NW Forest and Range Experiment Station, Portland, Oregon.

Tusneem, M. E. and W. H. Patrick, Jr. 1971. N transformations in water logged soil. Louisiana Agricultural Experiment Station Bulletin no. 657. 75 p.

U. S. Public Health Service. 1962. Drinking water standards. Title 42 - Public Health, Chapter 1 - Public Health Service, Dept. of Health, Education, and Welfare, Part 72 - Interstate Quarantine. Federal Register 2152.

Zavitkovski, J. and M. Newton. 1971. Litterfall and litter accumulation in red alder stands in western Oregon. Plant and Soil 35(2):257-270.

APPENDIX

Appendix Table 1. . Watershed Descriptions.

Watershed	Size (ha)	Stream Order at weir	Principal Exposure	Relative Location	Cover & Tree Age	Watershed Physiognomy	Treatment
Brush Creek Site: 32 km from ocean							
BT1	10.2	1st	N	upper Siletz River basin	+Alder: 65%, 30 to 80 yrs[1] D. fir: 5%, 1 to 80 yrs Grass & shrubs: 30%	Well-defined upper bench with channel connecting to Brush Creek	May '71 - 2.2 kg/ha Bk[2], 3/4 area and 4.4 kg/ha Bk, 1/4 area Apr '72 - 4.4 kg/ha Bk, entire area Aug '72 - 4/4 kg/ha 2,4,5-T[3] on 1/2 area, on salmonberry
BT2	9.3	2nd	N	adjacent to BT1	+Alder: 94%, 30 to 80 yrs D. fir: 2%, 1 to 80 yrs Grass & shrubs: 4%	Sloping trough-shaped drainage with a slump moving down the channel; channel deeply incised	May '71 - 2.2 kg/ha Bk, 2/3 area and 4.4 kg/ha Bk, 1/3 area Apr '72 & Aug '72 - same as BT1
BC1	4.8	1st	NNE	3 km from Brush Creek; upper Yaquina River basin	Alder: 87%, 30 to 80 yrs D. fir: 6%, 35 yrs Shrubs: 7%	Steep, tilted plane with several benches and stream surfacing at base; water impoundments caused by logging road	Control
BC2	29.1	3rd	N	5 km from Brush Creek; upper Yaquina River basin	Alder: 55%, 35 to 100+ yrs D. fir: 32%, 35 to 100+ yrs Grass & salal: 6%	Incised channels draining gently-sloping, undulating uplands	Control
D9	total: 15.9 trt: 9.2	2nd	S	opposite slope of BT1 & 2; adjacent to Big Alder	Logged (60%): *Alder: 50%, 80 yrs *D. fir: 10%, 80 yrs Residual, 40%: Alder: 1%, 80 yrs D. fir: 36%, 22 Grass & sedge: 3%	Fan-shaped, steep watershed with one prominent and two lesser source areas; numerous skid trails down to subsoil	Spring '72 - clearcut logged except ridges Apr '72 - 4.4 kg/ha Bk, 1/2 logged area Aug '72 - 4.4 kg/ha 2,4,5-T, entire logged area

(Continued on next page)

Appendix Table 1. (Continued)

Watershed	Size (ha)	Stream Order at weir	Principal Exposure	Relative Location	Cover & Tree Age	Watershed Physiognomy	Treatment
Big Alder Source Area	6.2	1st	W (shaded)	Adjacent to D9 & BT1	Alder: 10%, 22 yrs D. fir: 10%, 22 yrs Vine maple: 30% Sword fern: 20% Grass & sedge: 30%	Trough-shaped, flat bottomed source area with surface flow emerging 20 m from weir	'68 - clearcut logging, 1/4 area Winter '72 - thinned, 1/4 area and clearcut, 1/3 area Aug '72 - 4.4 kg/ha 2,4,5-T, 2/3 area
Depot Creek Site: 10 km from ocean							
ST1	12.5	2nd	W	8 km NW Yaquina Bay	*Alder: 38%, 45 yrs *D. fir: 60%, 45 yrs Salal & grass: 2%	Gently sloping, undulating topography with marshy area by weir	Spring '71 - 2.2 kg/ha Bk, entire area Summer '71 - clearcut logged, entire area
ST2	total: 15.5 trt: 9.3	2nd	W	Adjacent to ST1	Logged (60%): *Alder: 55%, 45 yrs *D. fir: 5%, 45 yrs Residual (40%): Alder: 8%, 45 yrs D. fir: 24%, 45 yrs Salmonberry: 6% Grass: 2%	Same as ST1	Spring '71 - 2.2 kg/ha Bk, 2/3 area Summer '71 - clearcut logged, 2/3 area
SC1	6.2	2nd	WNW	2.4 km N of ST1 & 2	Alder: 67%, 16 to 45 yrs D. fir: 32%, 45 yrs Grass & salal: 1%	Same as ST1	Control
SC2	5.4	2nd	WNW	Adjacent to SC1	Alder: 51%, 16 to 45 yrs D. fir: 43%, 45 yrs Grass & salal: 6%	Same as ST1	Control

(Continued on next page)

Appendix Table 1. (Continued)

Watershed	Size (ha)	Stream Order at weir	Principal Exposure	Relative Location	Cover & Tree Age	Watershed Physiognomy	Treatment
Drift Creek Site: 7 km from ocean							
HT1	8.5	2nd	ENE	2.4 km from Alsea Bay	*Alder: 60%, 65 yrs *D. fir: 20%, 65 & 200+ yrs Salmonberry: 20%	Fan-shaped, with upper bench as source area and deeply incised channels leading from source area	Winter '71 - clearcut logged, entire area Spring '71 - 2.2 kg/ha Bk, entire area Sept '71 - slash burn, entire area Spring '72 - 50 m powerline strip seeded to grass with fertilizer
HT2	1.8	1st	ENE	Adjacent to HT1	*Alder: 50%, 65 yrs *D. fir: 40%, 65 & 200+ yrs Clear: 10%	Steeply sloping trough with clear area due to eroding stream	Same as HT1
HC1	1.2	1st	NNE	Same slope as HT1 & 2	Alder: 35%, 65 yrs D. fir: 60%, 65 & 200+ yrs Clear: 5%	Same as HT2	Control
HC2	10.3	2nd	NNE	Adjacent to HC1 and H1	Alder: 84%, 65 yrs D. fir: 14%, 65 & 200+ yrs Salmonberry: 2%	Same as HT1	Control

---

[1] + = Dead; * = Logged

[2] Bk stands for "Brushkiller," a commercial mixture of 2,4-D(2,4-dichlorophenoxyacetic acid) and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) herbicides.

[3] 2,4,5-T stands for the herbicide 2,4,5-trichlorophenoxyacetic acid.

Appendix Table 2. Chemical descriptions of soils used in incubation study.

Soil	Cation Exchange Capacity (meq/100 g)	Extractable Cations				Organic Matter (%)	Total N (%)	C:N Ratio	pH	SO_4 (ppm)	NO_3 (ppm)
		meq/100 g		ppm							
		Ca	Mg	K	NH_4						
red alder	30.4	8.2	3.1	523	16.6	13.3	0.39	19:1	5.4	2.0	9.4
Douglas-fir	24.8	14.8	7.3	283	10.5	2.5	0.13	11:1	6.0	8.5	2.1
D9 May	40.9	10.2	4.9	856	12.6	15.7	0.45	20:1	5.5	2.3	6.4
D9 October	36.5	8.1	5.0	884	23.3	13.6	0.39	20:1	5.3	3.5	42.5

Appendix Table 3. Averages and maximum-minimum values of soil moisture holding capacities (percent of oven dry weight) of soils used in incubation study.

Soil	Saturated	Field Capacity (.3 atm)	Mid (2 atm)	Wilting Point (15 atm)
red alder	83.2 (83.8-82.8)	44.7 (45.4-44.0)	36.4 (37.0-35.8)	26.9 (27.1-26.4)
Douglas-fir	79.3 (81.8-77.4)	40.5 (42.8-39.9)	33.9 (34.2-33.6)	23.8 (24.3-23.5)
D9 May	95.5 (99.1-94.3)	47.0 (47.3-46.5)	---	---
D9 October	79.4 (86.5-78.1)	44.8 (46.0-42.8)	37.3 (37.8-36.8)	27.5 (27.9-27.2)

Appendix Table 4 . Averages and maximum-minimum values in stream water from disturbed and undisturbed upland watersheds in Oregon's Coast Range.

Watershed	Specific Conductance	Predicted Total Anions	Bicarbonate		Nitrate		
	(µmhos/cm)	(meq/liter)	(meq/liter)	(ppm)	(meq/liter)	(ppm)	(ppm N)
			Herbicide				
BT1	65.9	0.58	0.37	22.6	0.07	4.0	0.9
	(85.5-46.7)	(0.76-0.41)	(0.53-0.19)	(32.3-11.6)	(0.16-0.04)	(9.7-2.2)	(2.2-0.5)
BT2	63.0	0.56	0.29	17.7	0.12	7.5	1.7
	(76.9-51.3)	(0.68-0.45)	(0.41-0.17)	(25.0-10.4)	(0.20-0.06)	(12.4-3.5)	(2.8-0.8)
			Undisturbed Control				
BC1	80.3	0.71	0.42	25.6	0.14	8.5	1.9
	(100.0-60.6)	(0.89-0.54)	(0.57-0.23)	(34.8-14.0)	(0.20-0.08)	(12.4-4.9)	(2.8-1.1)
BC2	56.5	0.50	0.28	17.1	0.06	3.5	0.8
	(74.1-49.0)	(0.66-0.43)	(0.51-0.18)	(25.0-11.0)	(0.14-0.03)	(8.8-1.8)	(2.0-0.4)
			Partial Clearcutting & Herbicide				
D9	105.7	0.94	0.72	43.9	0.06	4.0	0.9
	(166.7-57.5)	(1.48-0.51)	(1.34-0.17)	(81.7-10.4)	(0.21-0.01)	(12.8-0.4)	(2.8-0.1)
Alder	47.3	0.42	0.26	15.9	0.03	1.8	0.4
	(77.0-23.2)	(0.68-0.21)	(0.31-0.19)	(18.9-11.6)	(0.08-0.01)	(4.9-0.4)	(1.1-0.1)
			Herbicide & Clearcutting				
ST1	52.9	0.47	0.16	9.8	0.03	2.2	0.5
	(76.9-37.0)	(0.68-0.33)	(0.25-0.09)	(15.2-5.5)	(0.06-0.01)	(4.0-0.4)	(0.9-0.1)
ST2	54.6	0.48	0.16	9.8	0.03	1.8	0.4
	(75.8-46.5)	(0.67-0.39)	(0.23-0.08)	(14.0-4.9)	(0.06-0.01)	(3.5-0.4)	(0.8-0.1)

(Continued on next page)

Appendix Table 4 . (Continued)

Watershed	Specific Conductance (µ mhos/cm)	Predicted Total Anions (meq/liter)	Bicarbonate (meq/liter)	Bicarbonate (ppm)	Nitrate (meq/liter)	Nitrate (ppm)	Nitrate (ppm N)
			Undisturbed Control				
SC1	53.2 (66.7-46.5)	0.47 (0.61-0.40)	0.13 (0.30-0.09)	7.9 (18.3-5.5)	0.05 (0.11-0.01)	3.5 (7.1-0.9)	0.08 (1.6-0.2)
SC2	48.4 (66.7-28.0)	0.43 (0.59-0.25)	0.14 (0.30-0.09)	8.5 (18.3-5.5)	0.03 (0.06-0.01)	1.8 (4.0-0.4)	0.4 (0.9-0.1)
			Clearcutting, Herbicide & Slash Burning				
HT1	62.7 (121.9-46.5)	0.56 (1.08-0.41)	0.20 (0.27-0.09)	12.2 (16.5-5.5)	0.08 (0.19-0.01)	4.9 (11.5-0.4)	1.1 (2.6-0.1)
HT2	71.7 (89.3-14.4)	0.64 (0.79-0.13)	0.31 (0.50-0.13)	18.9 (30.5-7.9)	0.06 (0.20-0.01)	4.0 (12.4-0.4)	0.9 (2.8-0.1)
			Undisturbed Control				
HC1	83.0 (100.0-58.5)	0.74 (0.89-0.51)	0.32 (0.46-0.26)	19.5 (28.1-15.9)	0.12 (0.07-0.01)	7.1 (10.6-1.3)	1.6 (2.4-0.3)
HC2	62.9 (76.9-56.8)	0.56 (0.68-0.49)	0.15 (0.20-0.12)	9.1 (12.2-0.73)	0.14 (0.21-0.08)	8.9 (12.8-4.4)	2.0 (2.9-1.0)