Chapter X

NUTRIENTS

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INTRODUCTION

Much concern has been expressed over nutrient additions to streams following silvicultural activities. Of the nutrients, nitrogen and phosphorus generally have the greatest impact upon water quality. Introduction of nitrogen and phosphorus to forest streams may result in enrichment of the receiving waters (i.e., eutrophication), as these two chemicals are normally limiting factors in the production of aquatic vegetation. Accelerated additions of nutrients to streams following silvicultural activities may result in accelerated eutrophication and adversely affect stream water quality. In other cases, however, enrichment of streams may be beneficial, particularly in streams relatively devoid of dissolved nutrients in their natural state.

Streams may show symptoms of overenrichment; however, there is usually minimal opportunity for a buildup of these nutrients in the stream system because of the continual transport of water and the normally brief period of increased nutrient influx to the stream. Other nutrients rarely cause water quality problems. This discussion, therefore, is limited to nitrogen and phosphorus. (For additional information on the nutrient cycle, see appendix X.A.)

Research conducted throughout the United States and Canada has found that nutrient outflux following silvicultural activity usually does not result in any measurable deterioration of water quality. The most notable exception is the Hubbard Brook experimental watershed in New Hampshire. This was, however, an extreme experimental treatment and not a normal silvicultural activity. Based upon existing research, it can be concluded that nutrient release associated with silvicultural activities may occur; but resulting concentrations of nitrogen and phosphorus will normally not be great enough to adversely affect the water quality of the receiving forest streams.

Quantification of nitrogen and phosphorus influx into a watercourse, given a specific site and proposed silvicultural activity, is not possible at this time. There are no available models capable of accurately predicting the total nutrient addition to streams due to silvicultural activities. The soluble component of the nutrient outflux can be examined presently only through a comparison of those nutrients contributed by silvicultural activities with those nutrients contributed by other land management practices. The insoluble component can be estimated with cautious use of one available model.

DISCUSSION

SOLUBLE COMPONENT EVALUATION

Numerous studies have been made of the relationship between streamflow and chemical load in the stream. The dilution theory principle (an average relationship between dissolved chemical load and stream discharge) is now widely accepted. A number of models have been proposed to describe the dilution theory (Carson and Kirkby 1962, Hendrickson and Krueger 1964, Toler 1965, Hem 1970, Hall 1971, Betson and McMaster 1975). However, this theory assumes both a relatively constant source of dissolved nutrients and a constant rate of release by weathering, independent of the volume of water passing through the soil. These models, therefore, are not suitable for evaluating nutrient outflux due to silvicultural activity because release is variable, depending upon vegetation uptake and microbiological processes.

The Loehr Study

In lieu of an adequate model, an evaluation of the relative impacts of non-point source nutrient pollution from silvicultural activities and other land uses has been published by Loehr (1974) and is presented here. Loehr compared available information on characteristics and relative magnitudes of certain non-point sources entering surface waters and commented on the feasibility of controlling these sources. Concentrations of organic and inorganic compounds representative of the range that could be anticipated from various non-point sources were compared. Loehr's results are displayed in figure X.1 and indicate that concentrations of nitrogen and phosphorus lost from forest lands approximate those found in precipitation. Additional data to support Loehr's findings are presented in figure X.2, and appendix X.B. Loehr's findings have been confirmed by all the data with the exception of the data from the Hubbard Brook experiment.

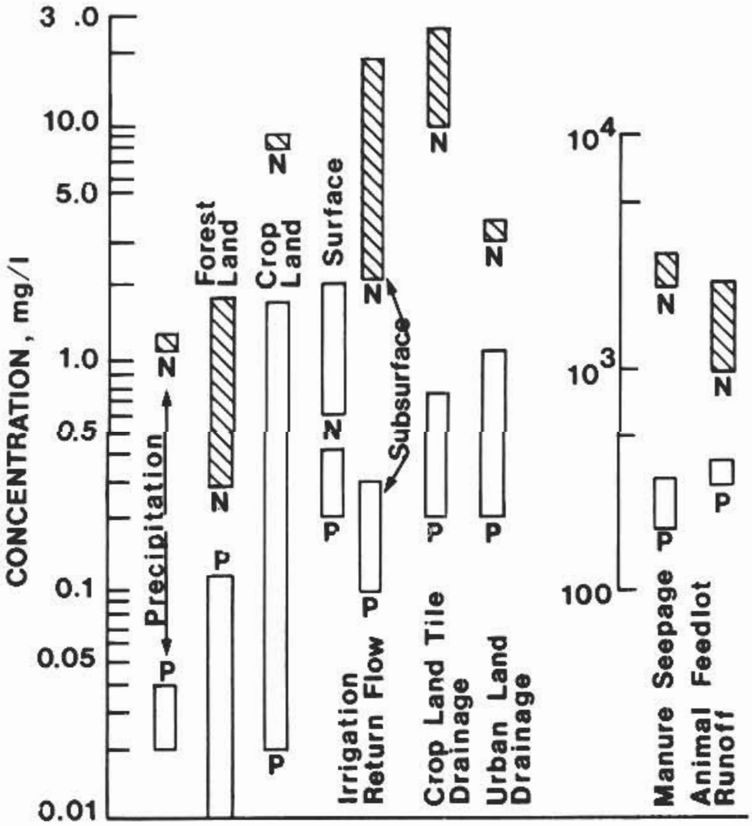

Figure X.1.—Range of total N and P concentrations found in various non-point sources (after Loehr 1974).

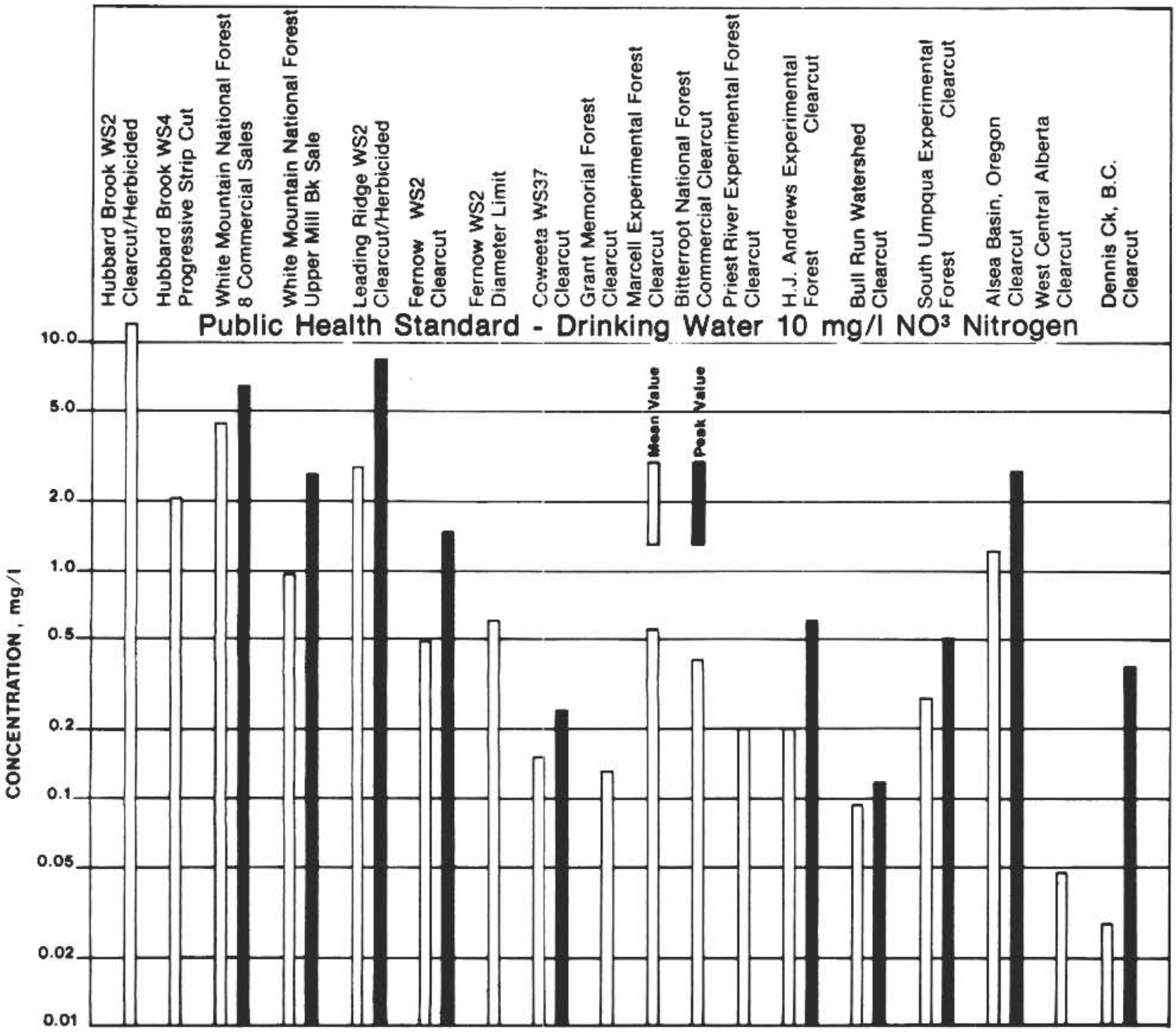

Figure X.2.—Summary of studies undertaken to quantify nitrogen release following silvicultural activities (see appendix X.B. for a more complete discussion of individual studies).

The Hubbard Brook Study

The potential problem of nutrient pollution in streams due to timber harvesting was made apparent in the late 1960's by a research study conducted at the Hubbard Brook Experimental Watershed in New Hampshire. The study was designed to quantify maximum water yield on a small watershed. This was done by cutting, limbing the fallen trees, and scattering the debris. However, none of the material was removed from the site. Herbicides were applied for 3 years following the cut to prevent reestablishment of vegetation. The nutrient outflow from the experimental area was measured. Following the treatment, concentrations of nutrients in the stream were significantly increased. Concentrations of $NO_3^-{-}N$ (nitrate-nitrogen) were recorded which exceeded recommended public health drinking water standards of 10 mg/l by almost a factor of 2 (Likens and others 1970).

This study represents the application of an extreme treatment and not a normal silvicultural activity. Its results have been verified by other studies, although the magnitude of the changes in nutrient release has not been as great in other studies. The conditions under which the Hubbard Brook study was conducted show that significant water quality degradation is possible if (1) all vegetation is killed, (2) revegetation is prevented by application of herbicides, and (3) the soils are coarse textured, with a low cation exchange capacity. These conditions do not normally exist under prevalent land management practices. Silvicultural activities are presently constrained so that devegetation of a complete watershed is not generally a viable land management option. In addition, the application of herbicides to prevent revegetation is contrary to normal forestry operations. Finally, many forest soils have a greater capacity to fix nitrogen and phosphorus, or otherwise prevent the loss of nutrients from a site.

INSOLUBLE COMPONENT EVALUATION

Nitrogen in the soil is primarily organically bound and is not readily transported in solution. Nitrate and ammonium ions are available and can be transported in solution in the soil water and eventually reach a watercourse. The nitrate ion (NO_3^-) is the principal dissolved nitrogen form lost from the forest ecosystem; the ammonium ion (NH_4^+) is ordinarily strongly adsorbed to exchange surfaces and is not readily lost. However, these available forms of nitrogen — NO_3^- and NH_4^+ — make up only a small proportion of the total nitrogen present in soil.

Phosphorus in soil may be present in the organic or inorganic form. The soluble inorganic forms derived from chemical weathering or decomposition of organic matter are readily immobilized in the soil and are not easily leached from it. The primary mode of transport for organic forms of both nitrogen and phosphorus is surface erosion.

Outflux of insoluble, precipitated or adsorbed, organic nitrogen and total phosphorus can be estimated in a manner proposed by Midwest Research Institute in their report to EPA (McElroy and others 1976). As proposed by Midwest, "loading" functions for organic nitrogen and total phosphorus can be estimated based upon the "sediment loading" function derived from a modified version of the Universal Soil Loss Equation. Concentrations of total nitrogen and phosphorus in the surface foot of soil can be obtained from existing general maps (figs. X.3 and X.4), from regional or local Soil Conservation Service data, or by actual measurement. The Midwest model includes an enrichment ratio that is based upon the soil texture and organic matter content. The general loading function is:

$$Y = aSCr$$

where:

- Y = total loading (organic and adsorbed nitrogen or total phosphorus) from surface erosion, lbs/ac/yr (kg/ha/yr),
- a = dimensional constant (20 for English units or 10 metric units),
- S = sediment loading from surface erosion, tons/ac/yr (MT/ha/yr),
- C = total (organic nitrogen or total phosphorus) concentration in surface foot of soil, g/100g,
- r = enrichment ratio, nitrogen values generally range from 2 to 5, and phosphorus values range from 1 to 3, with an average value of 1.5. The enrichment ratio is the concentration of nitrogen or phosphorus in the eroded material divided by its concentration in the soil proper (Massey and others 1953, Stoltenberg and White 1953).

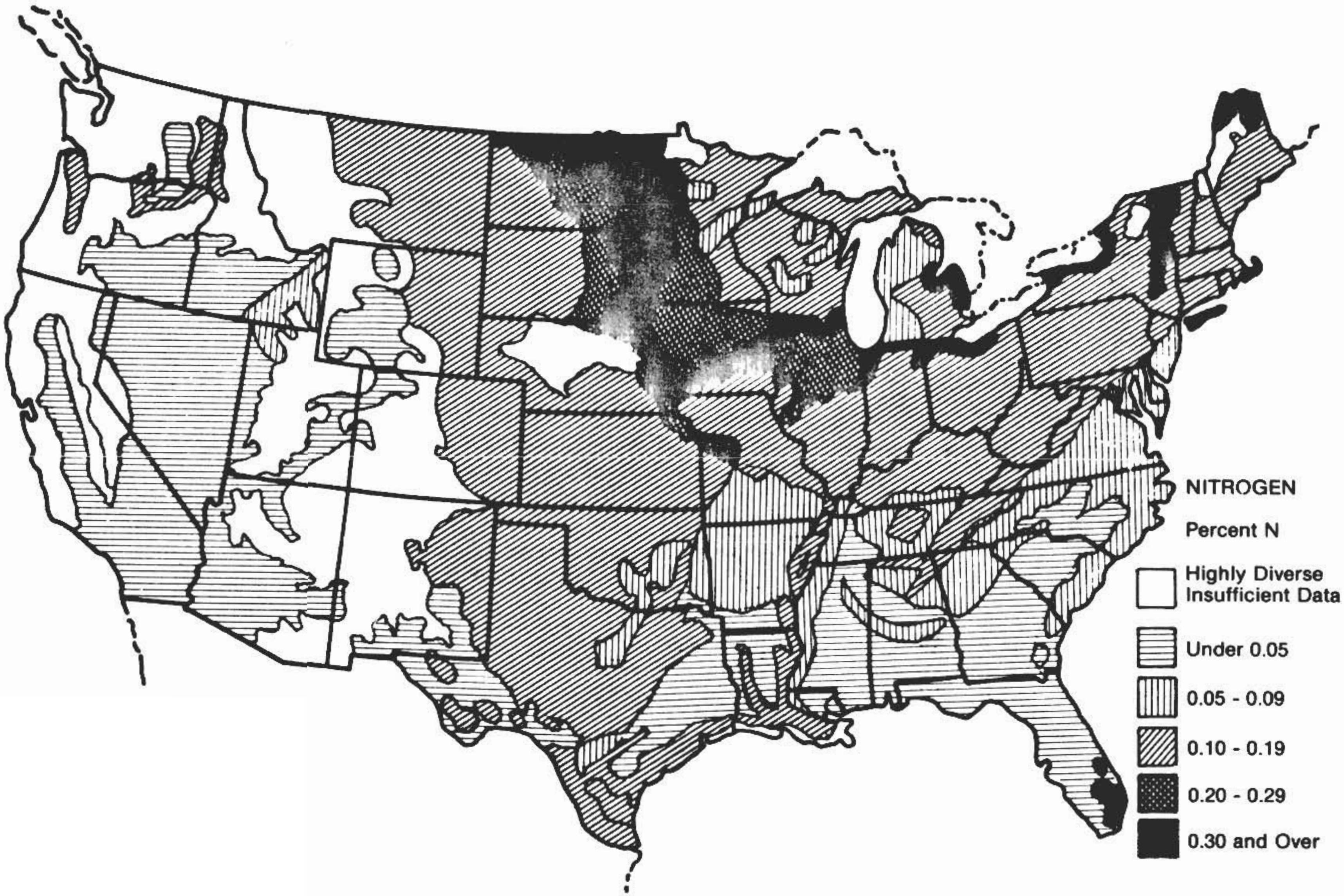

Figure X.3.—Percent nitrogen (N) in surface foot of soil (after Parker 1946).

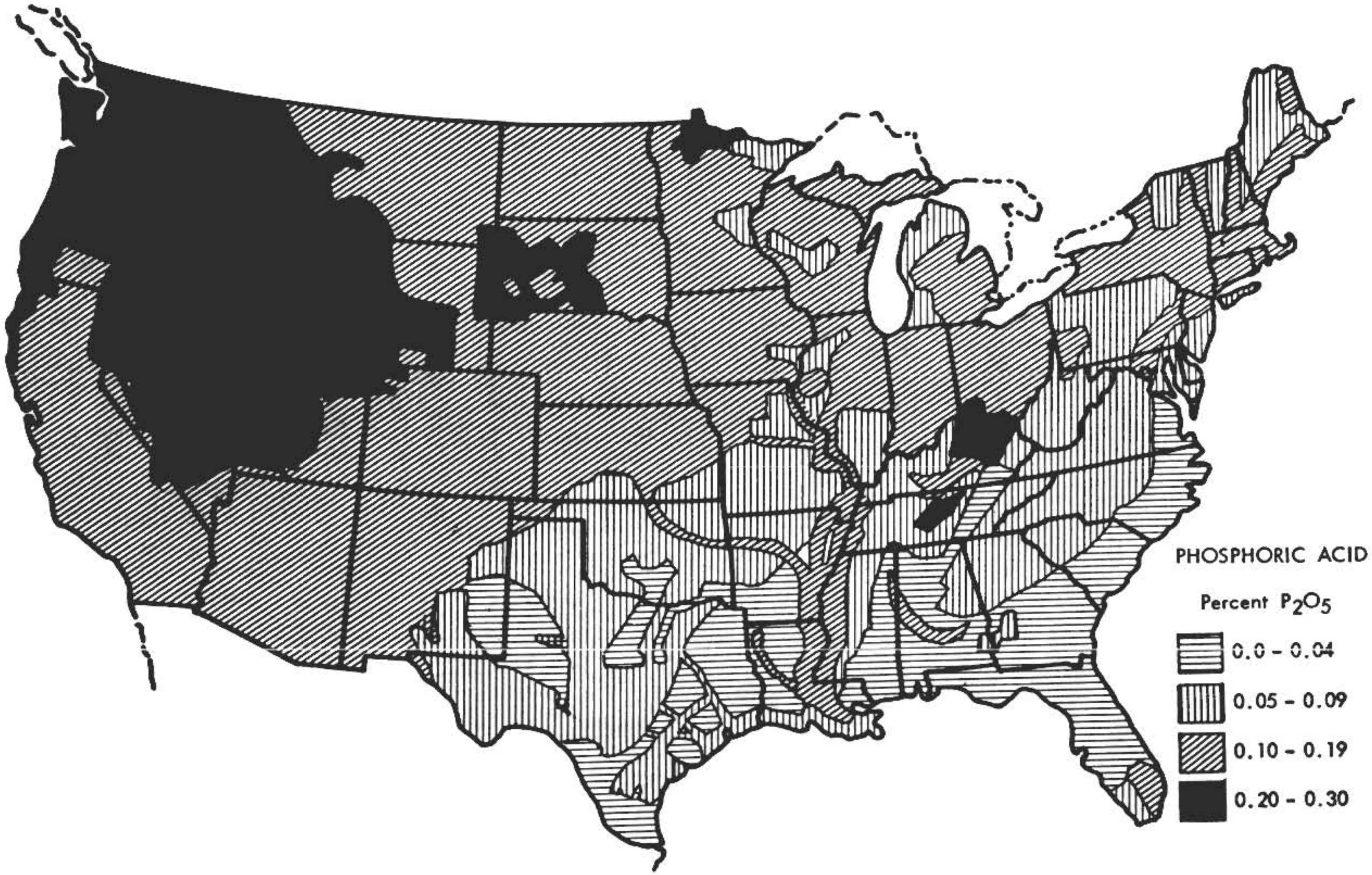

Figure X.4.—Percent phosphorus (P_2O_5) in surface foot of soil (after Parker 1946).

APPLICATIONS, LIMITATIONS, AND PRECAUTIONS

The insoluble component model represents the current state-of-the-art; however, it has not been adequately tested in forested situations and should be used with caution.

CONCLUSIONS

Reinhart (1973), Loehr (1974), Patric and Smith (1975), and Sopper (1975) evaluated available studies and concluded that normal silvicultural operations do not raise nitrogen and phosphorus concentrations above public health standards for drinking water. Loehr (1974) concluded:

> Control of forest land runoff and range land runoff does not appear to be necessary at this time because the concentrations and yields of constituents are comparable to those of precipitation. These two non-point sources, forest runoff and range land runoff, may generally be considered as background sources unless current practices or available data change drastically.

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APPENDIX X.A:
DETAILED DISCUSSION OF THE NUTRIENT CYCLE

The forest nutrient cycle is generally segmented into three compartments — input, intracycle, and output. The action and interaction of the major compartments of the process are depicted in figure X.A.1. Placing the nutrient cycle in such a format forces the investigator to consider the processes and variables that are likely to be impacted by silvicultural activities and the effect that these changes will have on soil and water chemistry.

INPUT TO THE NUTRIENT CYCLE

Nutrient inputs to a forest ecosystem come principally from (1) the atmosphere, (2) the soil and underlying bedrock, and (3) depositions by floods on alluvial terraces. Alluvial deposition is not a dominant nutrient input factor for many of the forested areas. Man enters the cycle with fertilizer additions.

Atmosphere

Atmospheric inputs account for most of the nutrients entering the cycle, usually during a precipitation event, in the form of dissolved gases, aerosols, and solid particulate matter. Nonprecipitation events, commonly referred to as dry fall, also contribute solid particulate matter; and in some areas, aerosols are carried by prevailing winds and storm tracts from cities, industrial centers, and agricultural lands, then deposited on the forest without benefit of a precipitation event (U.S. Senate Hearings 1971, Jorgensen and others 1975). Deposition of dry fall and aerosols may occasionally be extensive during initiation of a precipitation event, when these materials are "washed" from the atmosphere. In any event, precipitation falling on a forested area is not chemically pure water but may contain many chemical compounds, ranging from beneficial nutrients (such as nitrogen) to deleterious acid compounds (U.S. Senate Hearings 1971). An extensive coverage of the addition of acidic materials to the forest ecosystem can be found in the "Proceedings of the First International Symposium on Acid Precipitation and the Forest Ecosystem" (Dochinger and Seliga 1976).

Atmospheric Nitrogen

Precipitation contains significant quantities of numerous substances including nitrogen; one of the primary sources of nitrogen input to the forest ecosystem is through the atmosphere (fig. X.A.1). Nitrogen occurs in the gaseous form — principally as N_2, NO, NO_2 and NH_3, and in aerosols — as NH_4^+ and NO_3^-. However, the gaseous nitrogen form N_2 is considered inert and cannot be directly utilized by most organisms. Biological fixation by microorganisms during the intracycle process (discussed in detail in "The Intracycle Process") converts free nitrogen to the ammonia form which is then utilized in biological functions.

The compounds named are naturally produced; however, increasingly large concentrations of them are the result of industrial activities, vehicle exhausts, and agricultural operations (Feth 1966, Robinson and Robbins 1970). Transport of relatively large quantities of nitrogenous compounds from various concentrated pollutant sources by prevailing winds or storms has resulted in the deposition of large amounts of these materials (Likens and others 1976). Such deposition occurs not only as dissolved and particulate matter in precipitation, but it also occurs during nonprecipitation periods as dry fall and aerosol deposition. Junge (1958) reported a nationwide survey of ammonium and nitrate in rainwater over the United States. The study indicated that concentrations of NH_4^+ and NO_3^- varied markedly. Nitrogen input values have been estimated for the United States and are presented in figure X.A.2. It should be noted that the values are based on regional averages and specific sites can differ markedly from the regional values due to local conditions.

Electrochemical and photochemical fixation, lightning, and radiation convert a limited amount of elemental nitrogen to available inorganic forms.

Atmospheric Phosphorus

Precipitation may also be a source of phosphorus input into the system, but the quantities involved can generally be assumed to be minor in comparison to those from the weathering of soil and rock (Tabatabai and Laflen 1976).

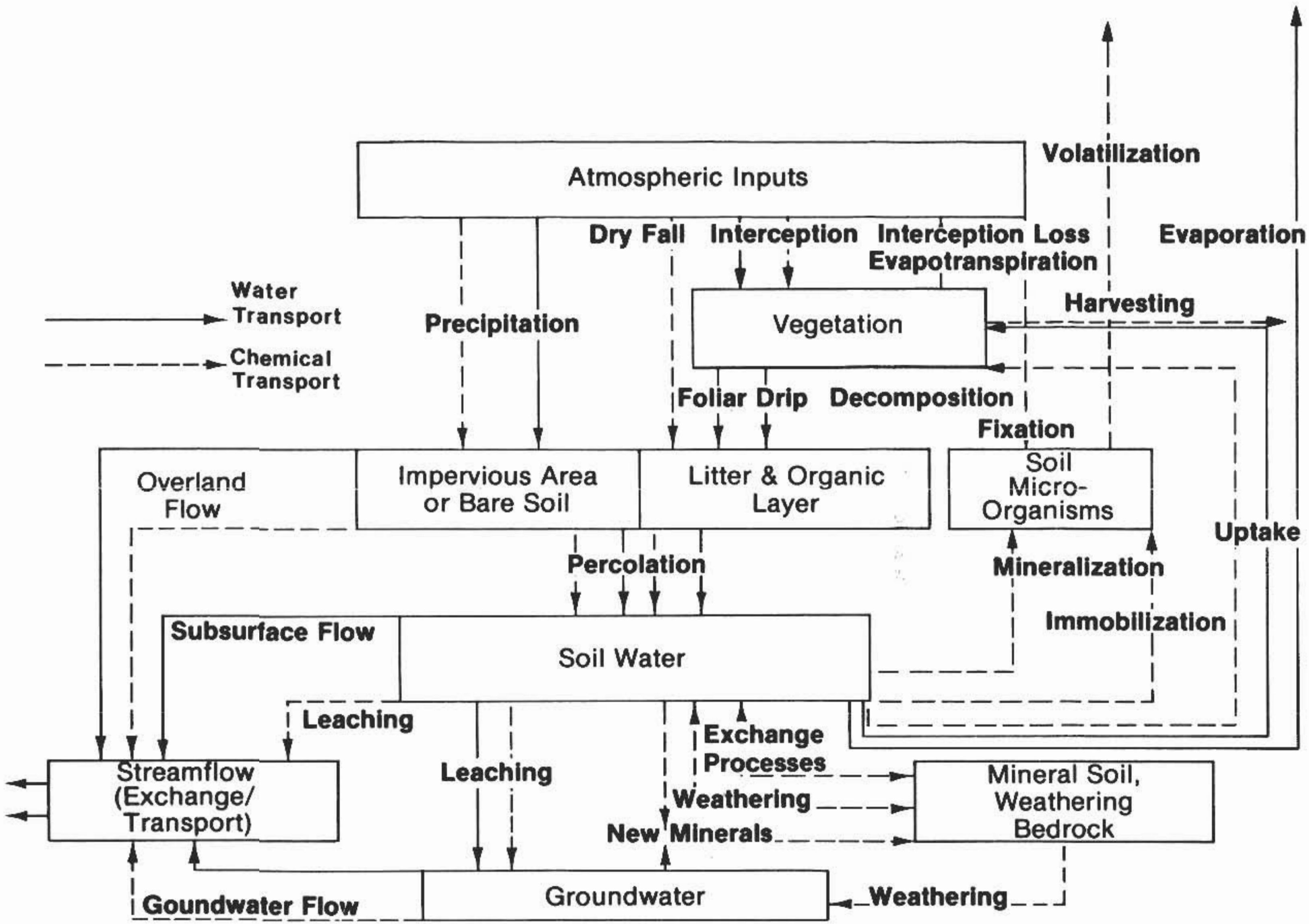

Figure X.A.1—Biochemical cycle for nitrogen in a forest.

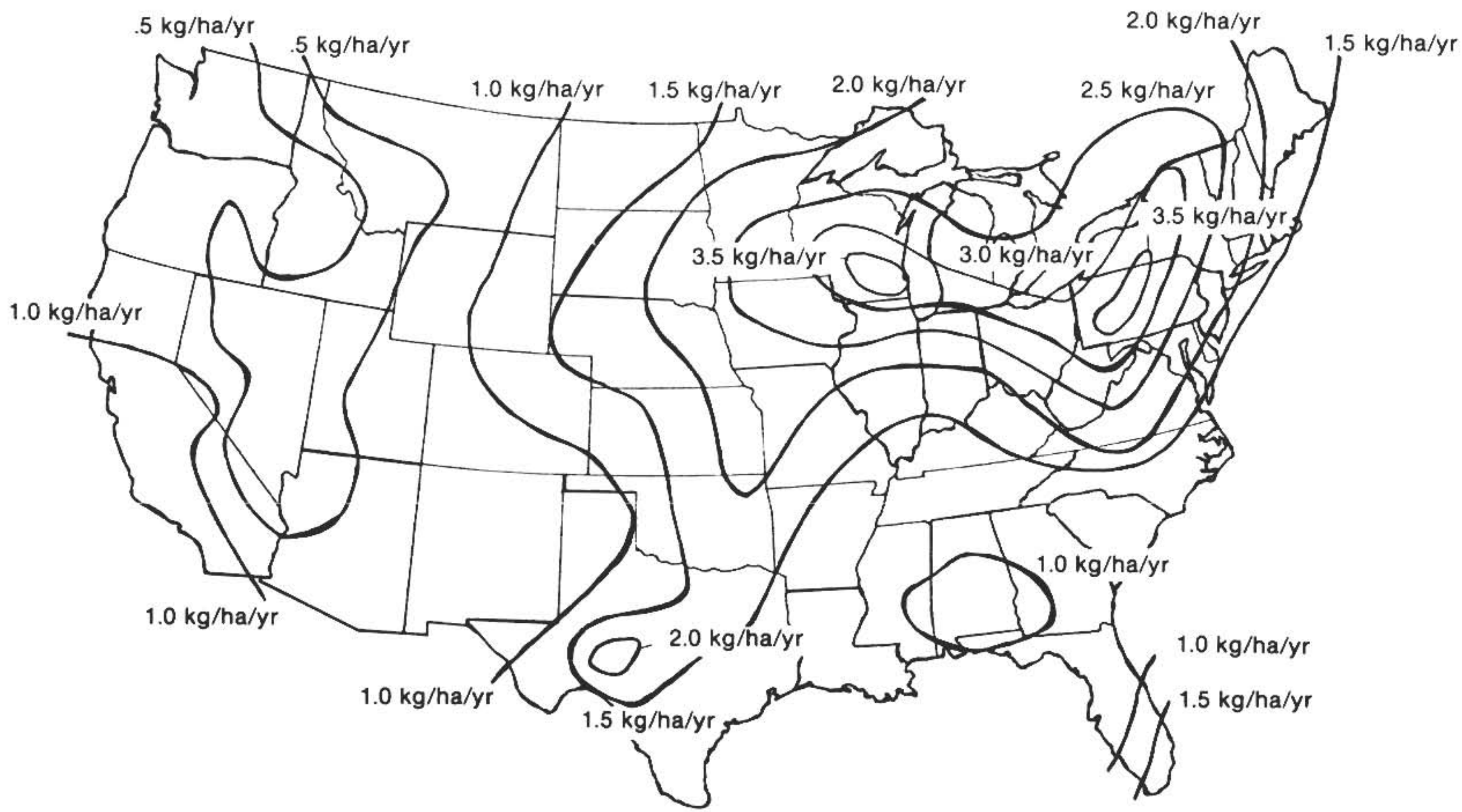

Figure X.A.2.—Nitrogen (NH_4^+ and NO_3^-) in precipitation.

Soil and Rock

Chemical decomposition and physical weathering of the soil and bedrock continually release nutrients to the ecosystem. Soil and bedrock are the principal sources of metallic cations, phosphorus, and trace metals.

Soil. — Weathering and decomposition of the solum and regolith add significant amounts of nutrients to the forest and the intracycle processes. Weathering and decomposition occur much more rapidly within the upper soil horizons (i.e., rooting zone) where plants, animals, bacteria, and soil fungi all contribute to decomposition of the soil and secondary minerals, and where the physical processes, particularly freezing and thawing, accelerate the weathering of the soil and rock (Lutz and Chandler 1961).

Bedrock. — Geologic weathering and decomposition of bedrock are not primary sources of nutrient input to the forest ecosystem over a short period (i.e., timber rotation age), in that nutrients released from rock do not normally enter the forest ecosystem directly through the intracycle processes, but are removed from the system via deep ground water. An exception occurs when the root zone penetrates to bedrock.

Nitrogen Inputs From Soil and Rock

Geologic formations do not have large amounts of nitrogen present, so nitrogen inputs to the forest ecosystem from geologic weathering and chemical decomposition are insignificant, especially when compared with nitrogen inputs from the atmosphere.

Phosphorus Inputs From Soil and Rock

Phosphorus input to the forest ecosystem comes almost exclusively from chemical decomposition of rocks. Phosphorus is estimated to rank eleventh among elements in igneous rocks. It occurs in all known minerals as phosphates (McCarty 1970). Apatites, the principal minerals containing phosphorus, are found in almost all igneous and sedimentary rocks. Phosphorus in soil can be classed generally as organic or inorganic. Phosphorus is found predominantly in the mineral fraction in combination with a heavy metal, iron, aluminum, or magnesium (McElroy and others 1976).

Forest Fertilization

Introduction of nitrogen and phosphorus to the forests by fertilization can be a potentially significant input source. However, at the present time forest fertilization has not been extensively undertaken and has been limited to the Pacific Northwest and to the Southeast. Fertilization is the only major nitrogen input source that the forest land manager can control. A more complete evaluation of its use and potential water quality degradation is presented in "Chapter XI: Introduced Chemicals."

The introduction of phosphorus to the forest by fertilization may also be a significant input in some locations but, as mentioned previously, forest fertilization is not being applied to large acreages nationally. See "Chapter XI: Introduced Chemicals," for a more complex discussion.

THE INTRACYCLE PROCESS

Intracycle processes (fig. X.A.1) are numerous and varied. Nutrients entering the ecosystem in available form are utilized by vegetation and animals and become unavailable (i.e., they become stored nutrients). The transfer rate of nutrients between living organisms (vegetation and animal), forest floor, and mineral soil is dependent upon the nutrient's chemical and physical characteristics and physiological function (Jorgensen and others 1975).

Intracycle Nitrogen

Mineralization

Mineralization, or ammonification, is accomplished by heterotrophic bacteria, actinomycetes, and fungi. These ammonifying microorganisms[1] metabolize organic nitrogen —

[1] *Two general groups of organisms fix nitrogen — symbiotic nitrogen fixers and free-living nitrogen fixers. Symbiotic organisms are associated with legumes, and several tree species, notably alder. The quantity of nitrogen fixed by symbiotic organisms exceeds that fixed by free-living nitrogen fixers by a factor of 100. Symbiotic nitrogen fixers are restricted to the terrestrial environment, whereas free-living nitrogen fixers are found in both terrestrial and aquatic environments. Azotobacter, Clostridium, and blue-green algae are the primary free-living nitrogen fixers (Stewart 1975, Weber and Gainey 1962, Kormondy 1976).*

amino acids, urea, uric acids and peptone (usually in the form of an amine group, $^-NH_2$) — to an inorganic form, ammonium. Excess ammonium produced by the organisms is released; some of this nitrogen is lost from the soil to the atmosphere as gaseous ammonia, NH_3 (Kormondy 1976).

Mineralization is the principal nitrogen process conducted by microorganisms in highly acidic soils. DeByle and Packer (1972) reported that nitrification rates were barely detectable in acid soils under a coniferous stand. They concluded that ammonium was probably the principal form of available nitrogen present and that because of its high solubility could easily be lost in deep seepage or overland flow.

However, most of the nitrogen remains within the forest ecosystem, being utilized by soil microorganisms or vegetation, becoming adsorbed on clay and organic colloids (through cation exchange), and by remaining in solution in the soil water (Bormann and Likens 1967).

Nitrification

Nitrification (fig. X.A.3) is the biological conversion of organic or inorganic nitrogen compounds from a reduced to a more oxidized state, NO_3^-. Although nitrification usually applies to autotrophic oxidation of ammonia or nitrate ions, numerous heterotrophs, including bacteria, algae, and fungi are known to oxidize organic nitrogen to nitrite or nitrate. It is generally acknowledged that the rate of nitrogen oxidation by heterotrophs is negligible compared to that by autotrophs. Autotrophic nitrifying bacteria are confined largely to Nitrosomonas (oxidation of NH_4^+ to NO_2^-) and Nitrobacter (oxidation of NO_2^- to NO_3^-); however, five other genera have also been shown to oxidize nitrogenous compounds. Adequate oxygen must be present for nitrification to occur. Nitrification has been detected in aquatic systems with approximately 0.3 ppm dissolved oxygen (Greenwood 1962).

For most soils, nitrification depends very much on pH. It usually decreases greatly at a pH below 6.0 and becomes negligible at a pH of 5.0 (Alexander 1967). The Hubbard Brook study, where nitrification rates were increased in an acid soil (pH 4) following a complete clearcut, is a particularly notable exception to the norm. It was hypothesized by the investigators that the increased nitrification rate was caused by a little known species of nitrifying bacteria adapted to more acid conditions (Likens and others 1970). Nitrate and nitrite, end products of the nitrification process, are the principal components of nitrogen outflux from the forest ecosystem. (This process is discussed in more detail under "Outputs From the Nutrient Cycle — Nitrogen Outflux" in this appendix.)

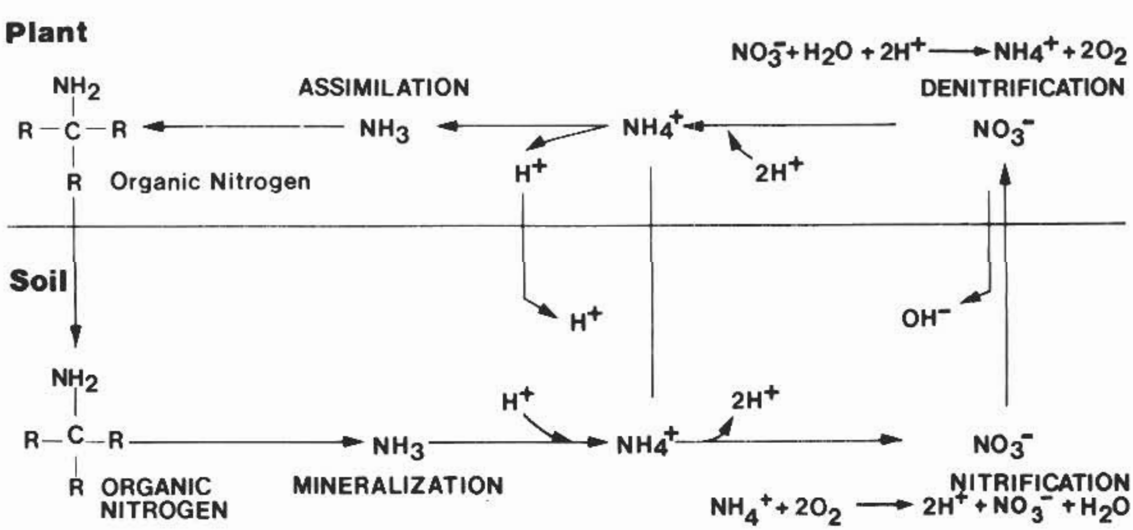

Figure X.A.3.—Simplified nitrogen cycle showing N utilized in the nitrate (NO_3^-) and ammonium (NH_4^+) forms and showing acid and base relations associated with the various processes (after Reuss 1976).

The intracycle nitrogen processes have been intensively investigated at the Coweeta Experimental Forest, North Carolina. A relatively undisturbed oak-hickory stand was selected, and a flow model of the nitrogen cycle for this forest was prepared. An estimate of the nitrogen pools, vegetation increments of nitrogen, and transfer rates among the various compartments was made and is illustrated in figure X.A.4. The model shows that most of the nitrogen in the undisturbed forest is contained in large storage pools that turn over slowly. Over 80 percent of the total nitrogen in this forest ecosystem is bound within soil organic matter, with about 11 percent in total vegetation, 3 percent in litter, 4 percent in microbial biomass, and 2 percent in free soil (Mitchell and others 1975, and Waide and Swank 1976).

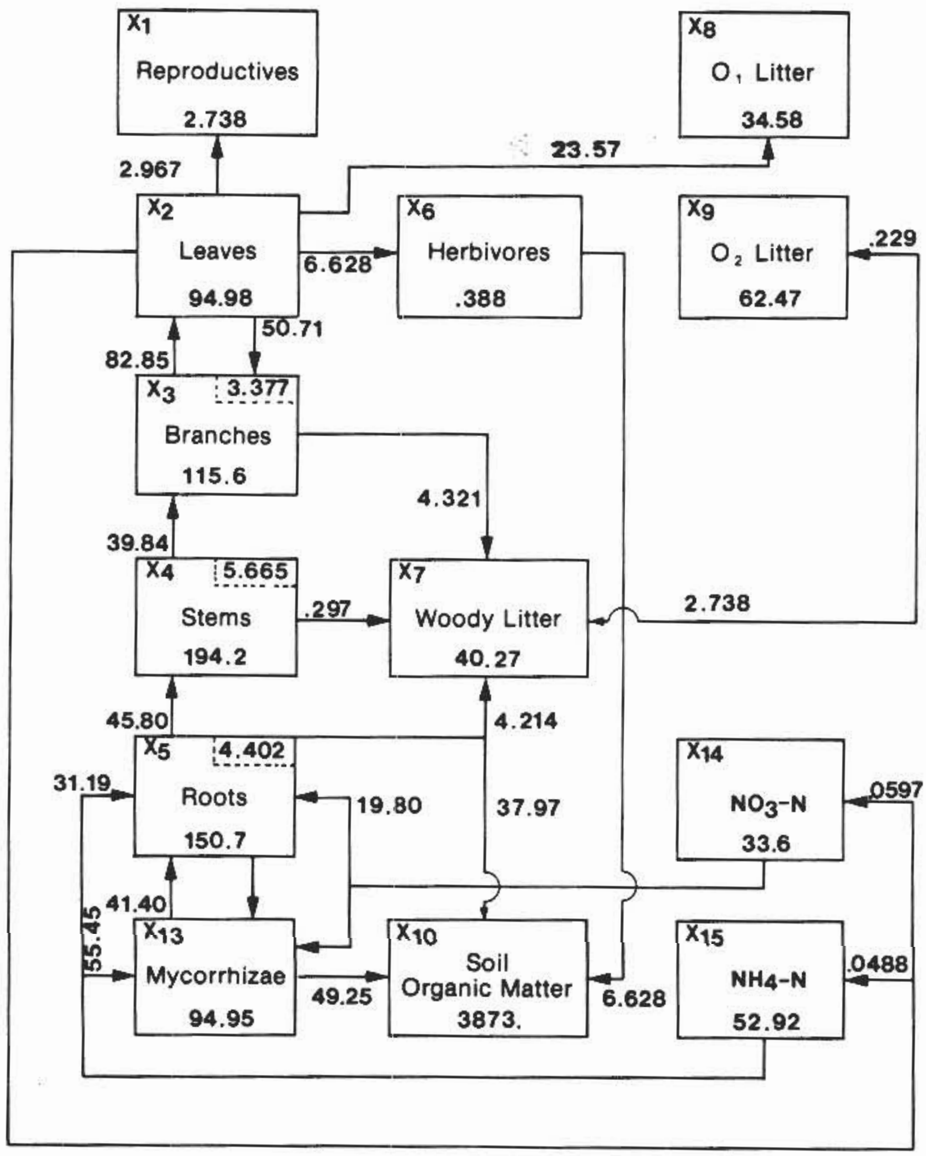

Figure X.A.4—Flow model of nitrogen cycling in an oak-hickory forest at Coweeta Experimental Forest, North Carolina. Values inside boxes represent standing crops of nitrogen (kg N/ha); values inside dotted lines are vegetation increments (kg N/ha/yr); numbers on arrows represent nitrogen transfers among compartments (kg N/ha/yr). This diagram shows nitrogen transfer associated with nitrogen uptake by plants and return to litter-soil pools (after Waide and Swank 1976).

Although the values presented in the flow model are valid only for the specific site studied, the flow model itself has general applicability to all forest types. Detailed analyses, similar to the one undertaken in this study, are necessary to quantify the actual amounts and rates of nitrogen in the cycle, but are not feasible except in a research environment. Forest managers could utilize the results of such studies to evaluate the potential impacts of changing the nitrogen cycle.

Intracycle Phosphorus

Phosphorus intracycle processes (figure X.A.5) are neither fully understood nor quantified. Research to date has been limited in scope to general processes and to site factors that influence them. Phosphorus occurs as both inorganic and organic compounds.

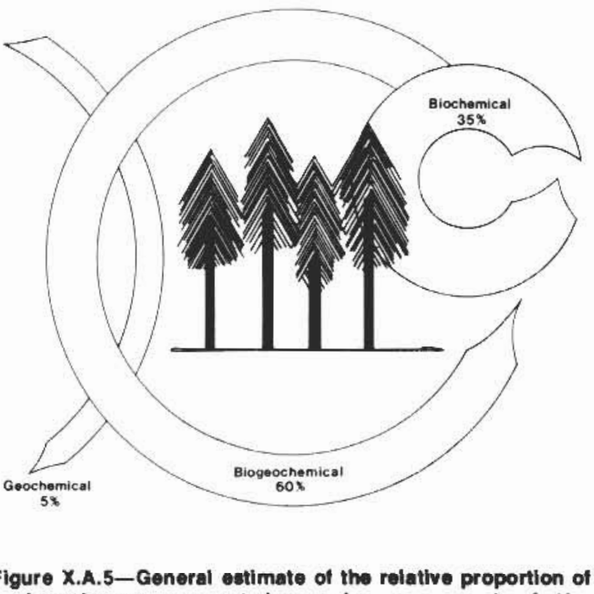

Figure X.A.5—General estimate of the relative proportion of phosphorus present in each component of the geochemical, biochemical, and biogeochemical cycles of loblolly pine plantation ecosystem, 20th year (after Switzer and Nelson 1972).

Organic Phosphorus

Organic phosphorus compounds found in forest soils and water are products of biochemical reactions. Almost no information is available to identify specific compounds or groups of compounds that may make up the dissolved organic phosphorus fraction of waters draining a forested ecosystem (Stumm and Morgan 1970). It has been estimated that about 40 to 50 percent of the organic soil phosphorus consists of nucleic acids, inositol phosphate and phospholipids; the remainder is largely unidentified. It is known that decomposition of organic matter results in the mineralization of organic phosphorus and the release of inorganic phosphate. Actual chemical reactions involved are not fully known.

Inorganic Phosphorus

Inorganic phosphorus compounds occur as condensed phosphates and orthophosphates. Condensed phosphates are generally manmade compounds but some are also generated by all living organisms. These latter compounds are unstable in water, where they are slowly hydrolyzed to the orthophosphate form (McCarty 1970).

Inorganic phosphate compounds generally react with metallic cations and clays present in soil to form complexes. Phosphate materials held by the soil may be loosely adsorbed and remain available to plants or may be firmly fixed and unavailable.

Acidic mineral soils generally contain appreciable quantities of adsorbed aluminum and smaller but significant amounts of iron and manganese. These ions combine with phosphates to form insoluble compounds that may be precipitated from soil solution or adsorbed on the surface of iron and aluminum oxides or on clay particles. The more acidic soils contain more adsorbed aluminum and iron; therefore, the products of phosphorus fixation are largely complex phosphates of iron and aluminum.

Another mechanism whereby phosphorus is fixed in the soil is the reaction of phosphates with silica clays. Phosphorus and polyphosphates are adsorbed onto clay minerals by chemical bonding of the anion to positively charged edges of the clays and by substitution of phosphates for silicate in the clay structure. In general, high phosphate adsorption by clays occurs at lower pH values (Stumm and Morgan 1970); in most soils phosphorus availability is at a maximum in the pH range 5.5 to 7.0 and decreases as the pH drops below 5.5 (Tisdale and Nelson 1966).

OUTPUTS FROM THE NUTRIENT CYCLE

Nutrients are naturally lost from the forest ecosystem in the form of dissolved or particulate matter in moving water or colluvium or both, through removal of the vegetation, through the diffusion or transport of gases or particulate matter by wind, and by fire or by animal activity. Gaseous exchange from the soil and vegetation to the atmosphere has not been extensively studied, but it does not appear that this would account for appreciable nutrient loss.

Dissolved Materials

Nutrients are lost from the system in overland flow, subsurface flow and ground water. Numerous studies have shown that overland flow rarely occurs within an undisturbed forest (Colman 1953); and even following silvicultural activities, overland flow does not normally contribute significantly to watershed discharge.

The chemical content of subsurface flow and ground water depends on both biochemical and geochemical cycles. Thus the chemical composition will vary regionally and seasonally depending on variations in rates of decomposition of organic matter and immobilization by microorganisms, differences in weathering and exchange processes, and changes in concentration brought about by vegetative uptake. Nutrients carried in the water draining a forest ultimately enter the streams and determine the chemical character of the receiving stream.

Removal Of Vegetation

Timber harvesting results in the loss of nutrients from the forest ecosystem. The proportion of nutrients in the vegetation lost from the forest is determined by the utilization that is made of the tree, being maximized when the entire tree (bole, limbs, foliage, and roots) is utilized and minimized when only the bole is removed from the site. The removal of overstory vegetation results in accelerated decomposition of organic matter on and in the forest floor due to an increase in soil temperature and moisture content. Increased soil temperatures are caused by removal of the shading trees, which allows direct solar heating of the soil surface. Soil water loss (i.e., evapotranspiration) is reduced, which increases soil moisture. Nutrients made available in the soluble form during the decomposition processes may exceed nutrient uptake capacity of the vegetation remaining on the site. Excess available nutrients then become lost from the forest ecosystem in surface and ground water flows to streams and deep seepage (Cramer 1974).

Nitrogen Outflux

Pathways Of Nitrogen Removal

Nitrogen is lost from a forest ecosystem by volatilization, removal of the biomass through harvesting, and by leaching to surface and subsurface flows.

Volatilization. — Generally, volatilization losses are extremely limited due to the nature of the forest environment. However, large volatilization losses of nitrogen occur when forest and logging residue are burned. Wildfire and prescribed burning of slash result in loss of organic nitrogen in the vegetation (DeBell and Ralston 1970). Grier (1975) reported that a wildfire on the Entiat Experimental Forest, Washington, caused a reduction of 97 percent of the nitrogen in the forest floor and two-thirds of the nitrogen in the A_1 horizon of the mineral soil. Ash from fires may be carried by the wind or by surface erosion into a watercourse. Losses via volatilization were discussed in "Nitrification and Mineralization."

Removal of the biomass. — Nitrogen assimilated by vegetation and utilized in biomass production is lost from the site when the vegetation is harvested and physically removed from the site.

Surface and subsurface flow. — Nitrogen loss from a site in the surface water or soil water has direct and immediate impact on the quality of water draining a forested area. Nitrogen may be in solution (principally as NO_3^-) or transported by the water adsorbed to suspend particles (principally as NH_4^+ and organic compounds). The intracycle processes — mineralization and nitrification — that have as their end products nitrate and ammonium, will be discussed in the next section. Nitrogen losses associated with surface erosion (i.e., adsorbed nitrogen) may be estimated using the insoluble component model previously presented.

Nitrification And Mineralization

The acid-base relations associated with nitrification and mineralization are shown in figure X.A.3. Acidity of the system remains unchanged as long as plant uptake of nitrogen equals the rate of mineralization of nitrogen and neither NH_4^+ nor NO_3^- accumulates in the soil.

When mineralization occurs followed by nitrification, an excess of hydrogen ions (H^+) is released, which may replace cations on the exchange sites. If plant uptake of nitrate does not take place, both nitrate ions and metallic cations are subject to leaching by subsurface flow. Bormann and Likens (1970) found that excess hydrogen ions may be released from exchange sites and go into solution in soil water, and are thereby lost from the forest ecosystem. The result is an increased outflux potential of nutrients from deforested watersheds that have increased nitrification rates. They reported that increased concentrations of calcium, magnesium, sodium, and potassium in water draining a clearcut occurred almost simultaneously with increased nitrate concentration.

Nitrate, an end product of nitrification reactions of the intercycle stage, is the principal component of nitrogen outflux from the forest ecosystem. Increased biological nitrification may result from silvicultural activities that reduce the vegetative cover, thus resulting in increased soil temperatures and moisture.

Accelerated nitrogen losses following some silvicultural activities have generally been attributed to changes in the forest floor environment conducive to nitrifying bacteria and to a reduction in assimilation due to the reduced vegetative cover.

Microbial populations in the forest floor generally increase following a timber harvest that exposes the soil to increased radiation, which results in warmer soil temperatures. Little decomposition takes place during the period when the soil is frozen or covered with snow. Thus, temperature of the growing season appears to be the decisive factor (Johnsen 1953, and Mikola 1960). The potential increase in nitrification rates is greater in the northern climates, where thick humus layers accumulate on the mineral soils and temperatures of shaded soils remain low most of the year (Stone 1973).

Soil moisture also influences the growth of microbial populations: removal of the overstory vegetation reduces interception and transpiration losses which results in increased soil moisture. Saturated soils, however, may retard microbial growth and thus reduce nitrification rates.

If nitrification and plant uptake of ammonium ions are less than the rate of mineralization, ammonium accumulates in the soil (fig. X.A.3). Ammonium ions are adsorbed on cation exchange sites and are not readily leached. Clay soils and soils with high cation exchange capacities hold ammonium ions most efficiently. Leaching of NH_4^+ occurs in soils with higher pH and lower cation exchange capacity (Coffee and Bartholomew 1964).

Denitrification. — Denitrification, the biochemical reduction of nitrate and/or nitrite, is one possible route whereby nitrogen may be lost from the forest ecosystem — microorganisms may reduce the nitrate and/or nitrite forms of nitrogen to gaseous nitrogen, and in some cases these forms are reduced to ammonia. Denitrification will occur in any microbial microenvironment that is essentially anaerobic. The microorganisms utilize the nitrogen oxides as a source of oxygen in the presence of glucose and phosphate. The rate of denitrification is partially controlled by pH. Denitrifying microorganisms are active in soils that range in pH from 5.8 to 9.2 (with an optimal value between pH 7.0 and 8.2).

Many commercial forest lands have soil pH values below 5.8 and are normally aerobic; therefore denitrification is severely limited, if detectable at all (Lutz and Chandler 1961, and Keeney 1973).

Phosphorus Outflux

Phosphorus is lost from the forest ecosystem in surface and subsurface water, and in vegetation removed from the site during silvicultural activities. Water quality is affected only by phosphorus lost from the site and entering the stream. Phosphorus loss via water transport includes not only the phosphorus dissolved in water, but also that adsorbed to suspended solids.

Generally, the greatest loss of phosphorus from a forest will occur as insoluble phosphorus complexes adsorbed on the clay-sized materials that are transported by surface flow. Research investigations (app. X.B.) have generally not reported significant increases in phosphorus concentrations in the receiving streams following silvicultural activities. It would appear that increases in available phosphorus due to silvicultural activities are normally utilized or fixed, and only a small fraction is transported from the site to a watercourse in the absence of excessive erosion.

APPENDIX X.B:

EIGHTEEN STUDIES OF NUTRIENT RELEASES FOLLOWING SILVICULTURAL ACTIVITIES

The results of research investigations into nutrient release of nitrogen and phosphorus following silvicultural activities are summarized and presented in figure X.2. A more thorough presentation of the results of these investigations is presented in the following 18 studies.

The Hubbard Brook study initiated concern regarding nutrient release following clearcutting and is presented first (study X.B.1.). It should be noted that the treatment was extreme. The NO_3^-−N and NH_4^+−N concentrations were greater in the precipitation than in the streams draining the control watersheds.

Concentrations of nitrogen and phosphorus in the control watersheds may be used as estimates of baseline water quality for the various geographic areas studied. It should be realized, however, that there may be considerable variation between adjacent watersheds as well as between geographic areas.

Study X.B.1
Hubbard Brook Experimental Forest,
New Hampshire

Silvicultural treatment:	Watershed 2 had all trees and brush cut (but left in place) during November and December 1965, and herbicides were applied during the following three summers to inhibit regrowth. Watersheds 4 and 6 were undisturbed and were used as controls.
Vegetation:	Northern hardwoods — beech, birch, and maple.
Drainage:	Treated, Watershed 2, 39 ac (15.6 ha). Control, Watershed 4, 90 ac (36 ha). Control, Watershed 6, 33 ac (13.2 ha).
Sampling:	October 1965-September 1968.

Results:

Study and year	$NO_3^-{-}N$ Mean annual	$NH_4^+{-}N$ Mean annual	Total dissolved P Maximum	Total dissolved P Mean annual
	mg/l			
Watershed 2				
1965-66	0.21	0.11	---	---
1966-67	8.67	0.05	---	---
1967-68	11.94	0.04	0.0026	0.00156
Watershed 4				
1965-66	0.19	0.09	---	---
1966-67	0.20	0.05	---	---
Watershed 6				
1965-66	0.19	0.09	---	---
1966-67	0.16	0.04	---	---
1967-68	0.29	0.02	---	0.00118
Precipitation				
1965-66	0.32	0.16	---	---
1966-67	0.34	0.14	---	---
1967-68	0.35	0.17	---	---

Sources: Likens and others 1970; Hobbie and Likens 1973.

Study X.B.2
Hubbard Brook Experimental Forest,
New Hampshire

Silvicultural treatment:	Progressive strip cutting. A 90 ac (36 ha) watershed was divided into 49 east-west strips, each 82 ft (25 m) wide. Every third strip was clearcut in October 1970. The remaining strips are cut at 2-year intervals.
Vegetation:	Uneven-aged northern hardwoods — beech, birch, and maple.
Drainage:	Treated, Watershed 4, 90 ac (36 ha).
Sampling:	January 1968-September 1972.

Results:

Date	NO_3^-–N Average concentration Estimated (if untreated)	Actual	Date	NO_3^-–N Average concentration Estimated (if untreated)	Actual
	-------- mg/l --------			-------- mg/l --------	
November 1970	0.43	0.56	November 1971	0.11	1.54
December 1970	0.50	0.70	December 1971	0.13	1.76
January 1971	0.61	0.74	January 1972	0.38	1.72
February 1971	0.68	0.79	February 1972	0.36	1.44
March 1971	0.70	0.88	March 1972	0.61	2.08
April 1971	0.86	1.24	April 1972	0.72	1.90
May 1971	0.52	0.77	May 1972	0.61	1.72
June 1971	0.16	0.25	June 1972	0.09	0.72
July 1971	0.11	0.25	July 1972	0.07	0.56
August 1971	0.04	0.34	August 1972	0.11	0.63
September 1971	0.02	0.43	September 1972	0.02	0.47
October 1971	0.02	1.15			

[1]No noticeable change in NH_4^+ concentration between treated and control watersheds.

Source: Hornbeck and others 1973.

Study X.B.3
White Mountain National Forest,
New Hampshire

Silvicultural treatment:	Timber sales conducted on the White Mountain National Forest. All areas were clearcut; more than 75 percent of the timber was cut. Adjacent undisturbed watersheds were also monitored.
Church Pond:	Clearcut in summer 1969, 329 ac (133 ha); 10 ac (4 ha); watershed monitored.
Conner Brook:	Clearcut in May 1969-Dec. 1969, 282 ac (114 ha); three 20 ac (8 ha) watersheds were monitored.
Davis Brook:	Clearcut Sept. 1969-Sep 1970, 160 ac (65 ha); three watersheds were monitored — 2.5 ac (1 ha), 7 ac (3 ha), 10 ac (4 ha).
D.O.C. Creek:	Clearcut July 1970, 126 ac (55 ha); two 20 ac (8 ha) watersheds were monitored.
Gale River:	Clearcut Dec. 1968-Aug. 1970, 297 ac (120 ha); three watersheds were monitored — two 10 ac (4 ha) and one 5 ac (2 ha).
Greeley Brook:	Clearcut initially 1960 and again 1967, 371 ac (150 ha); three watersheds were monitored — 35 ac (14 ha), 10 ac (4 ha) and 5 ac (2 ha).
HB 101:	Clearcut Nov. 1970, 30 ac (12 ha); 25 ac (10 ha) watershed monitored.
Stony Brook:	Clearcut Nov. 1968-May 1970, 160 ac (65 ha); 10 ac (4 ha) watershed monitored.
Vegetation:	Northern hardwoods (beech, birch, and maple) were present on all areas except Greeley Brook which had predominantly red spruce.
Drainage:	See "Silvicultural treatment," above.
Sampling:	Biweekly analysis from April-November 1971.

Results:

Watershed	NO_3-N Max	NO_3-N Mean	Watershed	NO_3-N Max	NO_3-N Mean
	mg/l			mg/l	
Church Pond			Gale River		
Control	0.95	0.81	Control	0.50	0.20
Clearcut	1.60	1.40	Clearcut	6.39	4.47
Conner Brook			Greeley Brook		
Control	0.40	0.20	Control	0.79	0.54
			Clearcut	1.85	1.31
Davis Brook			Stony Brook		
Control	0.09	0.02	Control	0.81	0.18
Clearcut	5.26	3.84	Clearcut	3.73	1.99
D.O.C. Creek					
Control	1.22	0.52			
Clearcut	3.54	1.90			

Source: Pierce and others 1972.

Study X.B.4
White Mountain National Forest,
Upper Mill Brook, New Hampshire

Silvicultural treatment: Harvesting operations were conducted on the Upper Mill Brook sale area from December 1971-February 1973

Watershed No.	Date	Treatment and drainage area
1	Jan.-Feb. 1972	Thinning (10-20 ac)
2	Feb.-Mar. 1972	Thinning (10-20 ac)
3	Dec. 1971-Jan. 1972	Clearcut (10-20 ac)
4	Dec. 1971-Jan. 1972	Clearcut (20-30 ac)
5	June-Sept. 1972	Clearcut with buffer (10-20 ac)
6	Sept. 1972-Feb. 1973	Clearcut (10-20 ac)
8	---	Control (30-40 ac)
9	---	Control (20-30 ac)
C	---	Control (620 ac)

Vegetation: Northern hardwoods.

Drainage: See "Silvicultural treatment," above.

Sampling: 1972-1974, 10 to 12 samples per year were collected. This number of samples was based on previous data evaluations.

Results

Watershed and treatment	NO_3-N Mean	NO_3-N Max	Total N Mean	Total N Max	PO_4^{-3} Mean	PO_4^{-3} Max
	mg/l					
1 and 2—thinnings	0.45	2.10	0.92	2.50	0.02	0.11
3—clearcut	0.79	2.55	1.32	3.55	0.03	0.13
4—clearcut	0.96	2.48	1.50	3.40	0.02	0.09
5—clearcut/buffer	0.39	1.51	0.94	2.92	0.02	0.09
6—clearcut	0.23	1.35	0.81	4.10	0.02	0.16
8 and 9—controls	0.23	1.21	0.71	2.88	0.02	0.12
C—control (upstream)	0.27	1.02	0.67	4.20	0.01	0.04

Source: Stuart and Dunshie 1976.

Study X.B.5
Leading Ridge Watershed 2,
Pennsylvania State University

Silvicultural treatment:	Forty-six percent of the watershed was successively clear-cut and herbicided. The sequence of operation was (1) winter of 1966-67—21.3 ac (9 ha) of the lower watershed were clearcut; (2) summers of 1967, 1968, and 1969 — stumps were treated with herbicide to control stump sprouting; (3) winter of 1971-72 — 2.70 ac (1.0 ha) of the middle watershed were clearcut; and (4) both clearcuts treated with herbicide in June 1974.
Vegetation:	Uneven-aged oak, hickory, and maple.
Drainage:	Treatment, Leading Ridge Watershed (LR) 2,106 ac (42 ha) with 48.3 ac clearcut. Control, Leading Ridge Watershed 1, 303 ac (121 ha). Control, Leading Ridge Watershed 3, 257 ac (100 ha).
Sampling:	Weekly sampling for nutrient concentrations in streamflow began in 1972.

Results:

Date	Control LR-1	Treatment LR-2 NO_3-N	Control LR-3
		mg/l	
Oct. 1972-Sept. 1973		Clearcutting had no apparent effect	
Oct. 1973-May 1974	0.02	0.10	0.01
June 1974-Dec. 1974	0.04	2.08	0.08
June-Aug. (ave max)		0.4	
Sept.-Dec. (ave max)		5.0	
Sept.-Dec. (max measured)		8.4	

Source: Corbett and others 1975.

Study X.B.6

Fernow Experimental Forest,
West Virginia

Silvicultural treatment:	Watershed 3 was clearcut 1969. Watershed 4 was undisturbed and used as a control. Watershed 2 was subjected to a diameter-limit cut in August 1972.
Vegetation:	Mixed deciduous — oaks, maples, yellow poplar, black cherry and beech.
Drainage:	Watershed 3, 84 ac (34 ha). Watershed 4, 94 ac (38 ha). Watershed 2, 38 ac (15 ha).
Sampling:	Weekly sampling, May 1970-April 1971, Watersheds 3 and 4. Weekly sampling, Aug. 1972-Sept. 1974, Watershed 2.

Results:

Watershed	NO_3^--N Mean	NO_3^--N Max	NH_4^+-N Mean	PO_4^{-3} Ave
	---mg/l---			
Watershed 4				
1970 growing season	0.32	---	0.48	0.04
1970-71 dormant season	0.10	---	0.13	0.02
Watershed 3				
1970 growing season	0.18	0.59	0.35	0.07
1970-71 dormant season	0.49	1.42	0.14	0.04
Watershed 2				
Growing season				
Pre-silvicultural activity	0.2			
Post-silvicultural activity	0.6			
Dormant season				
Pre-silvicultural activity	Values unchanged			
Post-silvicultural activity	Values unchanged			

Sources: Aubertin and Patric 1972; Aubertin and Patric 1974; Patric and Aubertin 1976.

Study X.B.7

Coweeta Hydrologic Laboratory,
North Carolina

Silvicultural treatment:

Watershed No.	
1	All trees and shrubs cut 1956-57, no products removed; white pine planted 1957, 40 ac (16.2 ha).
2	Control, mixed mature hardwoods, 30 ac (12.1 ha).
6	Cut 1958 and products removed; lime added, fertilized, and grassed in 1959; refertilized 1965; herbicided 1966 and 67, 22 ac (8.9 ha).
14	Control, mixed mature hardwoods, 151 ac (61.1 ha).
13	All trees and shrubs cut 1936, recut 1962; no products removed, 40 ac (16.2 ha).
18	Control, mixed mature hardwoods, 31 ac (12.5 ha).
17	All trees and shrubs cut 1942; recut annually through 1955, no products removed; white pine planted in 1956, 33 ac (13.4 ha).
21	Control, mixed mature hardwoods, 60 ac (24.3 ha).
28	All trees and shrubs cut on 190 ac (77 ha); cove hardwoods thinned on 96 ac (39 ha); no cutting on 69 ac (28 ha); products removed 356 ac (144.1 ha).
32	Control, mixed mature hardwoods, 102 ac (41.3 ha).
37	All trees and shrubs cut in 1963; no products removed, 108 ac (43.7 ha).
34	Control mixed mature hardwoods 81 ac (32.8 ha).

Vegetation: See "Silvicultural treatment," above.

Drainage: See "Silvicultural treatment," above.

Sampling: May 1972-April 1973.

Results:

Watershed[1]	NO_3^-–N		NH_4^+–N		PO_4^{3-}–P	
	Mean	Max	Mean	Max	Mean	Max
	mg/l					
1	0.029	0.077	0.003	0.020	0.006	0.022
2	0.004	0.017	0.002	0.020	0.006	0.020
6	0.619	1.230	0.004	0.010	0.007	0.030
14	0.004	0.024	0.004	0.031	0.005	0.017
13	0.044	0.084	0.003	0.014	0.004	0.013
18	0.003	0.014	0.004	0.022	0.005	0.018
17	0.154	0.249	0.004	0.012	0.012	0.336
21	0.003	0.016	0.004	0.024	0.004	0.029
28	0.094	0.208	0.003	0.017	0.004	0.020
32	0.003	0.015	0.003	0.013	0.004	0.013
37	0.149	0.246	0.004	0.038	0.006	0.095
34	0.002	0.019	0.003	0.024	0.006	0.019

[1]Watersheds listed below are alternated treated and controlled (1—treated, 2—control) for comparison. Refer to "Silvicultural treatment" for details.

Sources: Douglass and Swank 1975; Swank and Douglass 1975.

Study X.B.8
USAEC's Savannah River Plant,
Aiken, South Carolina

Silvicultural treatment:	Prescribed burn of surface litter.
Vegetation:	Loblolly pine.
Drainage:	Approximately 450 ac (180 ha).
Sampling:	Ground water samples were taken at control and burned areas 5 weeks after burn.

Results: Ground water.

Sample area	NO_3–N		PO_4^{3-}–P	
	Mean	Std error	Mean	Std error
	mg/l			
Burned	0.007	0.0005	0.0047	0.0012
Control	0.006	0.0009	0.0040	0.0010

Source: Lewis 1974.

Study X.B.9
Grant Memorial Forest,
Georgia

Silvicultural treatment:	77 ac were clearcut beginning in October 1974. Harvesting and site preparation (roller chopping) was completed in December 1975. The site was planted in January 1976. An adjacent untreated watershed was monitored as a control.
Vegetation:	Old field Loblolly pine.
Sampling:	December 1973-January 1977 (approximately 200 weekly samples).

Results: (Mean conc. of all samples)

Watershed	NO_3-N	Total P
	mg/l	
Treated		
Calibration, Dec. 1973-Oct. 1974	0.058	0.210
Harvest and site prep., Nov. 1974-Dec. 1975	0.029	0.190
Following planting, Jan. 1976-Jan. 1977	0.028	[1]0.476
Control		
Calibration, Dec. 1973-Oct. 1974	0.149	0.216
Nov. 1974-Dec. 1975	0.113	0.230
Jan. 1976-Jan. 1977	0.108	[1]0.582

[1]Particularly high values of phosphorus occurred during September-October 1976. Although unexplained, it is important to note that both the treated and the control watersheds exhibited high values during this period.

Source: Hewlett 1977.

Study X.B.10
H. J. Andrews Experimental Forest,
Eugene, Oregon

Silvicultural treatment: Patchcut using high-lead yarding; with 25 percent of the area cut, plus an additional 6 percent in roads. Clearcut entire drainage, but no roads were present. Harvesting operations were begun in the fall of 1962 and were completed in 1966. Both areas were broadcast burned following yarding. A third drainage was undisturbed and served as a control.

Vegetation: Old-growth Douglas fir.

Drainage: Patchcut, 237 ac (96 ha).
Clearcut, 149 ac (60 ha).
Control, 250 ac (101 ha).

Sampling: 119 samples were collected, usually during storm runoff, during the period April 1965-July 1968.

Results:

Clearcut

Date and treatment	NO_3-N Mean annual	NO_3-N Instantaneous max	NH_4^+-N	$PO_4^{3-}-P$ Mean annual	$PO_4^{3-}-P$ Instantaneous max
	mg/l				
1966 (H)[1]	0.020	0.050	---	0.024	0.066
1967 (B)	0.050	0.066	0.110	0.039	0.121
1968 (R)	0.200	0.600	0.001	---	---
1971 (R)	0.046	0.065	---	0.036	0.050
1972 (R)	0.023	0.056	---	0.034	0.045

Maximum and mean maximum taken during a 12-day period after broadcast burning in 1967

Measurement	NO_3-N Clearcut	NO_3-N Control	NH_4^+-N Clearcut	NH_4^+-N Control	$PO_4^{3-}-P$ Clearcut	$PO_4^{3-}-P$ Control
	mg/l					
Maximum	0.60	---	7.60	---	0.13	---
12-day mean	0.43	0.01	1.19	0.001	0.05	0.05

Patchcut

Dissolved solids concentration increased as a result of harvesting. The effect lasted for 6 years and was no longer statistically different from the pre-silvicultural activity in 1968.

Control

Date and treatment	NO_3-N Mean annual	NO_3-N Instantaneous max	NH_4^+-N	$PO_4^{3-}-P$ Mean annual	$PO_4^{3-}-P$ Instantaneous max
	mg/l				
1966 (U)	0.010	---	---	0.026	---
1967 (U)	0.003	---	0.003	0.016	---
1968 (U)	0.001	---	<0.001	---	---
1971 (U)	0.0003	---	---	0.032	---
1972 (U)	0.0015	---	---	0.016	---

[1]H = harvested, B = burned, R = revegetating, and U = undisturbed.

Source: Fredriksen 1971; Fredriksen 1977; Fredriksen and others 1975; Rothacher and others 1967.

Study X.B.11
Bull Run Watershed,
Portland, Oregon

Silvicultural treatment:	Clearcut on 25 percent of watersheds — the slash on one was burned and left to decompose on the other. On the burned watershed, harvesting was done the summer of 1969 and the slash was burned in the fall of 1970. On the unburned watershed, two seasons (1971 and 1972) were required to completely fell the units; harvesting was completed summer of 1973. The untreated watershed served as a control.
Vegetation:	Old-growth Douglas fir.
Drainage:	Fox Creek: Clearcut and burned, 145 ac (59 ha). Clearcut and not burned, 175 ac (71 ha). Control, 625 ac (253 ha).
Sampling:	Sampling began April 1970. Proportional samples taken over 3-week intervals throughout each year.

Results:

Year and treatment	NO_3-N Mean annual	NO_3-N Max	NH_3-N Mean annual	NH_3-N Max	Dissolved organic N Mean annual	Dissolved organic N Max	Total phosphorus Mean annual	Total phosphorus Max
	mg/l							
Clearcut								
1970 (H)[1]	0.012	0.019	0.003	0.020	0.037	0.058	0.035	0.065
1971 (B)	0.027	0.079	0.005	0.100	0.036	0.049	0.027	0.055
1972 (R)	0.046	0.056	0.001	0.022	0.040	0.062	0.014	0.030
1973 (R)	0.034	0.057	0.001	0.090	0.036	0.058	0.028	0.100
1974 (R)	0.045	0.064	---	---	0.043	0.133	0.011	0.093
1975 (R)	0.023	0.034	---	---	0.043	0.075	0.016	0.032
1976 (R)	---	0.033	---	---	---	0.051	---	0.025
Clearcut—Not Burned								
1970 (U)	0.002	0.014	0.002	0.005	0.036	0.078	0.028	0.070
1971 (F)	0.004	0.017	0.005	0.089	0.038	0.096	0.032	0.055
1972 (F)	0.014	0.030	0.001	0.010	0.029	0.046	0.013	0.045
1973 (H)	0.022	0.042	0.003	0.036	0.032	0.042	0.021	0.030
1974 (R)	0.080	0.115	---	---	0.032	0.082	0.011	0.062
1975 (R)	0.093	0.114	---	---	0.044	0.076	0.020	0.046
1976 (R)	---	0.066	---	---	---	0.066	---	0.030
Control								
1970 (U)	0.006	0.027	0.005	0.013	0.045	0.063	0.040	0.065
1971 (U)	0.003	0.020	0.004	0.078	0.043	0.064	0.032	0.070
1972 (U)	0.005	0.040	0.002	0.018	0.036	0.070	0.014	0.080
1973 (U)	0.013	0.056	0.002	0.007	0.038	0.062	0.024	0.100
1974 (U)	0.002	0.053	---	---	0.034	0.081	0.013	0.090
1975 (U)	0.002	0.028	---	---	0.050	0.068	0.015	0.033
1976 (U)	---	0.040	---	---	---	0.065	---	0.031

[1]H = harvested; B = burned; F = felled; R = revegetating, and U = undisturbed

Source: Fredriksen 1977.

Study X.B.12
South Umpqua Experimental Forest,
50 kilometers ESE of Rosberg, Oregon

Silvicultural treatment: Shelterwood harvest — 50 percent of the area removed; small clearcut — 30 percent of the area in 20 small clearcuts from 0.6 - 1.4 ha (3.1 ac); complete clearcut — all trees removed. Logging residue on watersheds was piled and burned. Roads were constructed June-September 1970 and harvesting done June-September 1971.

Vegetation: Mixed conifer.

Drainage: Coyote Creek: Shelterwood, 171 ac (69 ha).
Complete clearcut, 123 ac (50 ha).
Small clearcut, 169 ac (68 ha).
Control, 120 ac (49 ha).

Sampling: Sampling began October 1, 1969. Proportional samples taken over 3-week intervals throughout each year.

Results:

Year and treatment	NO_3-N mean annual (mg/l)	NO_3-N max (mg/l)	NH_4-N mean annual (mg/l)	NH_4-N max (mg/l)	Disolved organic N mean annual (mg/l)	Disolved organic N max (mg/l)	Total-P mean annual (mg/l)	Total-P max (mg/l)	Ortho-P mean annual (mg/l)	Ortho-P max (mg/l)
Shelterwood										
1970 (U)[1]	0.001	0.005	0.002	0.027	0.077	0.165	0.032	0.080	0.015	0.030
1971 (RC)	0.002	0.016	0.002	0.010	0.048	0.126	0.052	0.090	0.020	0.033
1972 (H)	0.004	0.012	0.003	0.009	0.075	0.114	0.043	0.095	0.026	0.070
1973 (R)	0.003	0.033	0.005	0.015	0.039	0.060	0.048	0.115	0.014	0.090
1974 (R)	0.001	0.017			0.051	0.155	0.030	0.076	0.015	0.021
1975 (R)	0.004	0.019			0.067	0.151	0.038	0.069	0.016	0.021
Complete Clearcut										
1970 (U)	0.001	0.009	0.001	0.020	0.093	0.142	0.048	0.150	0.048	0.100
1971 (U)	0.005	0.018	0.002	0.010	0.064	0.132	0.086	0.133	0.051	0.115
1972 (H)	0.002	0.007	0.003	0.008	0.080	0.178	0.062	0.140	0.054	0.062
1973 (R)	0.126	0.178	0.018	0.043	0.084	0.252	0.100	0.205	0.064	0.112
1974 (R)	0.242	0.365			0.104	0.176	0.068	0.130	0.054	0.082
1975 (R)	0.275	0.510			0.123	0.161	0.091	0.148	0.060	0.092
Small Clearcut										
1970 (F)	0.003	0.022	0.003	0.031	0.105	0.149	0.034	0.090	0.016	0.038
1971 (RC)	0.055	0.177	0.001	0.004	0.073	0.142	0.032	0.049	0.013	0.026
1972 (H)	0.004	0.031	0.001	0.005	0.081	0.120	0.035	0.070	0.031	0.045
1973 (R)	0.026	0.120	0.009	0.034	0.056	0.142	0.038	0.090	0.011	0.021
1974 (R)	0.007	0.087			0.070	0.138	0.023	0.058	0.011	0.018
1975 (R)	0.019	0.059			0.084	0.121	0.034	0.077	0.011	0.022
Control										
1970 (U)	0.001	0.004	0.001	0.006	0.105	0.185	0.036	0.118	0.025	0.060
1971 (U)	0.005	0.025	0.003	0.012	0.058	0.133	0.060	0.200	0.029	0.114
1972 (U)	0.003	0.005	0.002	0.006	0.078	0.095	0.045	0.080	0.039	0.045
1973 (U)	0.002	0.034	0.014	0.061	0.124	0.057	0.053	0.110	0.025	0.045
1974 (U)	0.004	0.022			0.072	0.132	0.036	0.069	0.024	0.033
1975 (U)	0.004	0.034			0.089	0.137	0.049	0.071	0.024	0.026

[1]U-undisturbed, F-fertilized, H-harvest, RC-road construction R-revegetating

Source: Fredriksen 1977.

Study X.B.13

Alsea Basin, Oregon Coast Range

Silvicultural treatment:	Needle Branch was completely clearcut beginning in March 1966; logging slash was burned (very hot fire) in October 1966. Deer Creek was 25 percent clearcut in three logging units. Only one unit in Deer Creek was burned (light burn). Flynn Creek remained untreated and served as the control.
Vegetation:	Douglas fir and alder. Alder was predominant species on Flynn Creek (68%) and Deer Creek (68%). Douglas fir predominated on Needle Branch (80%).
Drainage:	Needle Branch, 175 ac (70.68 ha). Deer Creek, 750 ac (303.32 ha). Flynn Creek, 500 ac (203.14 ha).
Sampling:	2 years before and 2 years after logging.

Results:

Watershed and treatment	Water year	NO_3-N Max observed	NO_3-N Yearly mean	Total phosphate P Min	Total phosphate P Max
		mg/l			
Needle Branch Clearcut	1965	0.20	0.12	0.01	0.10
	1966	0.70	0.19	0.01	0.10
	1967	2.10	0.44	0.01	0.10
	1968	1.65	0.43	0.01	0.10
Deer Creek[1] Patchcut	1965	3.17	1.12	0.01	0.10
	1966	2.10	0.98	0.01	0.10
	1967	2.70	1.21	0.01	0.10
	1968	2.40	1.12	0.01	0.10
Flynn Creek[1] Control	1965	3.19	1.21	0.01	0.10
	1966	2.18	1.16	0.01	0.10
	1967	2.70	1.18	0.01	0.10
	1968	2.20	1.18	0.01	0.10

[1]High nitrate-N values probably due to alder.

Source: Brown and others 1973.

Study X.B.14
Bitterroot National Forest,
Montana

Silvicultural treatment:	Three watersheds were clearcut and three paired watersheds were used as controls. Lodgepole Creek was 97 percent clearcut, most of it in 1969 and 1970. Mink Creek was 83 percent clearcut in 1968 and dozer piled in 1971. The lower 46 percent of Little Mink Creek was clearcut in 1963, dozer piled in 1971, burned in 1972, and planted in 1973.
Vegetation:	Mixed coniferous, ponderosa pine, Douglas fir, lodgepole pine, Engelmann spruce, and subalpine fir.
Drainage:	1. Lodgepole Creek, treatment, 497 ac (201 ha). 1. Spruce Creek, control, 467 ac (189 ha). 2. Mink Creek, treatment, 614 ac (249 ha). 2. Springer Creek, control, 866 ac (350 ha). 3. Little Mink Creek, treatment, 103 ac (41 ha). 3. Little Mink Creek, control, 152 ac (61 ha).
Sampling:	One year from October 1, 1972-September 30, 1973.

Results:

Watershed	NO_3-N Mean annual mg/l	Watershed	NO_3-N Mean annual mg/l
1. Lodgepole Creek	0.19	2. Springer Creek	0.13
1. Spruce Creek	0.11	3. Little Mink Creek	0.40
2. Mink Creek	0.17	3. Little Mink Creek	0.17

Source: Bateridge 1974.

Study X.B.15

Priest River Experimental Forest,
Idaho

Silvicultural treatment: Three watersheds were treated. Benton Creek was clearcut in 1969, with a waterside area remaining along stream, and broadcast burned in 1970. Ida Creek was clearcut in 1970, with waterside area, and the slash was windrowed and burned. Canyon Creek was also clearcut with a waterside area, and broadcast burned.

Vegetation: Mixed conifers, western white pine, western red cedar, Douglas fir, and western larch.

Drainage: Not defined.

Sampling: Benton Creek, September 1970 to June 1972.
Ida Creek, October 1970 to June 1972.

Sampling was done above and below the silvicultural operation.

Results:

Watershed	$^{1}NO_3$–N Mean	$^{1}NO_3$–N Std error	Watershed	NO_3–N Mean	NO_3–N Std error
	mg/l				
Benton			Canyon		
Control	0.20	0.05	Control	0.09	0.02
Treatment	0.18	0.02	Treatment	0.05	0.01
Ida			Precipitation		
Control	0.14	0.02		0.09	0.01
Treatment	0.16	0.02			

[1] NO_3–N values are higher than normally expected due to the minimum detection (0.14 mg/l).

Source: Snyder and others 1975.

Study X.B.16
Marcell Experimental Forest,
Minnesota

Silvicultural treatment:	62.5 ac of aspen uplands were clearcut between December 1970 and January 1972.
Vegetation:	Aspen/birch and black spruce (bog).
Drainage:	Treatment, 84 ac (34 ha). Control, 130 ac (52 ha).
Sampling:	Pre-silvicultural activity samples (9) were taken in the spring, summer and fall. Post-silvicultural activity sampling (26 samples) was concentrated during high flows.

Results:

Sampling	Organic -N		NH_4 N		NO_3 N		Total -N		Total PO_4	
	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error
	mg/l									
Silvicultural-activity										
Pre-	0.93	0.19	0.35	0.10	0.31	0.12	1.69	0.18	0.15	0.03
Post-	0.80	0.07	0.55	0.11	0.16	0.06	1.50	0.13	0.17	0.03
Control										
Pre-	0.92	0.16	0.25	0.03	0.30	0.10	1.48	0.14	0.13	0.01
Post-	0.85	0.07	0.41	0.06	0.12	0.01	1.39	0.07	0.12	0.02

Source: Verry 1972.

Study X.B. 17

West Central Alberta,
Canada

Silvicultural treatment:	Clearcutting progressively over 13 forest watersheds located in 3 working circles (management units).
Vegetation:	Lodgepole pine, white spruce, and aspen.
Drainage:	Ranged in size from 1,725 to 5,914 acres (700 to 2,400 ha).
Sampling:	Summer 1974, 117 samples during spring snowmelt and 104 samples during summer recession period.

Results:

		NH_4^+		NO_3^-		$PO_4^{3-}-P$	
		Mean	Std error	Mean	Std error	Mean	Std error
		mg/l					
Marlboro Circle							
2 controls	May-June	0.52	0.07	0.04	0.02	0.011	0.001
	July-Aug.	0.22	0.03	0.006	0.0002	0.007	0.001
2 treated	May-June	0.68	0.09	0.02	0.01	0.012	0.001
	July-Aug.	0.18	0.02	0.006	0.001	0.008	0.001
Berland Circle							
2 controls	May-June	0.39	0.05	0.011	0.003	0.010	0.001
	July-Aug.	0.10	0.01	0.004	0.001	0.005	0.003
2 treated	May-June	0.34	0.06	0.047	0.009	0.008	0.0005
	July-Aug.	0.09	0.02	0.028	0.004	0.004	0.0001
McLeod Circle							
2 controls	May-June	0.48	0.03	0.010	0.002	0.012	0.001
	July-Aug.	0.20	0.03	0.008	0.002	0.006	0.0003
2 treated	May-June	0.48	0.03	0.016	0.003	0.009	0.001
	July-Aug.	0.22	0.03	0.005	0.001	0.005	0.0005

Source: Singh and Kalra 1975.

Study X.B.18
Dennis Creek, Okanagan Valley,
British Columbia

Silvicultural treatment:	Clearcutting 383 ac (155 ha) representing about 25 percent of the drainage area.
Vegetation:	Engelmann spruce-subalpine fir.
Drainage:	Dennis Creek treatment, 2,370 ac (960 ha). James Creek control, 2,000 ac (810 ha).
Sampling:	Sampling was done at two sites each above and below the silvicultural operation and on an adjacent undisturbed watershed.

Results:

	Total Kjeldahl nitrogen			NO_3-N			Total phosphorus		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
	mg/l								
Below cut									
Site 1	0.090	0.189	0.351	0.002	0.003	0.010	0.005	0.015	0.038
Site 2	0.090	0.242	0.596	0.002	0.028	0.368	---	---	---
Above cut									
Site 1	0.095	0.166	0.346	0.002	0.004	0.013	0.002	0.010	0.031
Site 2	0.095	0.191	0.418	0.002	0.010	0.050	---	---	---
Control									
Site 1	0.100	0.308	0.448	0.002	0.015	0.040	0.014	0.028	0.056
Site 2	0.100	0.328	0.467	0.002	0.029	0.124	---	---	---

Source: Hetherington 1976.