NUTRIENT EXPORT COEFFICIENTS: AN EXAMINATION OF SAMPLING DESIGN AND NATURAL VARIABILITY WITHIN DIFFERING LAND USES

By

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ABSTRACT

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Lake management strategies and recent environmental legislation dictate that non point nutrient sources, associated with stormwater runoff, must be assessed. Estimation of nutrient flux is highly complicated by watershed and climatic factors which contribute to natural variability. Sampling design concepts, required to 1) reduce sampling error, and 2) adequately account for natural variability, are examined.

Nutrient flux is assessed through 1) an extensive literature review of nutrient export studies, 2) an examination and screening of nutrient export coefficients according to sampling design criteria, and 3) compilation of these coefficients according to land use. The ecological mechanisms within each land use influencing the magnitude of nutrient flux are discussed. The cross sectional and longitudinal variability of the compiled coefficients are examined through application to a hypothetical watershed.

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Finally, I wish to gratefully acknowledge the assistance of my close companion, Linda Wennerberg. Her love and untiring patience has been a major source of moral support. It is to her that I dedicate this thesis.

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CHAPTER I

INTRODUCTION

Inland lakes are being used as water supply reservoirs, sources of recreation and other human related activities at an increasing rate. The extent and number of water uses is strongly dependent on lake water quality which is, itself, influenced by land based activities within the drainage basin. To insure high water quality and continued multiple water use necessitates the proper management of the surrounding watershed and the control of point and non point sources. Because point sources are amenable to direct measurement and quantification, and thus to successful abatement programs, concern has shifted to the role diffuse (or non point) pollution sources play in water quality. The main focus of this thesis is non point pollution from quickflow (stormwater runoff)[1] and the ecological mechanisms within the watershed which control its magnitude. Since many of these mechanisms and watershed perturbations are land use specific, a hypothesis central to this thesis is that a relationship exists between land use and nutrient flux.

The Problem

Lakes have a variety of linkages for energy and nutrient exchange with surrounding terrestrial ecosystems. The vectors transporting

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energy and materials may be categorized as meteorologic, geologic, or biologic. The geologic output of water, dissolved nutrients, and other chemicals and particulate matter from the terrestrial ecosystem, is the main geologic input to most of these aquatic ecosystems, and one of the most important land-water linkages in the biosphere. In this regard, rivers, streams and overland runoff take on special significance as the primary connection between terrestrial and standing water systems (Bormann and Likens, 1967; Likens and Bormann, 1973, 1974).

Vollenweider (1968, 1975, 1976), Reckhow (1979) and numerous others have demonstrated the empirical relationships between the input (and recycling) of nutrients and lake nutrient concentrations. Excessive nutrient inputs from cultural sources are commonly associated with water quality problems and cultural eutrophication of lakes. In particular, two nutrients, nitrogen and phosphorus, have been singled out as leading causes of accelerated lake eutrophication.

Nutrient flux originates from the two aforementioned point and non point sources. Because of the greater emphasis on point sources, non point sources have historically been considered natural, unmeasurable, and generally uncontrollable. Vollenweider (1968) characterized these sources as:

1. natural sources such as eolian loading and eroded material from virgin lands, mountains, and forests, and
2. artificial or semi-artificial sources which are directly related to human activities, such as

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fertilizers, eroded soil, materials from agricultural and urban areas, and wastes from intensive animal rearing operations.

While natural sources seldom contribute to water quality deterioration, man's activities in the watershed tend to alter, remove or overwhelm the homeostatic capabilities of natural terrestrial ecosystems. Although the quantity of nutrient export varies widely, the greater the extent of human utilization and land disturbance, the greater the amount of nutrient export from the watershed. As a result, the increased nutrient load may accelerate the rate of eutrophication in aquatic systems.

The importance of non point sources in relation to water quality is reflected in the Water Pollution Control Act of 1972 (Public Law 92-500) and the 1977 Amendments. Section 208 outlines a cooperative local/state/federal mechanism for areawide water quality planning including the identification of non point sources as well as procedures and methods "...to control to the extent feasible such sources." According to Pavoni (1977), this areawide approach implies that planning for water quality also requires planning for land use since:

1. many water pollution sources are land use - specific, particularly non point sources, and
2. land use controls may be the most cost-effective method for controlling one or more pollution sources.

With this increased emphasis placed on non point sources and land use controls, *there is a clear and pressing need to develop tested* proce

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procedures and collect reliable data on nutrient flux from various land uses.

Current Research Practices

Although direct *in situ* measurements provide more reliable estimates, the time, expense and effort needed to derive annual nutrient loading coefficients for individual lakes, have prompted many water quality investigators to rely on values reported in the literature. Many of these early literature values have been included in comprehensive surveys relating specific land uses to the nutrient mass transported to surface waters (Lin, 1972; Loehr, 1974; Uttormark et al., 1974). Out of convenience these nutrient coefficients have been frequently cited in nutrient budgeting studies for lakes, and have become an integral part of water quality models.

Despite their wide acceptance, nutrient loading estimates in the literature still exhibit considerable uncertainty (O'Hayre and Dowd, 1978; Reckhow et al., 1980). Closer inspection of many of these studies reveals that errors often result from a lack of understanding of the factors involved in proper sampling design. According to Hines et al. (1977), the two prominent shortcomings of hydrologically related sampling programs are:

1. the arbitrarily derived, fixed temporal and spatial design of sampling programs from which quality data are derived, and
2. a failure to account adequately for the seasonal and reach-to-reach variability of water quality

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that results from hydrologic phenomena.
Subsequent use of these improperly derived coefficients in water quality management can potentially bias resulting policy decisions. In recognition of nutrient loading uncertainty, a number of investigators stress the need for either 1) additional data produced by skilled specialists using sound sampling methods, or 2) careful scrutiny of the nutrient export literature, to provide reliability for models used in large-scale lake management schemes (Thomann, 1977; Wanielista et al., 1977; Schindler, 1978; Dawdy, 1979).

The Problem Solution

For water quality planning to be effective, decisions must be based upon reliable and more realistic information. To satisfy this requirement, water quality data must be systematically quantified. According to Reckhow (1978), the design of a systematic sampling program is fundamentally a statistical problem with increasing knowledge or the reduction of uncertainty as the primary objective. Because the desired degree of precision is the function of parameter variability, sampling programs must account for these irregularities. While it is beyond the scope of this research to conduct *in situ* measurements, this thesis will provide, 1) a careful review of literature studies which focus on non point (quickflow) nutrient flux, and 2) a selection and compilation of nutrient loading estimates derived from an adequate sampling design for each land use.

To acquaint the reader with the thought processes involved in the selection criteria, a discussion of sampling design will form the basis o

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basis of Chapter II. In particular, the components of the sampling design best describing both temporal and spatial variability will be examined. These will include the 1) parameters to be sampled, 2) sampling frequency, 3) methods, 4) duration, and 5) location.

Chapters III through V focus on forest, agricultural and urban land uses, respectively. Each chapter will include an in-depth discussion of factors and activities which influence the "characteristics and comparative magnitudes" of nutrient cycling and export from each respective land use. For forest watersheds, these factors include geologic type, biome type, and ecological succession. Agricultural activities include crop type (row versus non row crops), pasture/grazing land, and feedlot/manure storage facilities. Percent impervious surfaces and other factors which influence nutrient export are discussed in the urban land use chapter. In addition to general discussions, the compiled nutrient export coefficients are presented both in tables and histograms for each land use, in accordance with the sampling/screening criteria described in Chapter II.

Chapter VI presents concluding comments on the compiled nutrient coefficients. To demonstrate to the reader and analyst the subjectivity involved in application and the resulting nutrient export variability, selected nutrient coefficients are applied to a hypothetical, mixed land use watershed for a two year period (reflecting high and low rainfall). Chapter VII summarizes the results of this research with notes on use of the compiled nutrient coefficients.

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CHAPTER II

NON POINT SOURCE SAMPLING DESIGN

Introduction

The bulk of non point source water quality studies have focused on either surface runoff alone or runoff combined with groundwater flow. Runoff (and the interstitial subsurface flow) flushes not only soluble and suspended matter deposited on the watershed but also impurities contributed by precipitation. Total storm induced water flux from a watershed is often called quickflow and consists of overland runoff, baseflow and interflow. It is the combination of these three fractions which poses a most serious threat to our lakes and streams.

While exceptions (i.e., floods) have been noted, the pollutants flushed from a particular land use during one storm event often are not significant. The cumulative effect of many such storms, however, are not only considerable enough to seriously degrade water quality, but often negate the positive effects of local point source pollution abatement programs.

In spite of the number of water quality runoff studies currently available in the literature, proper assessment of diffuse pollution loads is fraught with a high degree of uncertainty and variability. This variability is the result of essentially two factors; physiographic and climatic characteristics. Physiographic characteristics include those conditions within the watershed, such as geology, soil type,

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type, land use and other variables imposed by human intervention, which alter biogeochemical processes and pathway conditions of overland runoff. Climatic conditions influence the hydrologic cycle. However, in spite of many thousands of man-years spend in the pursuit of hydrologic knowledge, quantification of any hydrologic resource or process can be performed only with limited accuracy (Moss, 1979; Dawdy, 1979).

Diffuse Source Monitoring Deficiencies

In order to properly characterize the variable nature of diffuse runoff, a monitoring program must be utilized which accounts for this variability. Monitoring of annual nutrient flux is a statistical problem and this problem may be defined as "the minimization of uncertainty in the annual nutrient flux estimate subject to a budget (cost) constraint," or conversely, "the minimization of sampling cost subject to a desired precision level" (Reckhow, 1978). As a result, sampling problems are placed in an economic and decision making framework, thus introducing a need for the measure of worth of data (Dawdy, 1979). Accordingly, the problem is reduced to two of the basic variables of sampling design, precision (uncertainty) and cost.

Unfortunately, close inspection of a number of stormwater studies in the literature has demonstrated that these factors were not always fully considered. Some of the undesirable characteristics in these studies included:

1. Point sources of contamination were not adequately accounted for.

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2. Storm events were disregarded in favor of more easily obtained baseflow measurements.
3. Sediment or particulate matter was not adequately sampled.
4. Measurements taken during one season only, such as the dry summer period, were extrapolated to give yearly loading rates.
5. Sampling location often did not account for the horizontal and/or vertical variability within the monitored tributary.
6. The monitored watershed comprised a number of land uses thus making results difficult to interpret. (i.e., What are the sources of the pollutants?)

Consequently, many of the published sampling results are not truly representative of the actual conditions at the particular time and place under study or are not useful beyond the watershed of study. This inadequacy is often because of one or both of the following two scenarios:

1. Available time, money and personnel constraints often create many compromises which serve to undermine any conclusive information generated by the study.
2. Often little foresight is given toward the ultimate use (objective) of the generated data. This results in little thought invested in the representativeness of the water samples or types of data analysis to be used.

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Systematic Quantification - Sampling Design

To make sound water quality management decisions, the required data must be available, unbiased and exhibit low variability. These needs are facilitated through acknowledgement and application of a systematic monitoring program (or network). Development of a monitoring program is dependent on the objective, and a basic objective is to provide the optimal level of information subject to cost.

Identification of the network objectives (and criteria for measuring achievement) is perhaps the most important (if not most difficult) step in network design. Acknowledgement of these objectives, however, should provide a more systematic basis to the network development. To account for these objectives, Sanders and Ward (1978) suggest that the entire monitoring network must be examined and designed simultaneously if a balanced (collection versus use) monitoring system is to be developed. They categorize this system approach to monitoring into five major functions:

1. sample collection,
2. laboratory analysis,
3. data handling,
4. data analysis, and
5. information utilization.

In the context of water quality, these functions serve as a feedback loop from *in situ* water quality conditions to water quality management decision making. The information utilization function (Step 5) not only is dependent on the previous four steps but also establishes their objective or purpose. In particular, the sample colle

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collection process (Step 1) is crucial since 1) the data collected are commonly used to quantify processes that vary in one temporal and three spatial dimensions, and 2) it is usually desirable to use the data collected to determine the character of process changes in space and time (Lettenmaier, 1976). Accordingly, particular attention must be paid to the design of the sample collection stage in order to refine and strengthen the remaining functions (and objectives) of the monitoring system. The sample (collection) design explicitly details what, how and where samples are to be collected and is summarized by Sherwani and Moreau (1975) as consisting of the:

1. parameters to be sampled,
2. sampling frequencies,
3. sample collection methods,
4. design period determination, and
5. sampling locations.

The components of the sampling design should be incorporated into all water quality monitoring programs. Not only should these concepts be applied by the field researcher, but the water quality manager utilizing the reported data should also screen and disregard those reports which do not adequately conform to satisfactory design concepts (and objectives). Such a screening process can occur from an examination of the methods sections of the individual reports.

During this investigator's literature survey of nutrient export coefficients, considerable variability was found in the sampling designs. The lack of well-founded methods (or design objectives) unfortunately resulted in the rejection of some reported values. Since the sampling design

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design components are of such importance to the accuracy and precision of the reported data, the remainder of this chapter will focus on each component individually. It is hoped that researchers will acknowledge some of these standard procedures so that their results may be added to the literature on nutrient export coefficients in the future.

Parameters to be Sampled

eutrophication and the limiting nutrient concept

The problems of eutrophication are very well known and widespread, and the definitions are numerous. Among limnologists, the general concensus is that eutrophic conditions are synonymous with the increased growth rate of lake biota. Although there are many complex interactions connected with this process, the most conspicuous measure of increased productivity is the excessive growth of algae, aquatic plants and oxygen depletion (King, 1979). Under severe conditions, this can result in a general reduction of lake recreational value and aesthetics. If the lake is used as a water supply, clogged screens and higher chemical requirements for purification can increase water treatment costs (Borchardt, 1970).

To produce aquatic plant growth and reproduction, a large number of chemical elements are needed. Essential macronutrients include carbon, oxygen, nitrogen, sulfur, phosphorus, potassium, magnesium and calcium. Essential micronutrients include iron, boron, zinc, copper, molybdenum, manganese, cobalt and sometimes sodium, chlorine and vanadium (Simpson, 1979). While many are required only in trace amounts, certain elements, especially carbon, nitrogen, oxygen,

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oxygen, hydrogen, sulfur and phosphorus, are needed in large quantities because they are the basic building blocks for organic matter (Fruh, 1967; Thomas et al., 1979).

Nutrient utilization is a function of the plant's needs and plant growth is dependent on the presence of a sufficient quantity of nutrients in the water column. According to Liebig's "law of the minimun," the growth of a plant will be limited by those elements available to it in the minimum quantity relative to its stoichiometric requirements. If one compares the nutritional demands of algae to the amounts of nutrients likely to occur in aquatic systems, the limiting nutrients most often would be nitrogen and phosphorus. While these two nutrients are generally accepted as the most limiting, it must be noted that various other elements have at times been suggested as affecting or limiting the eutrophication process. These include iron, molybdenum, sulfate, vitamins, carbon and silicon (Goldman, 1960; Menzel and Tyther, 1961; Goldman and Wetzel, 1963; Goldman, 1964; Lange, 1967; Kuentzel, 1969; Provasoli, 1969; Kerr et al., 1970; King, 1970; Schelske and Stoermer, 1972; Vallentyne, 1974; Rast and Lee, 1975).

The relationship of nitrogen and phosphorus to eutrophication has been well documented (Sawyer, 1947; Sakamoto, 1966; Vollenweider, 1968; Shannon and Brezonik, 1971; Edmonson, 1972; Schindler and Fee, 1974; Vallentyne, 1974; Jones and Backmann, 1975; Rast and Lee, 1978). Of these two nutrients, phosphorus is generally the most common limiting factor, although, under certain conditions, nitrogen may become limiting, especially when man's activities add large amounts of phosphorus to the lake.

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Effluents from sewage treatment plants and agricultural and urban runoff often contain more phosphorus than nitrogen, relative to plant requirements. Thus, in many culturally-impacted lakes, nitrogen appears at times to be the factor limiting growth of many algal types (Dobsen et al., 1974; Miller, 1974; Stadelmann et al., 1974; Rast and Lee, 1978; Thomas et al., 1979). Nitrogen limitation also results from various nitrogen stripping mechanisms within the lake. As organic decomposition and oxygen depletion begins, denitrification occurs. If oxygen depletion is severe enough, nitrogen gas is formed and subsequently lost to the atmosphere (Vollenweider, 1975; King, 1978, 1979).

A major consequence of nitrogen limitation is the production of nitrogen-fixing blue-green algae. These forms are especially prone to cause water quality deterioration because they produce taste and odor problems and because of their ability to float and accumulate on beaches. As the gaseous nitrogen in the water is used up by the nitrogen-fixing algae, it is readily replaced from the inexhaustible atmospheric sources. Thus, it is impractical and very often futile to attempt to control eutrophication by restricting inputs of nitrogen even in areas where it is currently limiting the growth of most algal forms. To rehabilitate such areas, phosphorus inputs must be lowered to the point where phosphorus replaces nitrogen as the limiting factor, and then further reduced so that growth and yield of all algal forms is reduced (Thomas et al., 1979).

This reliance on phosphorus control (over nitrogen) for lake mana

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management and rehabilitation is based on two reasons (Reckhow et. al., 1980):

1. Phosphorus is often the major nutrient in shortest supply relative to the nutritional needs of algae and aquatic plants. This means that the concentration of phosphorus is frequently a prime determinant of the total biomass in a lake.
2. Of the major nutrients, phosphorus is the most effectively controlled using existing engineering technology and land use development.

Because of these relationships, it is easy to visualize the role phosphorus must play in any management plan to control cultural lake eutrophication. Therefore, phosphorus is the parameter to be sampled for non point source lake nutrient budget estimates. While the major emphasis is on phosphorus and its management, where applicable, information on nitrogen relationships and interactions, as they relate to the components of sampling design and diffuse runoff, will be presented for comparison purposes.

bioavailability

Phosphorus is collectable in basically two forms; particulate and solution. The particulate form consists of total particulate and sorbed or labile phosphorus. The solution form consists of total soluble, molybdate reactive and soluble unreactive phosphorus (Porter, 1975).

Until recently, eutrophication control programs have been based c

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largely on the regulation of any fraction of phosphorus that was amenable to management, irrespective of whether the phosphorus was in an available form which could support algae growth. More specifically, availability is defined as that nutrient fraction available for biological uptake and algal growth within one growing season. This has raised some serious questions concerning what fractions should be collected and/or measured.

It is generally agreed that the soluble inorganic forms of phosphorus are readily available biologically. This includes forms such as the soluble orthophosphates and condensed phosphates. There is a high degree of uncertainty, however, concerning what fractions of particulate inorganic and organic forms are available. Complicating matters is the presence of dynamic and complex sets of physical, chemical and biological processes which determine this availability in the aquatic system. For example, sediment-attached phosphorus that is not available under certain chemical conditions at one point in time, may become available under the same or different chemical conditions at another point in time. This is in sharp contrast to the static and controlled nature of the laboratory conditions where a variety of techniques are used to correlate algal uptake with actual and highly variable *in situ* conditions. Consequently, any estimates of bioavailability must be viewed with a high degree of uncertainty and as only "ball park" approximations.

One of the more comprehensive studies concerned with assessing algal-available phosphorus was conducted by Cowen and Lee (1976a, b) and Cowen (1974). From both urban runoff samples collected in Madison, Wis

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Wisconsin and agricultural runoff samples obtained in New York State, these investigators determined that in the absence of site-specific data, an upper bound estimate could be made of the available phosphorus in tributary waters:

$$\text{available P} = \text{SRP} + 0.2\text{PP}_T \qquad (1)$$

where:

SRP = soluble reactive phosphorus

PP_T = total particulate phosphorus

Lee et al. (1979) later made the following recommendation for the available phosphorus load from urban stormwater drainage and normal-tillage agricultural runoff. If the runoff enters a lake directly, or encounters a limited distance of tributary travel between source and lake, then the available phosphorus loading may be estimated as:

$$\text{available P} = \text{SP}_O + 0.2\ \text{PP}_T \qquad (2)$$

where:

SP_O = soluble orthophosphorus

Additional studies have demonstrated comparable, albeit variable, results. Based on independent, but limited, studies of rivers in the Great Lakes Basin, 40% or less of the suspended sediment phosphorus is estimated to be in a biologically available form. Overall, probably

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no more than about 50-60% of the tributary total phosphorus (including soluble P) is likely to be biologically available (Logan et al., 1979; Armstrong et al., 1979; Songzoni and Chapra, 1980; Thomas et al., 1979).

In contrast to phosphorus, the fraction of total nitrogen available for plant utilization can be higher since nitrogen is more soluble and, therefore, more easily transportable by water. The concentrations of nitrogen compounds in overland runoff are often many times higher than the critical level of 0.3 mg N/l of inorganic N, which was suggested by Sawyer (1947) for algal growth problems in lakes. Inorganic nitrogen forms such as ammonia, nitrite and nitrate are readily available for algal growth. However, the availability of the total nitrogen will depend on the relative amounts of the organic and particulate fractions in the runoff and their equilibrium and mineralization rates.

From studies of urban runoff in Madison, Wisconsin, Cowen et al, (1976), determined that 70% of total N was biologically available (with a range of 57-82%) as a result of nitrogen mineralization. Similar results were also found in earlier studies with river waters tributary to Lake Ontario (Cowen and Lee, 1976b).

It was previously mentioned that availability applies to the nutrient fraction that is utilized within one growing season. However, depending upon the conditions, there is a potential for at least some (if not all) of the remaining fractions of particulate/organic phosphorus or nitrogen to be utilized at a later date (due to sudden equilibrium changes). This remaining fraction can represent a significant, if unmeasurable, nutrient reservoir. In addition to this, the

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the collection of total (soluble and particulate) nutrient fractions is advised since total availability is unpredictable and depends, in part, on the ratio of particulate to soluble nutrient forms in the sample. This is especially important since particulate phosphorus or nitrogen can be an order of magnitude greater in quantity than the reported dissolved fraction. In this situation, failure to adequately assess the particulate forms can result in substantial underestimation of the total available fraction.

Sampling Frequency

Variation in nutrient flux through time is intimately linked to changes in flow. Both dissolved and particulate fractions respond to these flow changes differently. Proper assessment of the particulate fraction requires a greater emphasis on sampling during storm events since the bulk of this fraction is carried with stormwater runoff. Although variation exists, the response of both dissolved and particulate fractions relative to the storm hydrograph can be discussed in somewhat general terms (see Figure 1).

The initial storm induced increase in streamflow is often associated with a decrease in the dissolved nutrient fraction. This decrease is attributed to the dilution effect of the greater runoff volume as well as the resulting greater contribution from overland flow and reduced contribution from soil water which comprises baseflow. This results in the lowest dissolved concentration at the peak of the hydrograph. As flow rates decrease, the dissolved component tends to gradually increase to concentrations approaching that of the pre-storm

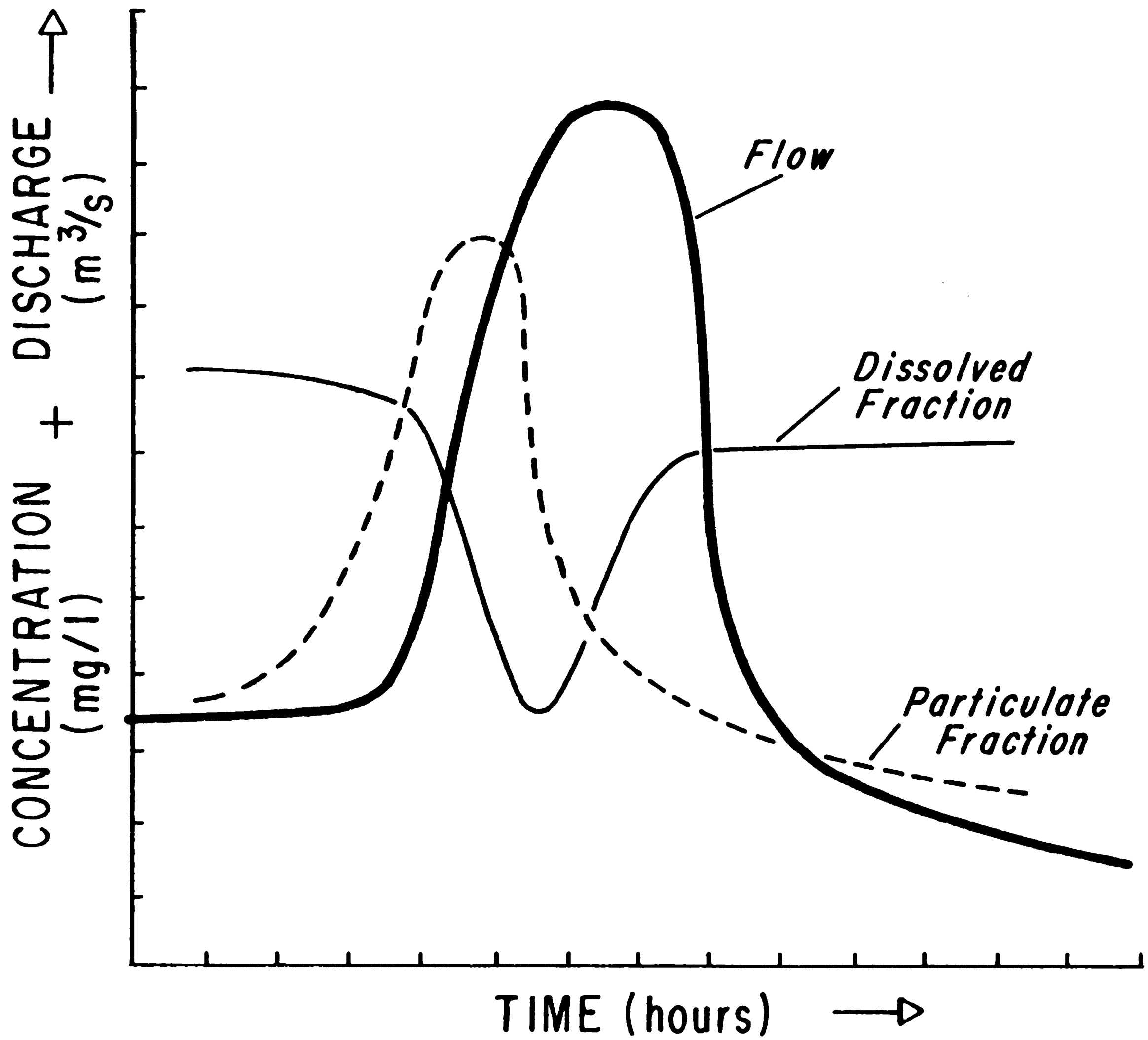

Figure 1: Dissolved and Particulate Nutrient Response to the Storm Hydrograph.

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baseflow conditions. This is because of the greater soil-water contact time associated with increasing contributions of soil water to baseflow.

For the particulate (or sediment) fraction, a different response is evident. During the initial rapid rise of the hydrograph, the particulate component increases dramatically - often reaching a maximum concentration preceding peak flow. This phenomenon, often referred to as "first flush," is the result of the dislodging of particulate matter from the land surface during the initial stages of runoff, leaving little material for transport at later periods. Regardless of where the particulates "peak out" relative to the hydrograph peak, a decrease in flow is accompanied or preceded by a decrease in particulate concentration.

To adequately account for these variabilities, and to reduce the amount of uncertainty in the phosphorus loading estimate, the sampling frequency should be dictated by the hydrologic response. Many previous sampling studies have failed to address this issue but have instead made broad but untested assumptions concerning watershed hydrology and loading responses. Sampling intervals have ranged from once per week to irregular periods during the year, resulting in many of the more sporadic storm events being missed.

Hydrologic response (and sampling frequency) differs according to drainage basin characteristics. As land use progresses toward urbanization, channels are straightened or paved, small tributaries are filled and the watershed surface generally becomes smoother and more conducive to sheet runoff. Therefore, as land use is intensified

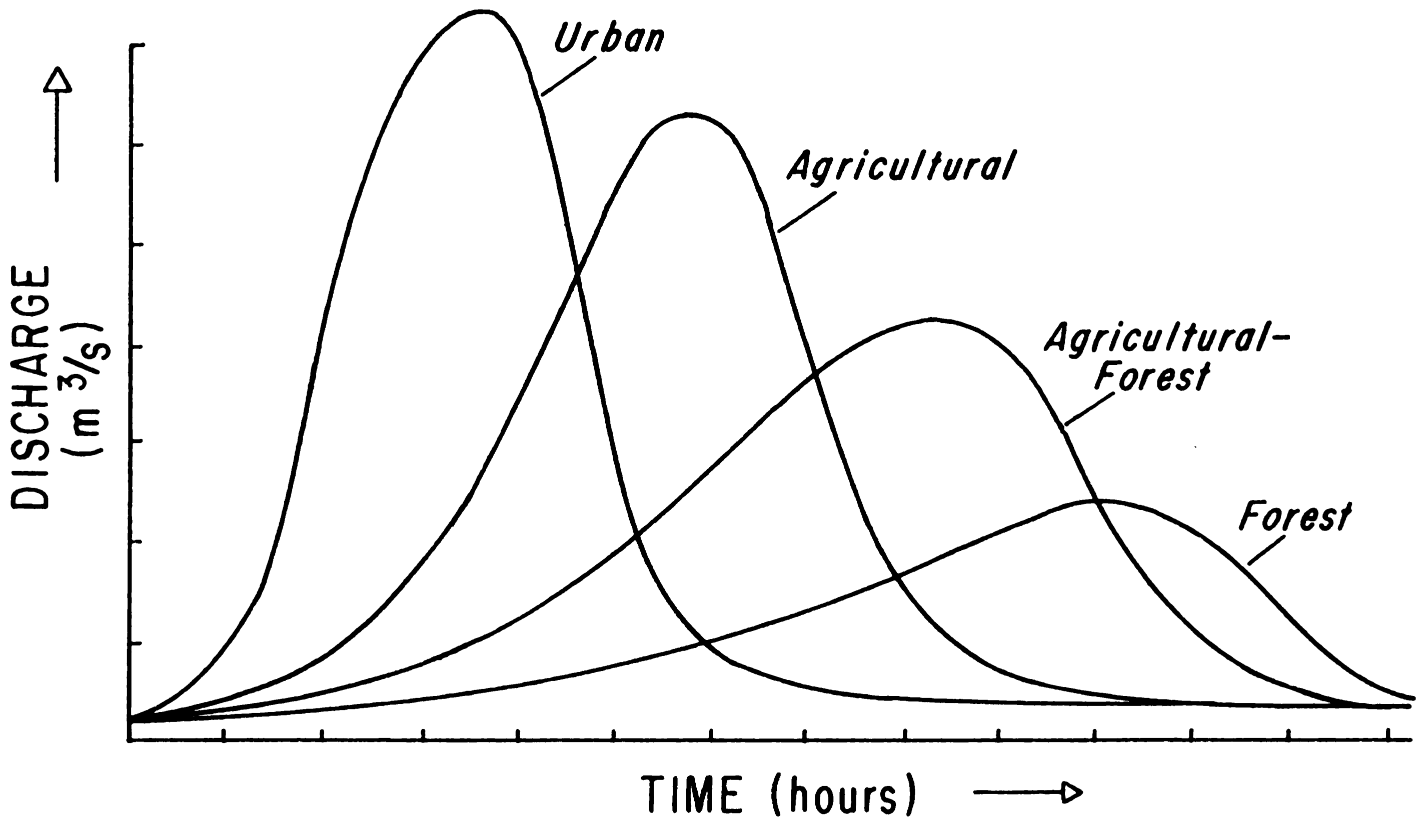

Figure 2: Hydrographic Response of Varying Land Uses to a Storm Event.

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3. half-life and response time of constituents,
4. seasonal fluctuations and random effects,
5. representativeness under different flow conditions,
6. short term pollution events,
7. magnitude of response, and
8. variability of the inputs.

Simply stated, there is no single best sampling frequency for all conditions. However, sampling frequency should be a function of the effect on the precision of the nutrient budget estimate (i.e., is uncertainty minimized?), and the associated cost.

For many sampling programs, the actual design is often based on random sampling. Under random sampling, all elements of the population have an equal likelihood of being selected for the sample. Cochran (1963) presents the following equation for the number of samples necessary to achieve a desired level of precision:

$$n = \frac{t^2 s^2}{d^2} \tag{3}$$

where:

n = number of samples

t = student's t

s^2 = population variance estimate

d = desired precision

This, in turn, may be related to cost through the common cost function:

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$$C(n) = c_o + c_i n \tag{4}$$

where:

$C(n)$ = total cost of sampling program

c_o = initial, fixed cost

c_i = cost per sample

Thus, random sampling design is specified by the variance estimate, the precision, and the sampling program cost (or number of samples). For a single population with constant variance, sampling frequency can be evaluated on the basis of a trade-off between cost versus precision, or uncertainty (Reckhow, 1978). However, in order to effectively apply Equation 3 for random sampling design, an estimate of the population variance is needed. According to Reckhow (1978), this implies specification of the population frequency distribution, and given the limited available data on nutrient mass flux to lakes, this is a difficult task.

The sampling collection process can often be made reasonably more efficient (further reducing loading uncertainty and increasing accuracy and precision) if a stratified random sampling program is employed (Reckhow, 1979). Under this sampling scheme, the population is divided into homogeneous sub-populations (strata) that are separately sampled according to the degree of variability which they exhibit (Snedecor and Cochran, 1973). The underlying assumption is that the population can be more accurately represented as the sum of sub-populations, therefore reducing the sample variance.

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In the context of hydrologic data collection, two temporal strata are evident:

1. high flow events produced by rainfall runoff and snowmelt, and
2. baseflow produced by groundwater flux.

To expect a gain in precision over simple random sampling, more frequent measurements should be applied to the stratum represented by high flow events. If the sample size is increased in this stratum and the final concentration properly weighted, a more precise and accurate estimate of the population average will be obtained. From a survey on sampling design, Reckhow (1979), states, that "sampling is allocated in stratified random sampling design according to:

$$\frac{n_i}{n} = \frac{w_i\ (c.v.)_{x_i}\ (x_i)}{\Sigma w_i\ (c.v.)_{x_i}\ (x_i)} \tag{5}$$

where:

n = total number of samples

n_i = number of samples in stratum i

x_i = magnitude (mean) of characteristic x in stratum i

w_i = a weight reflecting the size (number of units, for example) of stratum 1

$(c.v.)x_i$ = coefficient of variation (standard deviation divided by the mean) of characteristic x in stratum i

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If sampling cost may be estimated by:

$$C = c_o + \Sigma c_i n_i \tag{6}$$

then

$$\frac{n_i}{} = \frac{w_i\ (c.v.)_{x_i}\ (x_i)/\sqrt{c_i}}{\Sigma w_i\ (c.v.)_{x_i}\ (x_i)/\sqrt{c_i}} \tag{7}$$

In order to apply Equation 5 or 7, a relationship is needed for the total number of samples n. Two equations are available, depending upon whether precision or cost is fixed beforehand. If precision is fixed (at d), and cost may be estimated according to Equation 6, then (Cochran, 1963):"

$$n = \frac{[\Sigma w_i(c.v.)_{x_i}(x_i)\ \sqrt{c_i}]\Sigma w_i(c.v.)x_i(x_i)/\ \sqrt{c_i}}{d^2/t^2} \tag{8}$$

If cost is fixed, then (Cochran, 1963):

$$n = \frac{(c\ -\ c_o)\Sigma(w_i(c.v.)_{x_i}(x_i)/\ \sqrt{c_i})}{\Sigma(w_i(c.v.)_{x_i}(x_i)\ \sqrt{c_i})} \tag{9}$$

In summary, Reckhow (1978) concludes that the composition of the stratified random sampling design equations leads to the following gener

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general statements concerning stratified sampling. A larger sample should be taken in a stratum if the stratum is:

1. more variable (c.v.)
2. larger (w, x)
3. less costly to sample (c)

Sample Collection Methods

Hydrographic response and the associated pollutant loads vary widely between event/non-event periods thus increasing the potential for considerable estimation error. Since conclusions are naturally drawn from the nutrient estimates, it is imperative that both 1) methods of acquisition of concentration samples and flow values, and 2) flux estimation techniques, do not introduce unacceptable bias.

Concentration samples are determined by a variety of field collection techniques. One common method is manual grab sampling which usually involves the collection of samples at a predetermined rate, such as once per week, month, etc. However, grab sampling conducted on a uniform basis usually provides an adequate description of baseflow conditions only, since periodic storm events are often missed. In this respect, manual collection methods are often inadequate for storm event monitoring since:

1. Storms are highly random with respect to their timing, location, intensity and duration.
2. For large watersheds, travel time between stations is often great.
3. For small watersheds, runoff duration and associated

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lag time is relatively short (Nelson et al., 1978) with sharper peaks and higher storm levels (Likens et al., 1977).

4. The time between the period when the probability of the storm event is high to the time when it occurs is usually very small (i.e., warning time is short).

Because of these factors, the ability to mobilize field personnel and equipment is severely limited especially when one considers the probability of an event occurring during regular working hours. The cost of maintaining competent field crews on a round-the-clock basis for an extended time period would be prohibitive (Colston, 1974; Sherwani and Moreau, 1975).

To reduce the inefficiencies (and bias) of manual collection, many water quality studies have relied on automatic collection methods. Probably the simplest of these methods is the batch holding tank, which collects runoff, diverted by gutters or flumes, at the base of the watershed (or runoff plot). Under some conditions, however, this collection method is inadequate. With large watersheds or storms of long duration, holding capacity can be exceeded and a portion of the total load will be undetected. For some storms, the greater nutrient concentration associated with the first flush can be obscured by additional, less concentrated runoff.

More adequate, automated devices can collect individual samples during a storm event. The collection process can occur at either equal time intervals or on a flow-weighted basis. Sampling at equal time intervals, however, is often less desirable. Since each aliquot is g

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is given equal weight, the higher nutrient concentrations associated with first flush will be underrepresented. If the formula for the calculation of average concentration is examined:

$$\bar{c} = \frac{\sum_{i=1}^{n} c_i}{n} \tag{10}$$

it should be apparent that, as a consequence of this underrepresentation, the "average" computed concentration will be biased too low (McElroy et al., 1976; Grizzard et al., 1977; Huber et al., 1979). Flow-weighted sampling is a more precise concentration estimate since sample volume is accounted for and sample concentration appropriately weighted according to the following equation (Huber et al., 1979):

$$\bar{c} = \frac{\sum_{i=1}^{n} c_i \; Q_1}{\sum_{i=1}^{n} Q_i} \tag{11}$$

where:

Q_i = flow volume

Accordingly, high concentrations associated with first flush are more equitably represented than concentration estimates calculated from equation 10. This results in a lower variance and greater accuracy of the reported data.

In addition to the method and frequency of collection, Colston (1974) notes many special requirements of automatic samples. These include the following:

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1. The sampler should not interfere with water flow and must be immune to damage from larger objects and debris washing downstream during storms.
2. Water velocity through the system must be sufficient to keep all material in suspension to obtain representative samples and minimize system clogging.
3. The sampling mechanism must automatically activate during each runoff event.
4. The sampling system must be able to take discrete samples at predetermined intervals with a known time for the first and last sample.
5. The sampler intake must represent an average of the verticle profile of contaminant concentration with respect to depth.

While concentration samples should be collected during major storm events (or at least a representative number of storm events), the effectiveness of the "appropriate" number of samples to be taken during the temporal extent of sampling should also be considered. Reckhow (1978) reported on three papers, previously surveyed by Allum et al. (1977), discussing intensive sampling of tributary phosphorus. In all three studies, the sampling was quite frequent (twice weekly or daily). However, at a concentration sampling interval of between 14 and 28 days, the standard error of the annual phosphorus flux varied between 10% and 20% of the "true" flux.

Reckhow (1978) further comments that:

1. More frequent sampling will still reduce uncertainty

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in the phosphorus concentration, but at a reduced efficiency.

2. Less frequent sampling can still be used to estimate phosphorus concentration, but at a greater risk of significant error.

Flow estimation is determined by three methods. The most preferred method is continuous flow measurement, and many sampling studies take advantage of USGS gauging stations. Without these facilities, it is costly and often not feasible. Another alternative is to measure instantaneous flow at the time of concentration sampling. However, Reckhow (1978) argues that this method must be considered unacceptable because it does not yield an estimate of precision. A more acceptable third alternative is an annual flow regression equation developed by the USGS (for most states) which provides an estimate of annual flow and the estimated standard error (Reckhow, 1978).

To estimate flux, Reckhow (1978) surveyed a number of approaches described in the literature, each of which could be appropriate under certain conditions. These include techniques dependent upon a:

1. regression of mass flux versus watershed characteristics,
2. flow-weighted concentration,
3. regression of concentration versus flow, and
4. regression of flux versus flow.

He concludes that the estimation technique used should probably depend upon the:

1. intended use (A regression on watershed characteristics and land uses may be useful for future predictions.),
2. fit of the data to the equations, and

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3. simplicity of the mathematics.

The studies selected for inclusion in the nutrient export coefficient tables employ a wide variety of sampling techniques, but nearly all are based upon complete flow records and adequate baseflow concentration samples. While storm runoff was not sampled at every event, it was felt that a sufficient number of events were examined to allow for realistic estimates of the total load for a particular land use.

Temporal Extent of Sampling

Climate determines local weather conditions which in turn influence the quantity and duration of baseflow and the number and periodicity of storm events. While some areas of the country exhibit relatively uniform climates (e.g., pacific northwest) evenly distributed periods of precipitation are usually not the norm. Winter thaws and spring or summer rains often create seasonal cycles of high and low runoff.

Intimately associated with climatic periodicity is the modifying impact land use has on hydrologic response. The relatively uniform annual flow patterns of many undistrubed forests is in sharp contrast to the highly variable flows emanating from urbanized and agricultural basins. As vegetative cover is artificially reduced and the basin is increasingly developed, groundwater recharge and flux are reduced. Baseflow and nutrient export are often either inconsequential or absent during dry summer or winter periods. Consequently, a greater percentage of nutrient export occurs during wet periods of the year for disturbed watersheds than for undisturbed watersheds.

As a result of this seasonal variability, high runoff seasons exhi

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exhibit greater variance in nutrient concentrations and total nutrient loads than do low runoff or baseflow periods. For a given confidence level (precision) and a margin of error (accuracy), the temporal extent of sampling must include these high and low runoff periods (especially for the more disturbed watersheds). If sampling duration focuses exclusively on one season (e.g., spring), the nutrient flux estimate may sufficiently describe that time period but may not be indicative of other unsampled periods. For this reason, the analyst is warned against extrapolating seasonally reported results toward more extended time frames. This will bias the nutrient flux estimate toward whatever season in which the sampling was performed. To better account for this seasonal variability and to allow for a more standardized unit of measure for comparison purposes, a more informative approach is to sample and report the data in yearly increments.

While the bulk of studies included in the export tables are the result of intensive sampling and annual flow data, many investigators have refined the sampling period within the water-year time frame. According to Likens et al. (1977), the ideal water-year is that successive twelve-month period that most consistently, year after year, gives the highest correlation between precipitation and streamflow.

Examination of precipitation-streamflow data at Hubbard Brook resulted in a water-year beginning June 1 and ending May 31. Since the beginning of this water-year corresponds with the appearance of foliage, it allows for a separation of the vegetation growth and dormancy periods. This concept has been effectively applied by other investigators working with agricultural land uses (Alberts et al., 1978;

Burwell et al., 1975).

Watershed Designs and Locations

Of the criteria necessary for a non point source monitoring program, the sampling location, or more importantly, the watershed design, is crucial for accurate estimation of nutrient yields. To facilitate the sampling site/design selection process, two key interrelated factors are involved: the specific objective of the network design and the representativeness of the sample to be collected. To accomodate these factors, two basic approaches to diffuse load assessment are, in turn, available.

The first approach involves sample collection from relatively large streams draining large watersheds. If storm and seasonal hydrologic response are routinely sampled throughout the year, an accurate representation of total annual nutrient flux from particular drainage basins can be obtained. This approach has been extensively used to obtain estimates of Great Lakes tributary loads by the Pollution from Land Use Activities Reference Group (PLUARG) associated with the International Joint Commission.

A number of disadvantages to this approach have been noted (Whipple et al., 1978). First, many large streams, particularly in urban areas, include inputs from industrial and municipal point sources, so that total loading does not relate directly to pollution from storm water runoff. Second, subtraction of known point loads from total yield can result in a biased diffuse load estimate. This occurs because the magnitude of reactions such as sediment attenuation, nutrient

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uptake and degradation by bioseston are not accurately accounted for at the downstream sampling site. Since point sources, determined at their end-of pipe source, do not undergo these transformation processes, their subtraction from total loads may result in an underestimation of diffuse source contributions. (Alternatively, if there is no net accumulation of material in the stream, over a sufficiently long time period all phosphorus discharged will reach the lake. In the steady state, this suggests no bias from point source subtraction.)

Third, the land use of large watersheds is very often mixed, in proportions which vary from one tributary to the next. This makes it difficult if not impossible to determine the percent loading contribution from each land use, and application of the results to other watersheds for prediction purposes remains questionable.

If the objective of the sampling design is to describe runoff loads from specific perturbations, representativeness will depend on a comprehensive approach. This second approach is more specific and is based on the examination of drainage from catchment basins which define a particular land use. In order to maintain homogeneity, the monitored watersheds are relatively small (except for some forested systems).

The advantages to this approach are essentially two-fold. First, land use - water quality relationships are more carefully defined allowing for contrasts between natural and manipulated ecosystems. By comparison this can provide information about the functional efficiency and "health" of a particular land use. For instance, is a particular land use conservative of nutrient inputs (forests) or is the

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the assimilation capacity limited (pasture) or exceeded (feedlots)? Second, the results can be used in conjunction with other similar studies to predict future water quality changes corresponding to projected land alterations.

Because of the identified advantages, a large percentage of nonpoint source water quality investigations have utilized this latter approach with forest, agricultural and urban activities as the major land use categories studied. The remainder of this subsection contains a discussion of how diffuse runoff is monitored from each of these land use types.

forest land use

In order to provide hydrologic and nutrient flux information from natural (undisturbed) ecosystems, a number of experimental forested watersheds have been established across a wide range of climates, geology and biological structure. Some of the well-known watersheds are Hubbard Brook Experimental Forest in New Hampshire, Walker Branch Watershed in Tennessee, H.J. Andrews Experimental Forest in Oregon and Coweeta Hydrologic Laboratory in North Carolina.

Although biological (species type and age) and geological characteristics (bedrock and soil) are often substantially different among watersheds, the watershed designs are usually quite similar. Each drainage basin has to some degree vertical and horizontal borders, demarcated by ridges and functionally defined by biological activity and the drainage of water (Bormann and Likens, 1967).

Accurate monitoring of total hydrologic flux can pose problems.

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Since forest cover and litter layer dissipate much of the energy from precipitation events, infiltration is high and the opportunity for overland flow is slight. The runoff that does occur is usually associated with snowmelt events. To register the greater percentage of subsurface slow, v-notch weirs or flumes are often anchored to the bedrock at the base of each watershed.

As the size of the forested area increases, flow measurement methods change. Drainage basins covering hundreds or even thousands of hectares use gauging staffs or other flow measuring devices to determine the proportionately greater flow volumes. While automatic sampling devices facilitate collection in the smaller basins, manual methods often still persist in the larger watersheds because of the relative uniformity of forest flow and chemical concentration.

agricultural land use

Water quality monitoring in agricultural settings is often conducted in a manner similar to that for forested systems. Areas of agrarian activity are defined and the resulting runoff is examined separate from the influence of other land activities. Numerous studies are available which give representative loading estimates from general agricultural land use (Avadhanula, 1979; Campbell, 1978; Burton et al., 1977; Lake and Morrison, 1977; Grizzard et al., 1977; Nelson et al., 1978; Burwell et al., 1974; Taylor et al., 1971).

In contrast to nutrient export from forested systems nutrient export from agricultural areas demonstrates wide variability. Practices are highly diversified and an agricultural basin can consist of

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a mosaic of different uses such as pasture, feedlots, row and non row crops. Each type of perturbation creates different hydrologic responses, and depending on the percent composition of the basin, the effect of one activity can influence the final nutrient load. In order to further delineate these effects, individual activities should be, and often are, separately monitored.

Separation of the various agrarian activities into discrete hydrologic units is conducted through two basic approaches, and the differences between approaches are based primarily on the size of the basin under study. The first approach relies on relatively large dyrdologic units ranging from 5-500 hectares in size. In spite of these dimensions, the entire catchment basin contains a single activity such as row crop or pasture (Alberts et al., 1978; Chichester et al., 1979).

The second technique employs several small runoff plots, usually much less than a hectare in area. Separated by raised metal, wood or concrete borders, the individual plots are 2-5 meters wide and 10-25 meters long. Runoff studies using these plots may include 1 to 2-individual plots. At the base of each plot is the flow/sampling device often consisting of a collecting tank which generally relies heavily on "batch" collection methods.

Because of the low area and labor requirements, this particular design has increased in use by university agricultural experiemnt stations and other research agencies. Small size permits close proximity to research facilities and personnel, which allows for both close monitoring and manipulation of environmental conditions such as soi

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soil, slope, fertilizer, tillage methods and crops.

urban land uses

Sampling site selection for urban runoff monitoring potentially poses some additional problems not encountered in agricultural watersheds. Since it is not economically feasible to re-create urban settings using small runoff plots, available conditions must be utilized. These conditions simultaneously impose an expanding set of limitations on data transferability.

Urban runoff is often channeled into storm sewers which later discharge into nearby tributaries. In order to derive an areal loading rate, however, it is first necessary to ascertain that the network of storm sewers is restricted to the boundaries of the watershed and does not contribute runoff from other basins.

Many cities have combined storm and municipal sewers. During high runoff events, domestic sewage often overflows and mixes with effluent within the sewer system. While providing valuable information about a particular site, the results are difficult to apply to other areas because of the inability to separate the proportion of point source contributions from total flow.

If the above spatial uncertainties can be accounted for, the "flashy" nature of the individual runoff event must be suitably monitored. To accurately assess these transient events, flow must be continuously monitored. (To reduce monitoring costs, it is often necessary to locate the study site in close proximity to established stream gauges such as those used by USGS.) Similarly, water quality sample

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samples are (or should be) collected with automatic samplers.

Similar to agricultural lands, urban areas consist of a number of different land activities. These activities include industrial complexes, business and commercial districts, parking lots, residential areas, parks and playgrounds. Because of differing surface characteristics, the hydrologic and water quality responses from city parks or even large heavily vegetated residential lots are often quite different from the response from the essentially sealed surface of shopping malls or industrial complexes. Separation of these discrete types of activities into distinct drainage basins is not always possible because of the lack of conformity with topographical boundaries.

A study by AVCO (1970) indicates that aside from these problems, the following factors also influence site selection for urban runoff studies.

1. Minimum area requirements for the acquisition of a measurable sample.
2. Security of the sampling equipment from vandalism.
3. Accessibility of the sampling site.

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CHAPTER III

FOREST LAND USE

Introduction

The world's increasing population co-exists with a diminishing stock of resource reserves. Because of this dichotomy, man's future welfare may more than ever depend on an accurate knowledge of how the flow of energy and nutrients vital to ecological systems can be maintained. To more effectively facilitate resource decisions involving land use, it is imperative that planners/managers have a workable understanding of how undisturbed systems, such as forests, operate.

In forested ecosystems, nutrient flux is primarily through meteorological, geological and biological transport mechanisms. According to Likens et al. (1977), 1) biological inputs are assumed to equal outputs (unless a phenomenon such as animal migration imports more than it exports or vice versa), and 2) geological imports will be negligible (if ecosystem boundaries are sufficiently defined). Thus, nutrient inputs into unmanipulated forests are principally from the meteorologic vector (i.e., dust and rainfall) and export from the system is via geologic outputs (i.e., surface and subsurface drainage).

Within the ecosystem, forests can be viewed as complex processors in which nutrients are translocated from one portion of the community to the other. This nutrient exchange process involves biological,

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physical and chemical interactions and is often referred to as the biogeochemical cycle. This cycle can be described in very general terms. For example: a percentage of nutrients not retained within the plant's woody tissue is returned to the forest litter where it may be acted upon by microorganisms and subsequently passed on to heterotrophic consumers. Through respiration, organic decomposition and/or leaching from living and dead tissue, bound nutrients once more become soluble and available for plant uptake and recycling.

The major sites of accumulation and exchange within the system have been conceptualized as occurring among four basic compartments; 1) atmosphere, 2) living and dead organic matter, 3) available nutrients, and 4) primary and secondary minerals (Likens and Bormann, 1972; Likens et al., 1977). This proposed black-box scenario (Figure 3) provides a framework whereby not only structure and function are accounted for but ecosystem development and degredation can also be considered in light of an imbalance in any of these compartments.

Factors which influence this accumulation and exchange process also have an impact on total nutrient output from the watershed in streamflow. The rates at which these nutrients leave the watershed are affected by the manner in which these elements are circulated between the forest vegetation and the underlying soil, especially the degree to which these elements are bound into organic matter and held in tight circulation. No matter how tight the circulation, however, some loss of nutrients in water moving under and over the soil surface into the stream is inevitable.

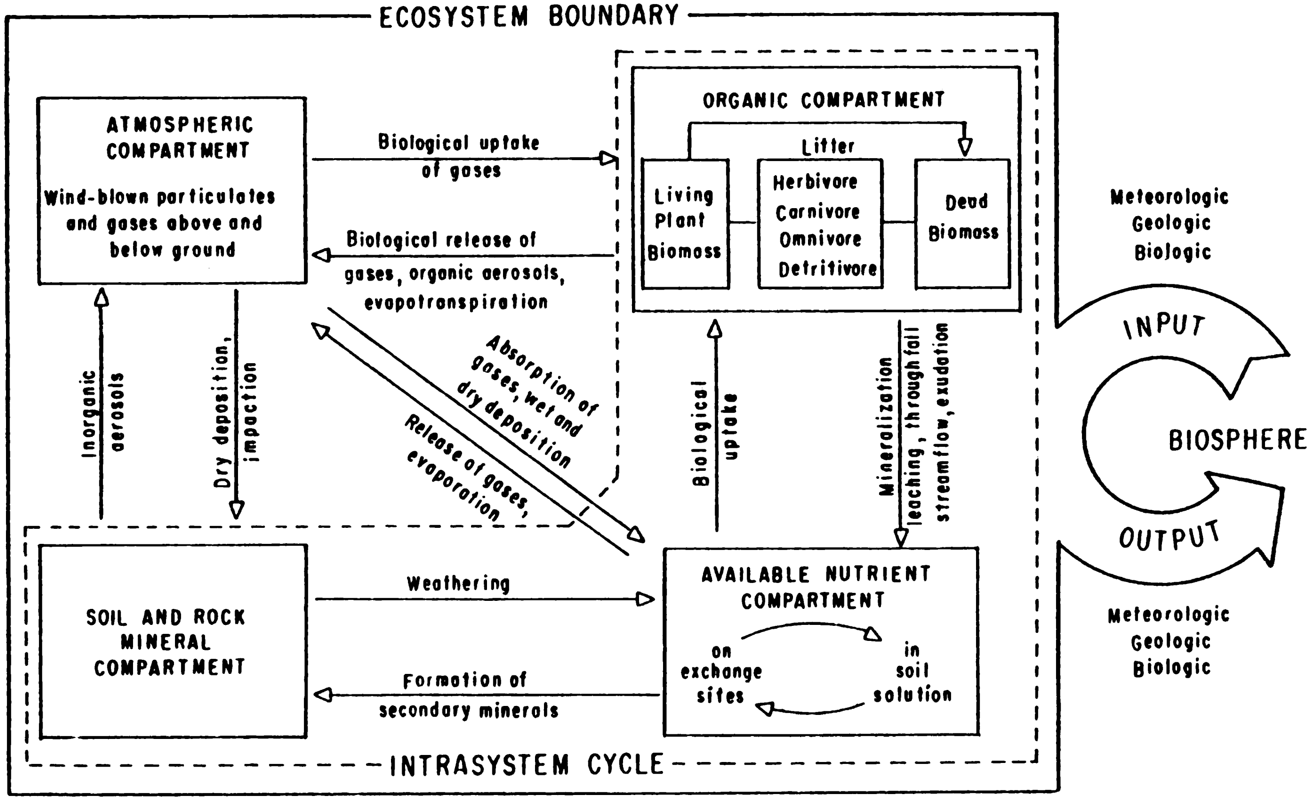

Figure 3: Major sites of accumulation and exchange within the forested ecosystem. From Likens et al., 1977.

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In general, aggrading forest systems retain nutrients relatively effectively as compared to other land uses. From a comparison of precipitation inputs to streamflow outputs, it appears that nutrients released from organic decomposition and the weathering process are rapidly incorporated by the vegetation to produce a net gain in nitrogen and phosphorus (Frederiksen et al., 1975; Singer and Rust, 1975; Likens et al., 1977; Swank and Douglass, 1977). Although the range of nutrient export from forested watersheds is relatively narrow (see Table 1 - page 63), a number of interaction factors such as geology, climate, vegetation type, and ecological succession can often influence the magnitude of elemental outflow concentrations and nutrient flux.

Geology

The geological influences on stream nutrient concentrations and loads should be considered. Unfortunately, little information is currently available on specific effects.

A study of southern Ontario drainage basins by Dillon and Kirchner (1975), indicates a strong influence of geology on stream phosphorus loads. Generally, their median value for phosphorus loads from streams draining sedimentary watersheds is 2-1/4 times greater than those from igneous watersheds. Similarly, Jones and Bachmann (1978), noted a greater ion content (especially for nitrogen) in lakes located in glaciated regions than in those of older non-glaciated areas.

From a comparison of forested watersheds from the nationwide

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EPA-NES survey, Omernik (1976) failed to reveal significant effects of geologic origin on either stream nutrient concentrations or loads. Omernik does suggest, that more appropriate comparisons should be based on the mineral composition of rocks rather than being based entirely or primarily on origin. Such a scheme might include two groups: one containing rocks generally considered as being high in phosphorus content and a second class containing rocks having very little phosphorus. Rocks included in the first, or "high" phosphorus group, would be the gabbros, diorites, and basalts or rocks largely composed of ferromagnesian minerals and containing considerable apatite (Goldschmidt, 1958).

The apatites represent by far the major amount of phosphorus in the earth's crust and contain nearly all the phosphorus in igneous rocks (Rankama and Sahuma, 1950). These mineral forms, however, particularly the high crystalline ones, are very insoluble and become available to organisms only slowly through physical or biological dissolution (IJC, 1977). Because of this, the phosphorus is generally termed "non-biologically" available. The rates of solution are sufficiently slow that the presence of even large quantities of cyrstalline apatite minerals in lake sediments is not apt to contribute significantly to lake eutrophication (Omernik, 1976), especially if more readily available forms are present.

Common rocks in the "low phosphorus" group include granite, syenite, granodiorite, rhyolite and andesite; or rocks largely made up of aluminosilicate minerals and containing little or no apatite.

Reinforcing this proposed method of comparison are studies by

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Smith et al. (1978) which suggest that the unusually high phosphorus load entering their study lakes may have been the result of erosion material containing naturally occurring calcium-phosphate apatites. Citing early studies performed in Kentucky, Thomas (1970) shows that streams draining high and low phosphorus limestone areas contain high and low phosphorus concentrations, respectively.

Although this scheme represents a better breakdown for studying the effects of general rock types on stream nutrient concentrations, Omernik (1976) suggests that it may present difficulties. For many parts of the U.S., geologic maps with the level of detail necessary to accomplish this breakdown, may be lacking or difficult to obtain.

Vegetation, Soil Type and Climate

Among the many interacting factors influencing nutrient flux in the forest community, vegetation, soil type and climate play major roles. Many vegetation types have the ability to either 1) reduce flow rates, or 2) repress/accelarate certain chemicals processes which lower/raise stream concentrations. Both measures can effectively control total nutrient export.

Active chemical weathering and organic decomposition occur in soils. On a long term basis, soluble compounds are extracted from originally insoluble minerals. In the short term, ion exchange and storage occur between soil solutions and solid soil components. In this latter function the soil may act as a chemical buffering agent with respect to the composition and concentration of solutes in groundwater (Johnson et al., 1969). Direct mineral soil influences

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on streamwater quality are often minimal since overlying humus and litter layers tend to protect the surface layers from direct rainfall impact (Singer and Rust, 1975).

Climate, however, is generally considered the most important single factor influencing soil formation. This is partially because of the influence it has on the distribution of vegetation and their associated fauna and microflora. As a consequence of the climate-vegetation interaction, soils tend to be distributed in broad zones which correspond roughly to the vegetation zones of the world. Since the structure of a plant community is similarly determined by climate and soil, broad areas of the world have been mapped into major ecosystems and biomes.

Instead of examining all species and soil types separately, this investigator will broaden the following discussion to include similar ecosystems or biomes. The remainder of this section will focus on the following major biomes in relation to water quality: 1) boreal-subalpine forest, 2) northern temperate rain forest, 3) temperate deciduous forest, and 4) temperate evergreen forest.

Boreal, Subalpine Forest Biome

Boreal, taiga, subalpine-subarctic forests are distinguished from other biomes by their cold winter and cool summer climate. Vegetation consists of spruce, fir, larch, tamarac and pine. Mean annual rainfall is generally less than 90 cm, however, the surface (humus) layer is perpetually moist.

The cold, wet substrate conditions favors slow organic decomposition and subsequent accumulation of a thick acid humus consisting of unconsolidated decomposing plant material which gradually but continuously releases organic acids. As a result, mineralization rates are low, producing chronic nitrogen deficiencies (Weetman, 1962), and cations (Fe, Al, Mn and Ca) are leached from the upper soil layers, reducing phosphorus retention capacity. Accordingly, less phosphorus is generally found in the predominantly nutrient-poor podzol type soils supporting coniferous stands than in those under north temperate hardwoods (Soil Survey Staff, 1975; Pritchett, 1979).

Nutrient-poor soils and extended winter freeze conditions reduce total nutrient export in runoff. Many low lying bog areas, however, often contain sufficient nutrients from groundwater flux to produce eutrophic conditions (Verry, 1975; Pritchett, 1979). Alternating freezing and thawing of the exposed litter layer has reportedly caused phosphorus concentrations in snowmelt to increase up to 350% above the average streamflow concentrations which may be sufficient to produce temporary algal blooms (Verry, 1975).

Temperate Rain Forest

Northern temperate rain forests occur along the northwest pacific coast from northern California to southeastern Alaska. Vegetation includes alders and coniferous evergreen species such as spruce, fir, and hemlock. The climate consists of a relatively high but well distributed rainfall with mild temperatures. Because of the climatic conditions, this biome exhibits high annual primary productivity and rapid nutrient cycling. Consequently, decomposition nearly keeps pace with the litter accumulation rate. Although not exhibiting the mull type humus layer of boreal forests, the upper soil layers are rather well supplied with organic matter.

Nitrification is reportedly limited or absent in soils of this region (Bollen and Wright, 1961) possibly because of low pH and lack of electrolytes or because of the adaptation of the tree species for ammonia over nitrate (Tiedmann et al., 1978). Streamwater nitrate concentrations are subsequently low (Fredriksen, pers. comm.).

Some vegetation types, such as alder (Alnus sp.) are nitrogen fixers and the underlying soils are much higher in nitrogen than are soils associated with other species (Franklin et al., 1968). Brown et al. (1973) reported both higher nitrate concentrations and loads from alder watersheds than from streams draining primarily Douglas fir and western hemlock.

Although coniferous species have a high capacity to survive and compete in low phosphorus soils (Pritchett, 1979), comparatively high phosphorus export has been observed from this region (Sylvester, 1960; Fredriksen, 1972, 1979). Fredriksen (pers. comm.) speculated that phosphorus export was influenced by local deposits of high phosphorus soils. The high regional rainfall and ensuing runoff may also play a major role in the high phosphorus flux from area watersheds.

Temperate Deciduous Forests

Temperate deciduous forests have relatively heavy but well distributed amounts of annual precipitation. Summers are generally warm and humid and winters are cool to cold with heavy snowfall in the northern regions. Typical broad-leaved deciduous species are oak, maple, beech, ash and poplar.

Litterfall is not only great but litter nutrient content also tends to be high, notably for nitrogen and phosphorus (Wells et al., 1972; Whittaker, 1975). Litter decay and nutrient release to underlying soils are more rapid than with pine/conifer litter, decomposition products are not as acidic and the underlying podzolic (brown earth) soils are relatively fertile, with higher nitrogen and phosphorus levels than the previously discussed soils. The deciduous forest thus functions with a nutrient rich economy, with a larger nutrient stock more rapidly cycled, a smaller fraction of the nutrients in plant tissue and a larger fraction in the soil (Whittaker, 1975). During high rainfall periods, especially during leafless seasons, runoff and nutrient export can be high (Swank and Miner, 1968; Likens et al., 1977).

Deciduous forests are also subject to the freeze-thaw leaching mechanism and to high nutrient snowmelt concentrations described for boreal forests. Because snowfall is higher in north temperate than in more northerly boreal ecosystems, additional amounts of nutrients are accumulated over winter and snowmelt concentrations can be high (Likens et al., 1970; Gosz, 1978).

Temperate Evergreen Biome

Climatic conditions within temperate evergreen ecosystems consist of warm temperatures with high rainfall, especially during the late summer months. Dominant vegetation is loblolly, shortleaf, longleaf and slash pine. Large expanses of these vegetative types occur in the coastal plain and piedmont of the southeast U.S. where they are sometimes collectively called "southern pine." Soil characteristics are highly variable but the positive water balance has often contributed toward a base-poor, moder type humus layer overlaying sandy soils of strong to slight acidity.

Much of the hydrologically related research with pine forested watersheds has been focused on the influence that needle-type vegetation has on the regulation of streamflow volumes. In particular, rainfall interception capacity and evapotranspiration rates have both been linked to streamflow fluctuations.

Studies in the South Carolina piedmont region have demonstrated that rainfall interception from 5-30 year old loblolly pine averaged 14-20% of the annual precipitation. On the average, the volume of intercepted water was approximately 10 centimeters greater than that from hardwood sites (Swank and Miner, 1968; Helvey, 1971; Swank et al., 1972). Further work by Swank and Douglass (1977), has indicated that pine forests also have greater evapotranspiration rates than hardwood forests. As a result of these two characteristics, annual streamflow was reduced about 20% below that expected for hardwood cover 15 years after experimental watersheds had been converted from mature deciduous hardwoods to white pine (Swank and Douglass, 1974).

With lower reported water runoff volumes, nutrient loads would also be expected to be lower. However, high nutrient yields from pine watersheds in northern Mississippi and Georgia (see Table 1) can be attributed to both high precipitation and selective erosion of fine clay sediments (Krebs and Golley, 1977; Duffey et al., 1978).

Exceptions to General Trends

Many forested areas deviate from the vegetation-soil-climate relationships which inspire ecosystem/biome classification. Poor drainage, steep slopes or the presence of large stones or outcroppings are often typical of forest soil conditions. Many mountain soils lack the kind of profile development described above and remain thin and stony. Forest soil fertility is often very low since the more productive and accessible soils have long since been converted to agricultural land.

Differential chemical weathering of the parent material can influence the distribution and growth of the forested vegetation because of changes in acidity, base status and nutrient availability associated with weathering intensity. Down the slope of a hill, soils become increasingly moist because of the gradual movement of water downslope beneath the soil surface. Nutrients and soil particles are likewise transported so that lowland soils tend to be deeper, contain more fine particles and are more fertile (Whittaker, 1975). Growth of vegetation on soils developed from transported materials may differ from that on adjacent soils developed from bedrock (Pritchett, 1979).

Differences in topography, drainage and parent material has often produced, within a given area, a very complex pattern of soil and vegetation. This complexity makes futile any attempts to implicate specific physiographic characteristics with nutrient flux. While the compiled nutrient export coefficients for forested watersheds exhibit a wide range of conditions across North America (Table 1), the range of nutrient flux values is quite narrow (Figure 5a and 5b).

One (non-physiographic) factor which does tentatively stand out as influencing nutrient load is climate. Areas of the country that exhibit warm climates with high rainfall (such as the pacific northwest and southeastern piedmont regions) are also associated with high productivity, high runoff and high nutrient export.

Ecological Succession

The relationship between ecological succession and ecosystem stability to nutrient cycling and loading is somewhat controversial. One suggested hypothesis is that as ecosystems mature, the ability to conserve nutrients increases (Odum, 1969). Nutrient losses from disturbed or early successional systems should therefore by higher than that from mature systems. Since inputs equal outputs at climax, it is inferred that losses will exceed inputs until climax is reached. To support this hypothesis, extensive work at a number of gauged forested watersheds have demonstrated that nutrient losses are progressively reduced as biomass increases (Likens et al., 1970; Marks and Bormann, 1972; Pierce et al., 1972; Woodwell, 1974; Likens et al., 1977).

The particular mechanism(s) responsible for nutrient losses is nutrient-specific. Phosphorus losses are controlled more by solubility than are nitrogen losses. Beginning successional systems have less canopy and the potential for water runoff and phosphorus loss is greater than for more mature forests. Nitrogen is influenced to a greater extent by biologial interactions (i.e., vegetation type, soil nitrifiers, etc.) and is usually more often growth limiting in terrestrial habitats and exhibits more variation than phosphorus. A number of investigators have observed that as forest ecosystems approach steady-state, tannins and their derivatives, which inhibit nitrifying bacteria, accumulate in the soil. As a result, ammonium is not oxidized to nitrate as readily in the climax as in earlier successional stages and nitrogen solubility in general is reduced with lower losses to streamflow (Rice and Pancholy, 1972, 1973; Todd et al., 1975). Consequently, climax vegetation can either inhibit the nitrification process (Rice and Pancholy, 1973) or the vegetation can better utilize NH_4-N more efficiently than previous seral stages (Todd et al., 1975).

A second hypothesis proposes that "changes in nutrient losses through ecosystem development are an inverse function of the amount of each element bound up in the total biomass increment of an ecosystem" (Leak and Martin, 1975; Vitousek and Reiners, 1975; Vitousek, 1977). Ecosystems accumulate nutrients during the middle stages of succession, but losses increase to equal outputs upon maturity. Stated differently: intermediate successional ecosystems will have lower nutrient losses to streamwater than either very young or very old (mature) ecosystems.

Woodmansee (1978) offers a third alternative hypothesis. He infers that the long term balance of nutrient capital (steady-state) in undisturbed systems may not ever be reached on an ecosystem scale. Minor but continuous perturbations caused by natural events (i.e., blowdown, insect infestations, landslides, etc.) can cause a mosiac

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of successional stages (Martin, 1979), and nutrient accumulation will vary accordingly. As a result, nutrient output is continuously variable depending on the number or extent of natural or man-made disturbances.

For comparison of these three hypotheses, refer to Figure 4. From this diagram, disagreement on nutrient accumulation and output in later stages of ecological succession is apparent. All three groups of investigators do agree that in the initial stages of succession, nutrient accumulation increases while output decreases. It is proposed here, however, that nutrient output differences among the three hypotheses (or between early and mature ecosystems), are within the range of nutrient export coefficients presented in Figure 5. This is because the compiled nutrient export coefficients (Table 1) not only represent a wide cross-section of physiographic and climatic conditions but also a wide range of successional stages.

Disturbed Forested Systems

Aside from the previously discussed factors which influence nutrient flux, forest perturbations can also increase the nutrient yield. These perturbations range from encroachment of agricultural and urban land to timber harvest, forest fire and fertilization. The impact of agricultural and urban land use on nutrient flux will be discussed in the following two chapters. The potential effects of the latter disturbances will be the focus of the remainder of this chapter.

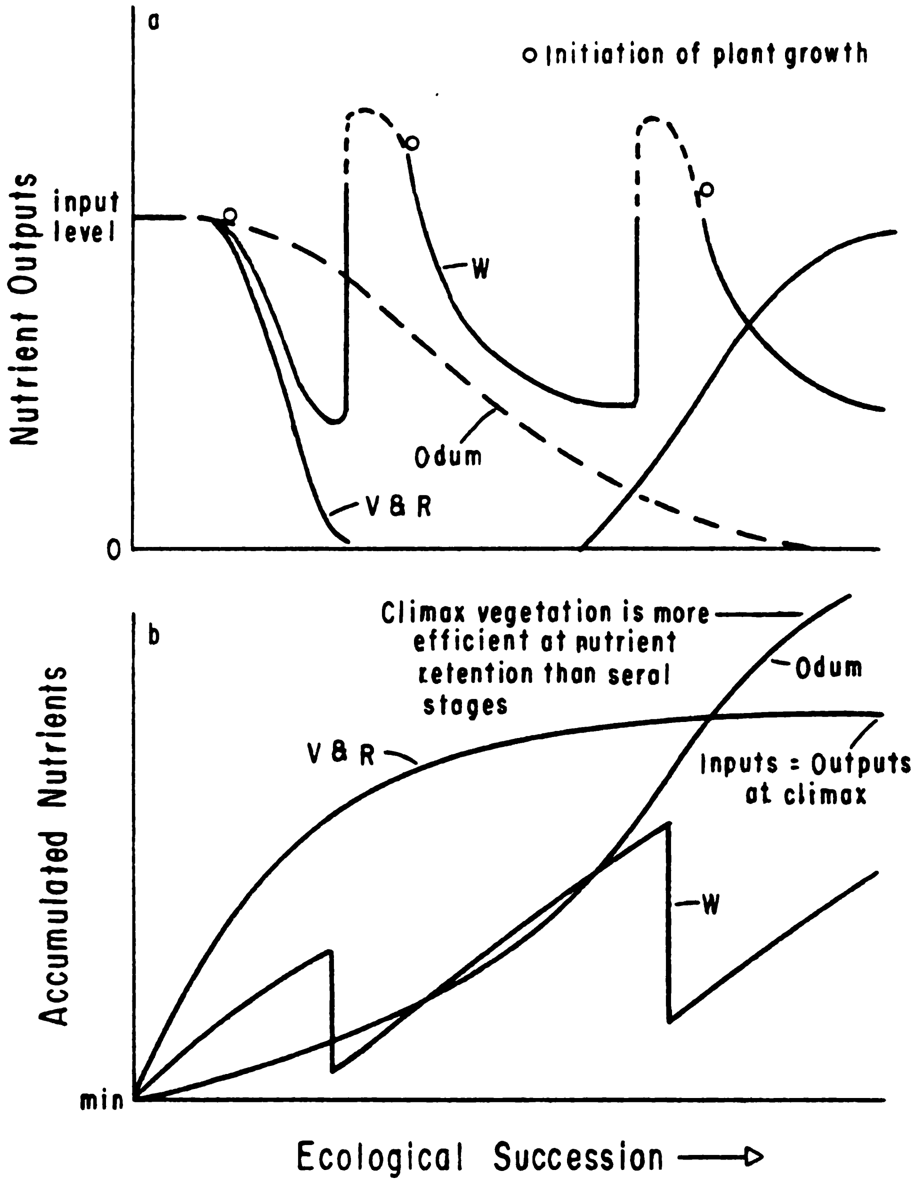

Figure 4: (a) Relationship of nutrient output rate to the successional status of ecosystems. The V and R curve is from Vitousek and Reiners (1975), and the Odum curve from Odum (1969). The W curve is from Woodmansee (1978).
(b) Relationship of nutrient accumulation to ecological succession. [from Woodmansee (1978)]

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Timber Harvest

Watersheds with ongoing timber harvest tend to have higher nutrient export than do undisturbed systems. This is because deforestation: 1) blocks the nutrient uptake pathway from the available nutrient and organic matter compartments to the vegetation (see Figure 3), 2) increases the nutrient pool by contribution of dead organic material (slash), 3) raises the forest floor temperature through increased exposure to sunlight, 4) increases the frequency of drying and wetting, 5) reduces evapotranspiration rates and interception capacity and 6) increases microbial activity (respiration rate and bacteria numbers) (Birch, 1958; Likens et al., 1970; Pierce et al., 1970, 1972; Bormann et al., 1974; Likens et al., 1977).

Increased biological decomposition is the principal factor responsible for increases in nitrogen export. Nitrifying bacteria of the genera Nitrosomonus and Nitrobacter increased up to 18 and 34-fold, respectively, in the soils of disturbed (clearcut) watershed when compared to populations in undisturbed forest soils (Likens et al., 1970, 1977).

In contrast, phosphorus export is reportedly not as sensitive to harvest operations as is nitrogen. Dissolved phosphorus export tends to remain at either pre-harvest levels or exhibits only slight increases during the first few years (Aubertin and Patric, 1974; Fredriksen et al., 1975; Likens et al., 1977; Swank and Douglass, 1977). Bormann et al. (1974) reported that particulate phosphorus output rose sharply a couple of years after clearcut as biotic control and erodability weakened.

The output of nutrients is also dependent on the extent and method of harvest and on the proximity of the harvest operation to tributaries. Many logging operations use undisturbed buffer strips along forest streams to absorb the impact of excess runoff. Humus layer thickness, however, may also be a factor in nutrient yield (Fredriksen et al., 1975) since the thicker the layer, the higher the organic content and the greater the potential for mineralization and nutrient loss to streamwater.

Forest Fire

Forest fire has a greater potential for degrading water quality than timber harvest alone. Elimination of the overstory blocks nutrient uptake pathways, and reduces evapotranspiration and rainfall interception capacity. Incineration of litter and humus layers converts the forest floor into a readily soluble, nutrient-rich form much faster than do natural decay processes. It also decreases infiltration capacity and water storage, increases soil weathering and enhances nutrient runoff potential (Wright, 1976).

The effects of forest fires on the physical, chemical and biological properties of soils and vegetation are variable and directly related to the type and severity of the burn. Materials consumed in a controlled burn are often confined to the understory vegetation and forest floor debris and only a small part of the total may be destroyed. A severe wildfire may destroy a much larger percentage of the standing biomass and organic matter (Wells, 1971). Unfortunately, information on the effects of fire on water quality is limited and research results are sometimes conflicting. Many studies have examined the combined effects of forest fire with timber harvest and/or fertilization, making it difficult to determine actual cause-effect relationships.

From a study in northeastern Minnesota, Wright (1976) observed that, compared to natural background levels, runoff and phosphorus export increased 60% and 93% respectively, after a fire. In a clear-cut and slash-burned Douglas-fir forest in Oregon, inorganic phosphorus loads increased four times that of the control area to approximately 0.6 kg/ha/yr. Total loss of nitrogen amounted to 2.2 kg/ha/yr for the first two years after burning before dropping toward control levels of 0.05 kg/ha/yr (Frederiksen, 1970). However, during the two years following a similar treatment in Oregon's coast range, nitrate-nitrogen export increased from 4 to 15 kg/ha/yr (Brown et al., 1973).

Forest Fertilization

With a steadily decreasing production base and an increasing demand for wood products, management practices on forest lands have been intensified. As a consequence, the use of forest fertilization to increase timber growth rates is becoming more widespread.

Since nitrogen is the most common growth-limiting element on terrestrial systems, especially in the pacific northwest, fertilization with granular urea (46% N) or ammonium nitrate has been intensified (Fredriksen et al., 1975). Phosphorus fertilizers have not been as extensively used and are normally applied to tree plantations near the time of planting. Phosphorus has seen limited use, however, on stagnated stands of slash pines on the phosphorus deficient wet savanna soils of the coastal plain (Pritchett and Smith, 1970, 1974).

Application methods include spray irrigation and manual dispersal but most operations require aerial techniques using either helicopters or fixed wing aircraft. Large headwater streams are intentionally avoided but application to the forest floor often includes and impacts upon smaller tributaries. According to Moore (1975), urea application to Douglas-fir stands pose little threat to water quality unless there is direct application to stream channels. This does not rule out the possibility of groundwater contamination and eventual impaction on surface waters further downslope. In this situation, ammonium nitrate has a greater pollution potential than urea because of the mobility of the nitrate ion. While essentially no leaching of phosphorus occurs from most forested systems, exceptions have been noted where soluble phosphates have been applied to acid organic soils or acid quartzitic sands low in iron and aluminum (Hymphrys and Pritchett, 1971).

Fertilizer materials undergo a number of transformations when applied to soils and the proportional increase in nutrient flux will depend on 1) the type and form of fertilizer used, 2) rate and time of applications, 3) vegetative type and root uptake efficiency, 4) the soil's physical and chemical properties (i.e., ion exchange capacity), and 5) climate (Hornbeck and Pierce, 1972; Pritchett, 1979). According to available published accounts, stream nutrient levels were only temporarily elevated immediately following fertilization, did not approach toxic levels, revealed no significant impact on aquatic organisms and were usually associated with direct application to surface water. Since only a small fraction of the forested watershed is fertilized in a given year, the evidence does not implicate forest fertilization in significant eutrophication of lakes or streams (Moore, 1970; Norris and Moore, 1971; Hornbeck and Pierce, 1972; Malueg et al., 1972; Moore, 1974, 1985; Fredriksen et al., 1975; Stay et al., 1978; Tiedemann et al., 1978).

Table 1: Nutrient Export from Forested Watersheds

Land Use	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
75-100 year old jack pine & black spruce, with birch & trembling aspen (342.1 ha)	Kenora Experimental Watershed Rawson Lake Ontario, Canada	medium-fine silicate sand overlying deeper deposits containing some clay fractions	77.3[a] (70.1 - 96.7)	26.55[a] (22.3 - 35.4)	6.26[a] (5.69 - 7.32)	.309[a] (.220 - .435)	Schindler et al., 1976
Climax hardwoods maple, beech, red oak, with yellow birch and hemlock (125 ha)	Clear Lake Watershed Haliburton County, Ontario, Canada		126.3	68.00		.090	Schindler and Nighswander, 1970
Jack pine - black spruce	Northwest Ontario, Canada	sandy loam			2.37[b]	.060[b]	Nicholson, 1977
Jack pine - black spruce	Northwest Ontario, Canada	sandy loam			1.38[b]	.036[b]	Nicholson, 1977
Mixed deciduous forest	Southern Ontario, Canada	sandy soils overlying granitic igneous formation				.047[c] (.025 - .077)	Dillon and Kirchner, 1975
Mixed deciduous forest	Southern Ontario, Canada	loam soils overlying sedimentary formation				.107[d] (.067 - .145)	Dillon and Kirchner, 1975
Mixed deciduous forest (.01 ha)	Lake Minnetonka Watershed, Minnesota	loam, silt loam, clay loam	129.0	84.3		.090	Singer and Rust, 1975
70% aspen 30% black spruce and alder (10 ha)	Marcell Experimental Forest, Minnesota	70% loam, clay & sands 30% organic peats		17.70[e] (15.5 - 19.2)	2.26[e] (1.74 - 2.37)	.157[e] (.124 - .179)	Verry, 1979
Aspen - birch forest (6.48 ha)	Marcell Experimental Forest, Minnesota	loam, clay and sands	79.48[e] (75.51 - 82.10)	15.56[e] (13.73 - 21.47)	2.46[e] (1.92 - 3.29)	.280[e] (.19 - .38)	Timmons et al., 1977

Table 1: (continued)

Table 1: (continued)

Land Use	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Maple, birch and beech (15.6 ha)	Watershed #6 Hubbard Brook Experimental Forest, New Hampshire	sandy loam	132.2[f]	83.30[f]	4.01[f]	.019[f]	Likens et al., 1977
Deciduous hardwood and pine (17.6 ha)	Coshocton, Ohio	silt loam	88.9[e] (85.4 - 95.8)	32.00[e] (25.3 - 35.6)	2.82[e] (1.37 - 3.16)	.035[e] (.0349 - .0722)	Taylor et al., 1971
Oak-hickory forest (97.5 ha)	Walker Branch Watershed, Oak Ridge, Tennessee	limestone bedrock	136[g]	70.70[g]	3.1[g]		Henderson and Harris, 1973
Oak-hickory forest (97.5 ha)	Walker Branch Watershed, Oak Ridge, Tennessee	limestone bedrock	157.1[a] (128.2 - 187.5)	94.65[a] (71.0 - 116.1)	2.0[g] (1.7 - 2.2)	.025[a] (.010 - .030)	Henderson et al., 1977
Oak maple yellow poplar, black cherry, beech (34 ha)	Fenrow Experimental Forest, Parsons, West Virginia	silt loam				.140[e] (.040 - .180)	Aubertin and Patric, 1974
Mixed pine and hardwood (40 ha)	Eatonton, Georgia		164.0	48.70		0.275	Krebs and Golley, 1977
Mixed pine and hardwood	Rhode River Watershed, Maryland				1.50	0.200	Correll et al., 1977
99% mixed forest 1% developed (6495 ha)	Woodlands, Texas	clays		7.30		0.212	Bedient et al., 1978
Loblolly and slash pine	Copperville, Mississippi	loess over sedimentary deposits					Duffy et al., 1978
2.81 ha			205.0	36.90		0.281	
1.93 ha			205.0	38.95		0.306	
2.39 ha			205.0	34.85		0.357	
1.64 ha			205.0	30.75		0.321	
1.49 ha			205.0	22.55		0.226	

Table 1: (continued)

Land Use	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Douglas fir and western hemlock (47139.5 ha)	Yakima River, Western Cascade Range, Washington				3.32	0.830	Sylvester, 1960
Douglas fir and western hemlock (32376 ha)	Cedar River, Western Cascade Range, Washington					0.360	Sylvester, 1960
Douglas fir and western hemlock (10.1 ha)	H. J. Andrews Experimental Forest, Western Cascade Range, Oregon		215.0	135.0		0.520	Fredriksen, 1972
Douglas fir and western hemlock	Fox Creek, Western Oregon	silt & clay loams		158.0		0.180	Fredriksen, 1979
Douglas fir and western hemlock	Coyote Creek, Western Oregon	silt & clay loams		76.0		0.680	Fredriksen, 1979

a. Four year median
b. Four year mean from twelve watersheds
c. Two year median from twenty watersheds
d. Two year median from four watersheds
e. Three year median
f. Twelve year mean
g. Two year mean

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Figure 5a: PHOSPHORUS EXPORT FROM

Figure 5a: PHOSPHORUS EXPORT FROM FORESTED WATERSHEDS

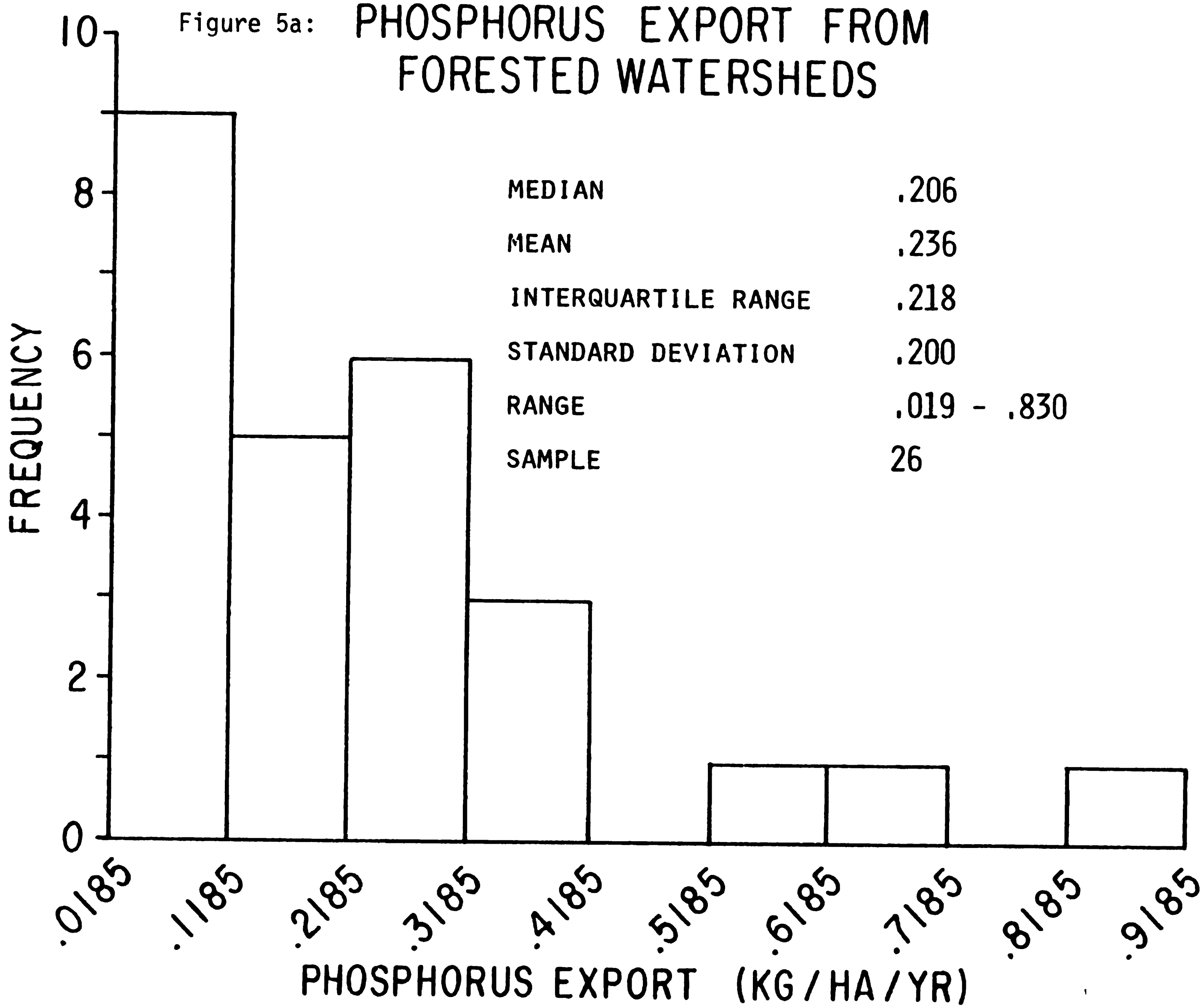
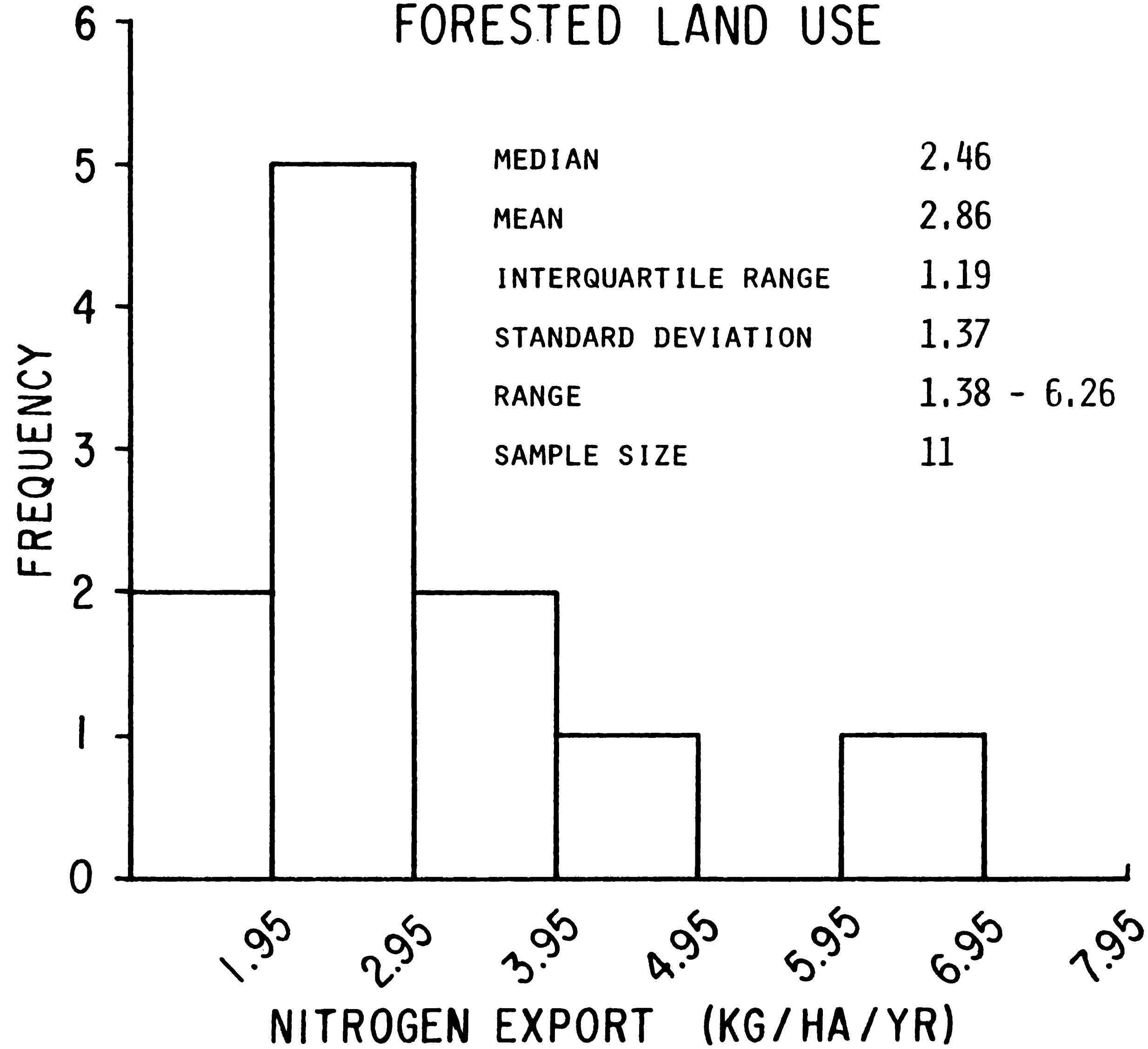


Figure 5b: NITROGEN EXPORT FROM FORESTED LAND USE



CHAPTER IV

AGRICULTURAL LAND USE

Introduction

While forested regions represent areas with a) well-developed and long-lived overlying canopies and b) well-defined underlying successions of natural soil horizons, agricultural areas are artificial products of human manipulation. Agricultural soils are generally more productive (at least initially) than many existing forest soils and have been further modified by cultivation, liming and fertilization. The short-lived vegetation (crops) have a much lower leaf-area index than forest products which allows for less rainfall interception capacity and an increased potential for water runoff. The elimination of crops through harvesting disrupts the plant-soil nutrient cycle, promotes plant residue decomposition and exposes the land surface to accelerated weathering, water runoff and soil erosion. The end result is generally an increase in nutrient export in comparison to undisburbed conditions.

Aside from the more obvious effects of climate and topography, other factors such as soil type, fertilization rate, tillage practices and crop type can have significant influence on nutruent export. Non-crop activities such as pasture, feedlot operations and manure storage facilities can also cause elevated nutrient loads from accumulated animal wastes and loss of vegetative cover. The remainder of this chapter contains a discussion of how these factors cause increases or fluctuations in nutrient export.

Soil Influences

With limited vegetative cover and lack of a protective litter of humus layer, the exposed soils are subject to high weathering and erosion rates. In spite of continued efforts by soil conservationists with improved cropping and land and soil management, over 4.0 billion metric tons of sediment are eroded from agricultural areas in the U.S. each year, of which approximately half washes into lakes and streams (Holeman, 1968; Burwell et al., 1974). From the Maumee River alone, over 856,000 metric tons of sediment discharges into Lake Erie annually, composed mostly of fine clay-sized particles carrying a high nutrient load (Nelson et al., 1978).

Aside from the influence of parent geology (see Chapter III), drainage water nutrient levels are also dependent on both soil type and texture. Soil type can be broadly classified as either organic or mineral while texture refers to the degree of coarseness of a material (i.e., fine, medium, coarse).

Organic Soils

The level of organic matter needed to classify a soil as organic is highly variable. Depending on climate and soil structure, the level of organic material is a function of the steady-state between added and native plant residues and their rate of decomposition. According to the Soil Survey Staff (1975), "organic soils are those soils which are saturated with water for long periods or are artificially drained, and excluding live roots, have:

1. 18% or more organic carbon if the mineral fraction is 60% or more clay,
2. 12% or more organic carbon if the mineral fraction has no clay, or
3. have a proportional content of organic carbon between 12% and 18% if the clay content of the mineral fraction is between 0% and 60%.

Soils are also classified as organic if they are never saturated with water for more than a few days and have 20% or more organic carbon."

Because of their chemical nature, organic soils are high in nitrogen and phosphorus. Reinhorn and Arnimelech (1974) reported that soil containing only 1% organic carbon contained approximately ten metric tons of nitrogen per hectare in the top 90 cm. It is suspected by this investigator that phosphorus levels would be approximately one order of magnitude less.

As virgin soils are cultivated for crop production, a marked reduction (20-50%) in the soil's organic content occurs. Depletion of organic soil material through oxidation, mineralization and leaching lasts about 10-20 years depending on the soil's organic content and depth, crop type, irrigation practices and climate (Reinhorn and Arnimelech, 1974). This breakdown process results in the release of large quantities of mineral nutrients, often to overland runoff.

In addition to nutrient release through decomposition, organic colloids also tend to have a low capacity for nutrient adsorption, particularly for phosphorus. The adsorption that does occur depends on the amounts of associated soil cations (Fe, Al, Mg, Ca), soil composition, depth, and the nature of underlying mineral material (Kilmer 1974; Duxbury and Peverly, 1978; Miller, 1979).

With a finite capacity for phosphate fixation, the importance of fertilization rates must not be underestimated. Fertilized agricultural watersheds with organic soils such as mucks and peats can yield higher amounts of nutrients than mineral soils to stormwater (Mackenzie and Viets, 1974; Nielsen and Mackenzie, 1977; Duxbury and Peverly, 1978; Miller, 1979).

Mineral Soils

Mineral soils are a mixture of rocks and the end products of the weathering process, and their texture is a key determinant of both water adsorbtion capacity and nutrient interactions. The basic textural classes are: clay, silty clay, sandy clay, silty clay loam, clay loam, sandy clay loam, silt, silt loam, loam, sandy loam, loamy sand and sand.

Clay particles are microscopic in size. When dry, they adsorb large amounts of water, swell when wet, are highly plastic and are slowly permeable. As clay content increases the cation content also tends to increase causing stronger reactions with anions than coarser materials and often resulting in lower soluble nutrient levels in drainage water. Conversely, clay particles are preferentially eroded by size and because of the greater affinity for dissolved salts (such as PO_4-P) to the finer fractions, are a potential source of sediment nutrients (Schneider and Erickson, 1972; Loehr, 1974; Lake and Morrison, 1977).

Table 2 : Trophic Classification Scheme for Soils*

	Nutrient export in g/m^2-yr		
	Inorganic Nitrogen	Total Phosphorus	Phosphate Phosphorus
Oligotrophic	0.5	0.02	0.01
Mesotrophic	0.5-2.5	0.02-0.05	0.01-0.025
Polytrophic	2.5	0.05	0.025

*Modified from Vollenweider, 1968, p. 105.

From the integration of considerable Great Lakes Basin data, the International Reference Group on Great Lakes Pollution from Land Use Activities (1975) developed a more comprehensive approach and related annual phosphorus loads to both management practice and land form. Land form was based on soil texture (i.e., fine, medium, coarse) and slope (Table 3).

The above authors hasten to warn the readers that "from a management perspective, the relative differences of numbers are more important than the absolute values." Unique characteristics of individual land areas may result in significantly different area loads. In addition, extrapolation of this information beyond the Great Lakes area is of limited value.

Based on the amount of variability, and previous classification attempts, it is likely that broad classification schemes relating soil type to nutrient flux are currently not possible. According to Logan (1977), the current state-of-the-art does not allow prediction

Table 3 : Predicted Total Phosphorus Unit Area Loads for Rural Land, Forested Land and Wetlands[a]

Land Use Intensity	kg/ha/yr — Type of Soil: Sand	Coarse Loam	Medium Loam	Fine Loam	Clay	Organic
Rural						
Row Cropping (>50 percent row crops)	0.25	0.65	0.85	1.05	1.25[b]	----
Mixed Farming (25-50 percent row crops)	0.10	0.20	0.30	0.55	0.85	----
Forage (<25 percent row crops)	0.05	0.05	0.10	0.40	0.60	----
Grassland	0.05	0.05	0.10	0.15	0.25	----
Forest	0.05	----	----	----	0.10[c]	----
Wetlands						
Natural areas	----	----	----	----	----	0
Cultivated Organic Soils	----	----	----	----	----	2.20

[a]data above are arranged for use in the U.S. portion of the Basin. Soil characteristics and loads are arranged differently in the Canadian analysis. The end results are comparable.

[b]unit area loads may be higher when soil has an unusually high clay content. Values up to 2.5 kg/ha/yr were used in portions of the U.S. Lake Erie basin.

[c]unit area loads may be higher in certain unique forested areas with clay soils (e.g., the Nemadji River basin, which flows into Lake Superior, contributes about 1.0 kg/ha/yr).

From the International Reference Group on Great Lakes Pollution from Land Use Activities, 1978, p. 65.

beyond the observation that total nutrient content in both soil and drainage water tends to be higher for clay and organic soils than in the coarser sands.

Fertilizer Effects - Commercial and Manure

With rising return per dollar invested in fertilizer, the use of fertilizers in this country has substantially increased since the second World War. In 1974 alone, 8.2 million metric tons of nitrogen and 4.5 million metric tons of P_2O_5 were applied in the U.S. (Baldwin et al., 1977).

Fertilizers are generally applied either as animal manure or as a commercial grade product. The nutrient content of commercial fertilizers varies between 0-82% for nitrogen and 42% for P_2O_5 (Robertson, pers. comm.). Modern commercial varieties such as ammonium nitrate (NH_4NO_3), triple superphosphate ($Ca(H_2PO_4)_2$), monoammonium phosphate ($NH_4H_2PO_4$) and diammonium phosphate ($(NH_4)_2HPO_4$) are completely water soluble. When added to the soil they react with mineral and organic constituents and a high percentage is rendered insoluble.

In contrast to commercial fertilizers, fresh manure contains 50-90% moisture, 0.2-6% total nitrogen and 0.6-2.5% total phosphorus on a dry weight basis (Frere, 1976). Most of the nitrogen and phosphorus is in the organic form and must first undergo microbial breakdown and mineralization into more soluble and available forms. This breakdown, in turn, is dependent on manure composition at the time of application since fresh, fermented or anaerobic liquids are all commonly used.

Because of strong reactions with the soil, approximately 5-30% of the phosphorus and 50-60% of the nitrogen applied as (commercial/manure) fertilizer is recovered by the current crop (Hensler et al., 1970; Lin, 1972; Loehr, 1974; Gambrell et al., 1975b; Frere, 1976; Logan, 1977). Losses from the remaining nutrient reservoir from a variety of pathways are high. The bulk of applied phosphorus is lost by soil erosion (Burwell et al., 1977; Young and Holt, 1977; Alberts et al., 1978; McDowell et al., 1978; Menzel et al., 1978). Nitrogen losses of a similar magnitude can occur from both erosion and leaching. Volatilization losses, however, are also significant.

Loehr (1974) estimated 5-10% of any commercial ammonia applied was lost through volatilization while Frere (1976) estimated up to 50% of the total collectable manure nitrogen was lost through volatilization during storage and before soil incorporation. From "in field" studies, Lauer et al. (1976) observed average losses at 85% of the total ammoniacal manure nitrogen content at the time of spreading.

Ammonia volatilization can have a significant impact on mineralization processes since it decreases the potential for NO_3 formation and release into water supplies. This is partially reinforced from early studies by Hensler et al. (1970) who observed higher nitrogen (and phosphorus) losses from fresh manure applications as compared to fermented and anaerobic liquid.

Efforts to find a direct relationship between applied nutrients and nutrient export in drainage waters have been hindered by extraneous nutrient sources and interactions. Besides the nutrients supplied by the native soil reservoir, crop residue and detritus, *in situ* bio

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biological transformations make direct relationships difficult to interpret. Comprehensive input-output budgeting hinges on the delicate balance between optimum plant needs and nutrient availability from the total nutrient pool.

Similarly, application of optimum fertilizer amounts also depends on "available nutrient" levels in the soil (concentrations weak enough for root extraction) and plant uptake capacity. Optimum rates "ideally" stimulate early plant growth and produce thicker foliage with higher rainfall interception capacity, transpiration rate and soil moisture deficit. All these factors interact to reduce runoff and nutrient export.

In nutrient budgeting studies with optimum fertilization rates, losses were generally less than 5% and 20% for applied phosphorus and nitrogen, respectively, It is assumed that a significant amount of the nutrient loss also included nutrients from the soil-nutrient pool (Moe et al., 1968; Blurek and Heald, 1974; Gambrell et al., 1975b; Kissel et al., 1978; Nelson et al., 1978; Nicholaichuk and Read, 1978).

Even at optimum fertilization rates, a number of investigators have indicated that the magnitude of nutrient losses appeared to be a function of the timing of the fertilizer inputs. Manure applied to frozen ground, especially when thaw and rainfall occurred simultaneously, was favorable to high nutrient export (Minshall et al., 1970; Hensler et al., 1970; Klausner et al., 1974, 1976; Young and Mutchler, 1976).

An examination of fertilizer additions beyond the recommended rate have been observed to cause increases in nutrient runoff rates. Heavily fertilized watersheds tend to lose 2-3 times more nitrogen and phosphorus than do watersheds subject to recommended rates of fertilization (Schuman et al., 1973a, b; Kilmer et al., 1974; Burwell et al., 1977).

Conversely, while fertilizer overuse is uneconomical and enhances nutrient losses, under use can result in a more costly food supply and increased erosion of valuable land (Viets, 1971). Under certain conditions, water, sediment, and nutrient losses from plots receiving less than optimal fertilization can be greater than optimum fertilized plots, reflecting the influence of a good crop canopy (Gambrell et al., 1975b; Frere, 1976; Smith et al., 1979).

Tillage Practices

Conventional tillage methods, in which crop residues are removed at harvest, and the ground is left fallow during non-growing periods, are a prime cause of high nutrient export. Conversely, conservation tillage methods ideally have conservation of soil, water and energy as the primary objective. These methods will reduce the export of nutrients.

Among the conservation tillage methods are practices that increase soil incorporation of fertilizers. Deep plowing is reportedly superior to disking (Holt at al., 1970; Romkens et al., 1973; Timmons et al., 1973; Baker et al., 1978), and at times nutrient losses from deep plowed fields approach those from unfertilized plots (Timmons et al., 1973). Deep mixing tillage incorporates organic matter from plant residues into the soil and promotes a more favorable soil structure. This increases the cation exchange capacity in the upper soil horizons thus retaining greater concentrations of PO_4-P and NO_3-N (Klausner et al., 1974; Rogers et al., 1976).

Runoff and subsequent soil and nutrient loss is also reduced by tillage systems that leave a residue cover on the soil surface (i.e., no-till). With large amounts of surface residue remaining during critical erosion periods from late fall through early spring, soil nutrient loss is reduced during the period when crop canopy is not significant (Lake and Morrison, 1977; Laflen et al., 1978).

Variations in efficiency have been noted. Moldenhauer et al. (1971) demonstrated that no-till planting (crop residues undisturbed on soil surface until planting), though superior to conventional tillage in controlling soil losses, was not nearly as effective as ridge planting (residues remain undisturbed until cultivating time).

Unfortunately, no-till methods do not proportionately reduce nutrient solution and sediment phases. McDowell et al., (1978) indicated that total nutrient losses from no-till plots were 10-16% of nitrogen and phosphorus losses from conventional tillage, respectively. Solution phosphorus concentrations, however, were increased in part because of a) limited sorption of fertilizer phosphorus by the soil resulting from decreased fertilizer incorporation, b) release of phosphorus from crop residues, and c) greater phosphate carrying capacity of sediments in runoff from no-till.

Other water and soil conservation tillage measures, such as contour planting and terracing, may be used in conjunction with the above and other practices to further reduce nutrient loss. While both can substantially decrease losses, terracing has been observed to reduce sediment nitrogen and phosphorus loads by 2/3 that of contour methods (Schuman et al., 1973; Alberts et al., 1978).

Crop Types

While tillage practices undoubtedly influence nutrient loss, especially during nongrowing seasons, vegetative type (and its associated density-ground cover percentage) is also a major factor controlling runoff and nutrient loss (Loehr, 1974). Watersheds or plots sown with high density, non-row crops such as wheat, millet, rye and other small grains a) protect the soil surface from rainfall impact energy, b) maintain the integrity of the upper soil layers, and c) do not promote sheet or rill runoff. As a consequence, water runoff and sediment (and total) concentrations from non row crops are lower than row crops. This results in low export of nutrient loads.

On the other hand, row crops, such as corn or soybeans, do not protect the soil surface as efficiently as non row crops and promote channelization and erosion. Export of nutrients from row cropped watersheds will be much higher than export from non row crop watersheds, especially if soil and water conservation practices are underused.

Data collected for both row and non row crops types support this phenomena (Tables 4 and 5, respectively). Frequency distributions (Figures 6 and 7) constructed from this data indicate a median phosphorus and nitrogen export value for non row crops 1/3 and 2/3 that

Table 4: Nutrient Export from Row Crops

Land Use	Fertilizer Application kg/ha/yr N P K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Corn (.004 ha)	0 0 0	Lancaster, Wisconsin	silt loam	77.0[a] (65.76 - 77.6)	10.7[a] (8.51 - 21.95)	3.96[a] (3.61 - 5.53)	1.22[a] (1.22 - 1.49)	Minshall et al., 1970
Corn; fresh manure applied in winter (.004 ha)	109 39 99	Lancaster Winconsin	silt loam	77.0[a] (65.76 - 77.6)	12.26[a] (5.97 - 19.41)	7.97[a] (3.05 - 26.88)	2.00[a] (1.03 - 5.77)	Minshall et al., 1970
Corn; fermented manure applied in spring (.004 ha)	102 44 85	Lancaster, Wisconsin	silt loam	77.0[a] (65.76 - 77.6)	11.51[a] (5.59 - 15.32)	3.38[a] (3.35 - 5.32)	.75[a] (.68 - .96)	Minshall et al., 1970
Corn; liquid manure applied in spring (.004 ha)	78 33 114	Lancaster, Wisconsin	silt loam	77.0[a] (65.76 - 77.6)	12.45[a] (5.61 - 15.60)	2.88[a] (2.81 - 5.07)	.95[a] (.76 - 1.18)	Minshall et al., 1970
Corn (.004 ha)	0 0 0	Wisconsin	silt loam		11.52[b] (8.71 - 14.33)	4.33[b] (4.08 - 4.58)	1.30[b] (1.00 - 1.60)	Hensler et al., 1970
Corn; fresh manure applied in winter (.004 ha)	108 39 99	Wisconsin	silt loam		9.32[b] (7.11 - 11.53)	15.25[b] (4.44 - 26.06)	3.40[b] (1.13 - 5.66)	Hensler et al., 1970
Corn; fermented manure applied in spring (.004 ha)	108 34 99	Wisconsin	silt loam		8.81[b] (7.11 - 10.52)	4.22[b] (3.68 - 4.76)	.81[b] (.73 - .90)	Hensler et al., 1970
Corn; liquid manure applied in spring (.004 ha)	108 39 99	Wisconsin	silt loam		9.45[b] (8.10 - 10.79)	3.88[b] (3.70 - 4.07)	.94[b] (.91 - .97)	Hensler et al., 1970
Corn (.009 ha)	112 29	Morris, Minnesota	loam	62.6[c]	8.6[c]	79.6[c]	18.6[c]	Young and Holt, 1977
Corn (.009 ha)	29 81	Morris, Minnesota	loam	65.7[d]	10.1[d]	44.2[d]	14.0[d]	Young and Holt, 1977

Table 4: (continued)

Land Use	Fertilizer Application kg/ha/yr N P K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Corn; surface spread manure (.009 ha)	29 81 plus 239 43 from manure	Morris, Minnesota	loam	65.7[d]	3.8[d]	27.9[d]	8.6[d]	Young and Holt, 1977
Corn; plowdown manure (.009 ha)	29 81 plus 239 42 from manure	Morris, Minnesota	loam	65.7[d]	4.0[d]	33.0[d]	9.8[d]	Young and Holt, 1977
Corn (.009 ha)	56 29	Morris, Minnesota	loam	57.2[e]	4.57[e]	14.24[e]	3.14[e]	Burwell et al., 1975
Corn (.009 ha)	112 29	Morris, Minnesota	loam	57.2[e]	8.03[e]	23.63[e]	5.55[e]	Burwell et al., 1975
Corn; contour planting (30 ha)	448 64	Treynor, Iowa	deep loess, fine, silty mixed mesics	79.79[f] (63.07 - 105.95)	5.47[f] (1.37 - 12.57)	8.69[f] (2.2 - 72.47)	.59[f] (.092 - 2.118)	Alberts et al., 1978
Corn; contour planting (33.6 ha)	168 39	Treynor, Iowa	deep loess, fine, silty mixed mesics	78.65[f] (62.16 - 104.59)	3.86[f] (1.52 - 9.76)	5.36[f] (1.69 - 43.71)	.35[f] (.083 - 1.288)	Alberts et al., 1978
Corn; contour planting (60 ha)	280 64	Treynor, Iowa	deep loess, fine, silty mixed mesics	73.76[f] (52.8 - 102.5)	1.75[f] (.35 - 10.71)	2.1[f] (.67 - 26.7)	.26[f] (.024 - .613)	Alberts et al., 1978
Corn (1.29 ha)	284 54	Watkinville, Georgia	sandy loam-sandy clay loam	107.7	13.0	12.42	2.21	Smith et al., 1978
Corn (.001 ha)	100 35 35	Northern, Alabama	silt loam	87.39		3.29	.40	Bradford, 1974
Soybeans; two crops/yr; conventional tillage (.01 ha)	0 29 56	Holly Springs, Mississippi	silt loam	143.75[b]	55.75[b]	46.50[b]	17.64[b]	McDowell et al., 1978

Table 4: (continued)

Land Use	Fertilizer Application kg/ha/yr N P K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Soybeans; two crops/yr; no till (.01 ha)	0 29 56	Holly Springs, Mississippi	silt loam	143.75[b]	27.9[b]	5.1[b]	2.6[b]	McDowell et al., 1978
Cotton (17.9 ha)	33 25 24	Chickasha, Oklahoma	silt loam	81.3[g] (72.7 - 97.3)	13.1[g] (8.8 - 24.1)	9.31[g] (4.99 - 11.49)	4.31[g] (2.38 - 11.52)	Menzel et al., 1978
Cotton (12.1 ha)	33 25 24	Chickasha, Oklahoma	silt loam	80.7[g] (72.9 - 96.3)	12.7[g] (8.0 - 24.8)	11.16[g] (5.18 - 14.84)	4.58[g] (2.07 - 10.75)	Menzel et al., 1978
Soybeans - Corn two crops/yr no till (.01 ha)	0 29 56	Northern, Mississippi	silt loam	143.8	54.9	23.0	7.2	McDowell et al., 1978
Corn - Soybeans two crops/yr no till (.01 ha)	136 20 37	Northern, Mississippi	silt loam	143.8	50.5	19.3	3.7	McDowell et al., 1978
Tobacco and Corn	85 40	Rhode River Watershed, Maryland	fine sandy, loam	114.7		3.7	1.4	Correll et al., 1977

a. Three year median
b. Two year mean
c. Ten year mean
d. Three year mean
e. Six year mean
f. Seven year median
g. Four year median

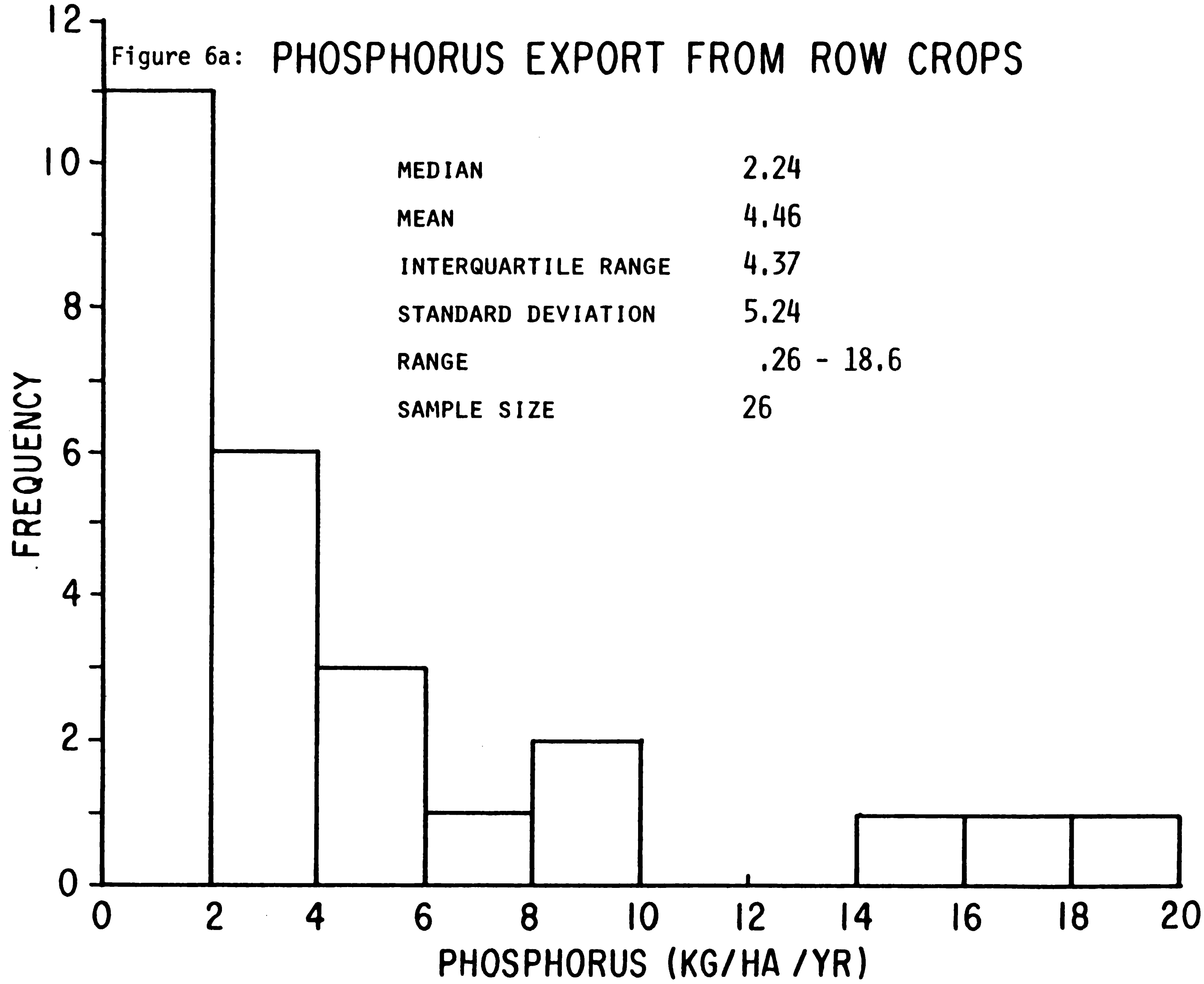


Figure 6a: PHOSPHORUS EXPORT FROM ROW CROPS

Figure 6b: NITROGEN EXPORT FROM ROW CROPS

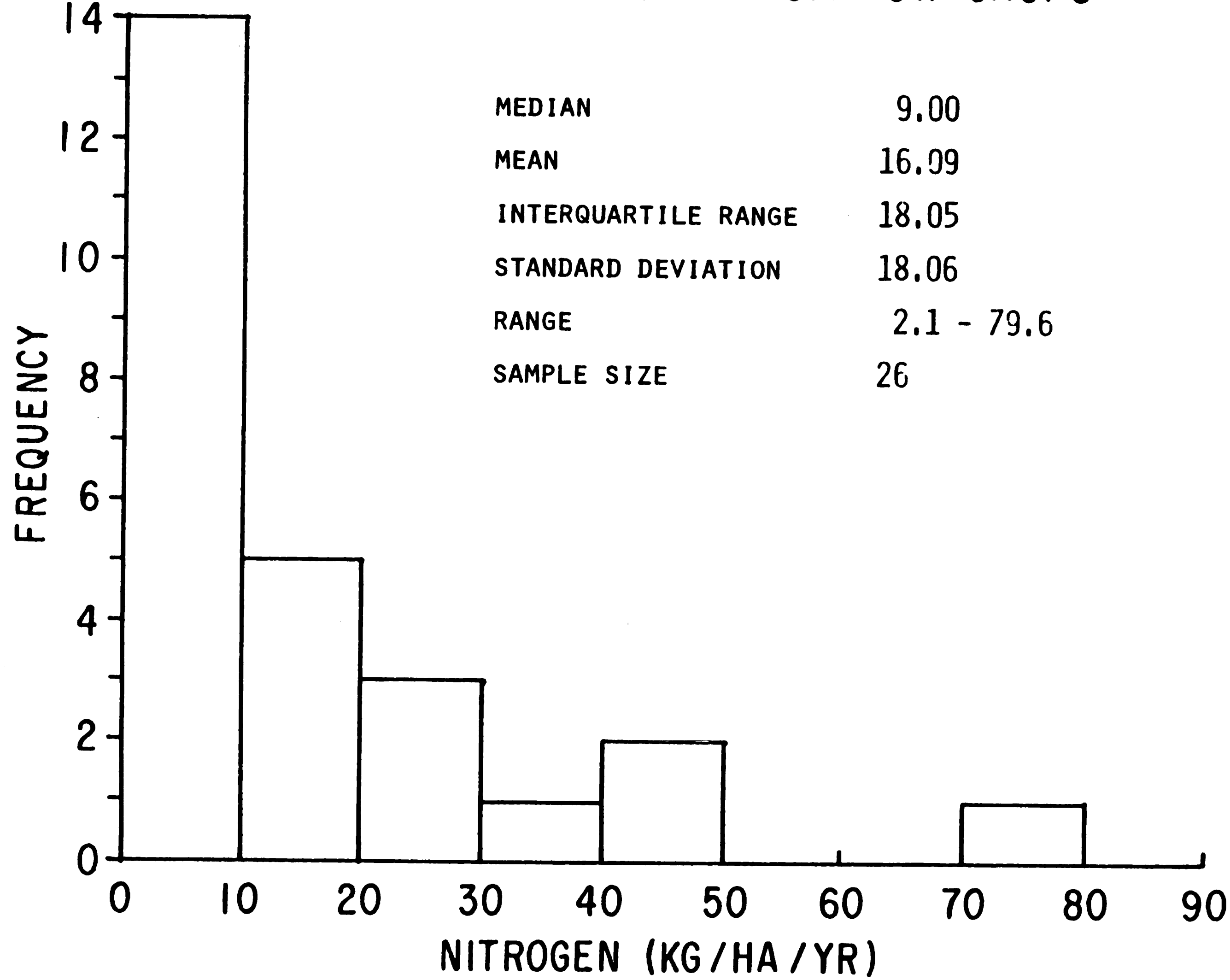


Table 5: Nutrient Export from Non Row Crops

Land Use	Fertilizer Application kg/ha/yr N	P	K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Alfalfa (.004 ha)	0	0	0	Madison, Wisconsin	silt loam	107.8[a] (105.4 - 108.8)	14.2[a] (8.2 - 18.5)	6.28[a] (5.66 - 14.67)	.76[a] (.75 - 2.40)	Converse et al., 1976
Alfalfa; fall applied manure (.004 ha)	121	24	100	Madison, Wisconsin	silt loam	107.8[a] (105.4 - 108.8)	7.8[a] (5.2 - 9.0)	6.63[a] (6.10 - 23.09)	1.24[a] (1.20 - 8.08)	Converse et al., 1976
Alfalfa; winter applied manure (.004 ha)	121	24	100	Madison, Wisconsin	silt loam	107.8[a] (105.4 - 108.8)	10.3[a] (8.2 - 12.8)	7.82[a] (5.88 - 38.22)	.64[a] (.58 - 6.09)	Converse et al., 1976
Alfalfa; spring applied manure (.004 ha)	121	24	100	Madison, Wisconsin	silt loam	107.8[a] (105.4 - 108.8)	10.1[a] (6.7 - 15.0)	6.43[a] (4.07 - 11.42)	1.81[a] (.55 - 2.39)	Converse et al., 1976
Alfalfa and Bromegrass two plots: 3.55 - 4.10 ha				Eastern South Dakota	sandy clay loam	57.9[b] (50.0 - 65.7)	2.69[b]	.97[b]	.10[b]	Harms et al., 1974
Wheat (5.2 ha)	45	7[c]		Chickasha, Oklahoma	silt loam	80.4[d] (72.9 - 96.5)	8.75[d] (5.5 - 20.8)	5.88[d] (3.77 - 7.12)	1.64[d] (.80 - 3.34)	Menzel et al., 1978
Wheat (5.3 ha)	45	7[c]		Chickasha, Oklahoma	silt loam	80.5[d] (72.9 - 96.6)	7.4[d] (5.4 - 23.0)	6.53[d] (2.89 - 8.95)	1.56[d] (.59 - 4.29)	Menzel et al., 1978
Spring wheat and summer stubble Two year rotation (4-5 ha)	0	0	0	Swift Current, Saskatchewan, Canada	loam		35.0[b] (7.0 - 62.5)		.35[b] (.1 - .6)	Nicholaichuk and Read, 1978
Spring wheat and summerfallow (4-5 ha)	0	0	0	Swift Current, Saskatchewan, Canada	loam		58.5[b] (19.0 - 98.0)		1.35[b] (.4 - 2.3)	Nicholaichuk and Read, 1978
Spring wheat and fall fertilized summerfallow (4-5 ha)	50	54		Swift Current, Saskatchewan, Canada	loam		28.0[b] (7.0 - 49.0)		2.9[b] (.2 - 5.6)	Nicholaichuk and Read, 1978

Table 5: (continued)

Land Use	Fertilizer Application kg/ha/yr N P K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Millet (.001 ha)	100 35 35	Northern Alabama	silt loam	87.39		3.04	.44	Bradford, 1974
Oats (.009 ha)	18 30	Morris, Minnesota	loam	57.2[e]	6.89[e]	4.22[e]	.65[e]	Burwell et al., 1975
Hay (.009 ha)	0 0 0	Morris, Minnesota	loam	57.2[e]	14.2[e]	4.09[e]	.64[e]	Burwell et al., 1975

a. Three year median
b. Two year mean
c. Eleven year mean
d. Four year median
e. Six year mean

Figure 7a: PHOSPHORUS EXPORT FROM NONROW CROPS

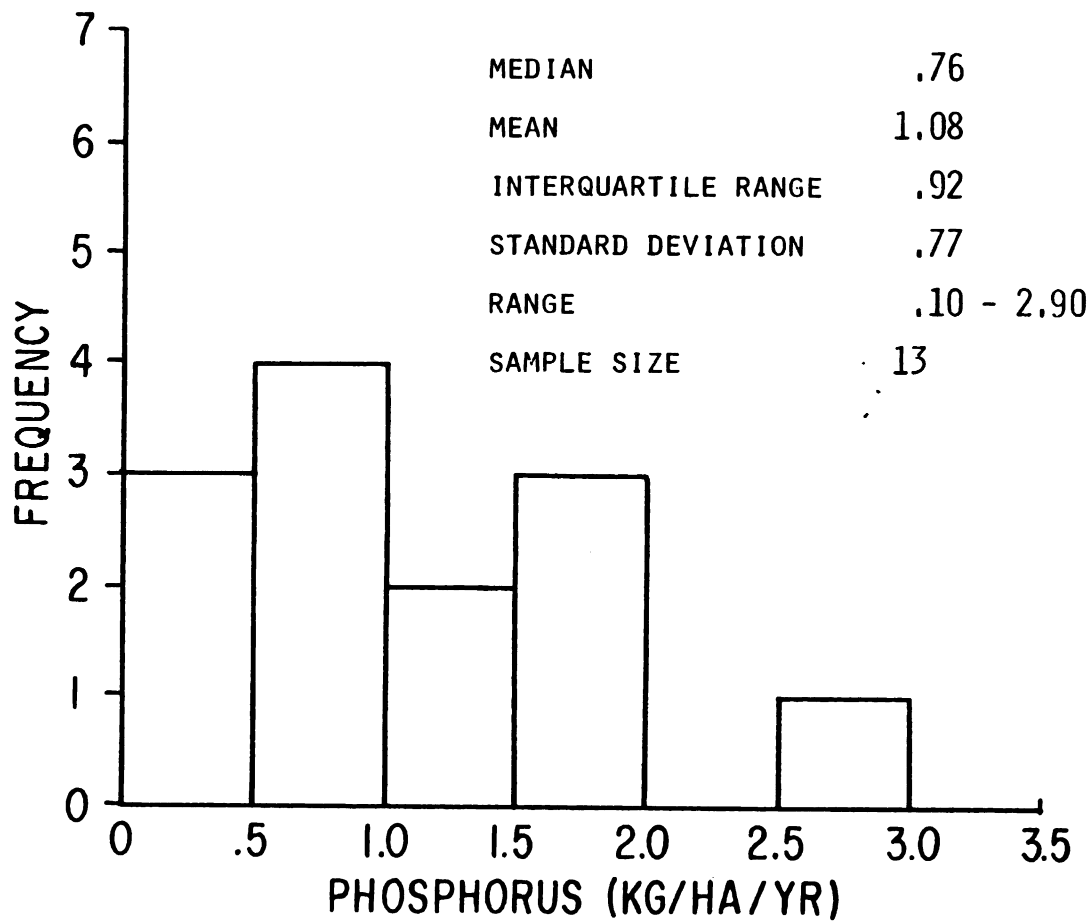
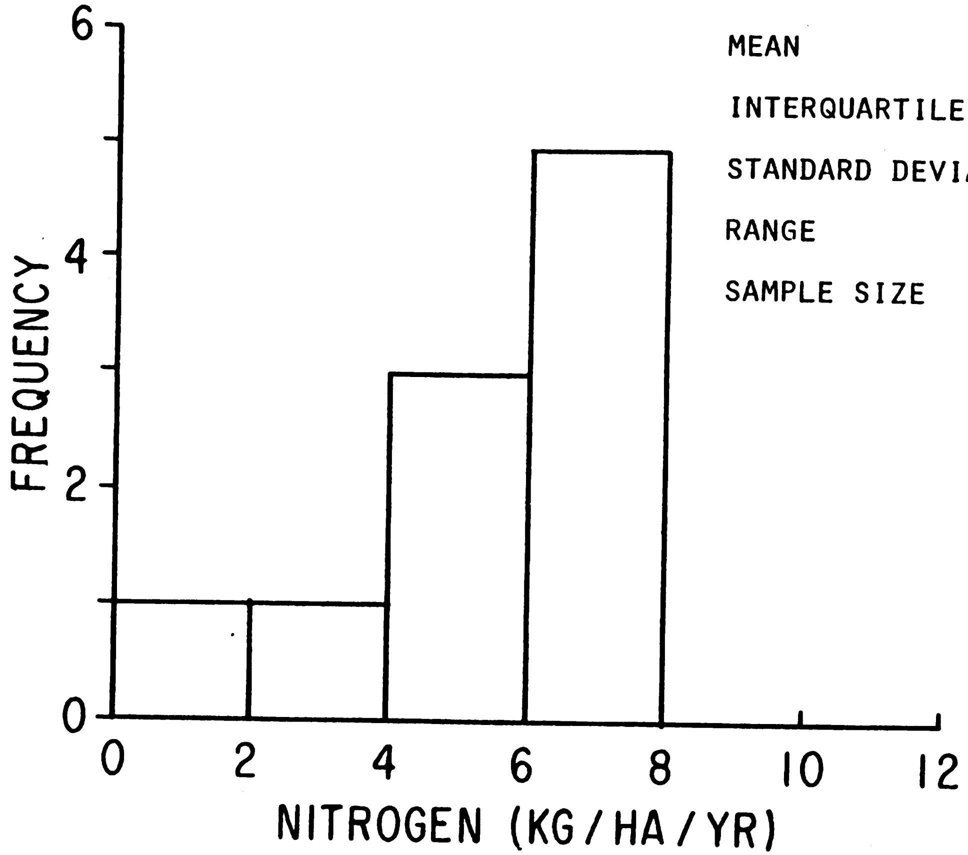


Figure 7b: NITROGEN EXPORT FROM NONROW CROPS



MEDIAN	6.08
MEAN	5.19
INTERQUARTILE RANGE	2.38
STANDARD DEVIATION	2.07
RANGE	.97 - 7.82
SAMPLE SIZE	10

of the phosphorus and nitrogen export from row crops, respectively. Note also the much higher degree of variation (range, standard deviation, etc.) exhibited by the row crops in comparison to the non row crops.

Pasture and Range Land

A major component and accepted practice of livestock production is the use of pasture and rangeland. Both dairy farming and sheep production are mainly range and pasture operations as are production of feeder calves and a substantial portion of swine production (Sutton, 1976). While both operations share the same function, range generally consists of less productive vegetation with a sparser distribution of grazers than does pasture land. Common features of both are manure accumulation and nutrient runoff from animal waste contaminants.

The hydrologic characteristics of pastured watersheds are noticeably different than those for undistrubed land. Murai et al. (1975) noted that when a forest was converted to grazing land, the compactness of the top soil was 10% higher, the non-capillary porosity and percolation rate was less than 50% of previous rates, and the final rainfall infiltration capacity was 20-25% of the original (forest) conditions. Soil compaction was attributed primarily to cattle trampling and rolling farm machinery. With less rainfall infiltration, runoff and nutrient export increases.

The temporal extent of grazing is also a key issue determining nutrient export. In a comparison between rotational and continuous grazed pastures, Chichester et al. (1979) indicated that not only was soil compaction and animal waste accumulation increased, but the decrease in vegetative cover combined to increase the volume of surface runoff. This produced a chemical transport many times greater than that from summer-grazed watersheds. A similar study in Oklahoma examining continuous versus rotational grazing produced comparable results (Menzel et al., 1978).

A more recent grassland management practice is the use of fertilizers to increase forage yields and quality. As with other practices using fertilizers, some risk of nutrient loss with surface runoff can be expected. In comparisons between paired fertilized and unfertilized, rotation and continuously grazed watersheds, fertilization increased surface runoff nutrient loads, but over longer time periods it was suspected of also increasing plant cover. The increase in plant cover would presumably decrease runoff volume and soil erosion resulting in subsequent decreases in nutrient loss (Olness et al., 1980).

All approved studies (selected according to the sampling design criteria in Chapter II) focusing on phosphorus and nitrogen export from pastured and grazed watersheds were compiled and are presented in Table 6. When the information was available, characteristics such as continuous and rotational grazing, fertilization and animal type and density were also noted. From this table, frequency distributions were constructed and are presented for phosphorus and nitrogen in Figures 8a and 8b, respectively. Note that the median values for nutrient export from grazed and pastured lands are very similar to those presented for non row crops.

Table 6: Nutrient Export from Grazed and Pastured Watersheds

Land Use	Fertilizer Application kg/ha/yr N	P	K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Moderate dairy grazing, bluegrass cover (1.88 ha)	37	16	8	Wayneville, North Carolina		106.1[a] (104.3 - 119.8)	21.3[a] (12.3 - 24.6)	3.46[a] (2.41 - 3.83)	.14[a] (.12 - .16)	Kilmer et al., 1974
Heavy dairy grazing, bluegrass cover (1.48 ha)	149	64	12	Wayneville, North Carolina		106.1[a] (104.3 - 119.8)	26.4[a] (19.9 - 31.8)	10.99[a] (8.31 - 18.05)	.16[a] (.11 - .70)	Kilmer et al., 1974
Pasture (6.28 ha)				Eastern South Dakota	sandy clay loam	58.4	4.44	1.52	.25	Harms et al., 1974
Winter grazed and summer rotational, orchardgrass and bluegrass cover (1 ha)	56	0	0	Coshocton, Ohio	silt loam	108.0	12.94	30.85	3.6	Chichester et al., 1979
Summer grazed (1 ha)	56	0	0	Coshocton, Ohio	silt loam	108.0	2.92	21.35	.85[b]	Chichester et al., 1979
Rotation grazing (42.9 ha)	168	39		Treynor, Iowa	silt loam	75.44[c] (73.3 - 77.83)	3.86[c] (.94 - 4.39)	2.32[c] (.47 - 4.28)	.251[c] (.081 - .512)	Schuman et al., 1973 a, b
Pasture for brood cattle (10 ha)	0	0	0	Eatonton, Georgia		164.0	61.8		1.35	Krebs and Golley, 1977
Continuous grazing with some supplementary winter feeding; some hay production (351.2 ha)				Rhode River Watershed, Maryland	well drained, sandy loams	114.7		13.0	3.8	Correll et al., 1977
Continuous grazing, little bluestem cover, Active gullies (11.1 ha)	0	0	0	Chickasha, Oklahoma	silt loams	88.25[d] (50.7 - 105)	15.1[d] (2.02 - 28.4)	6.13[d] (1.33 - 9.23)	1.46[d] (.27 - 3.86)	Menzel et al., 1978

Table 6: (continued)

Land Use	Fertilizer Application kg/ha/yr N	P	K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Rotation grazing little bluestem cover; good cover (11.0 ha)	0	0	0	Chickasha, Oklahoma	silt loams	88.35[d] (52.4 - 109.1)	5.95[d] (.35 - 17.8)	1.48[d] (.15 - 2.3)	.25[d] (.02 - 1.44)	Menzel et al., 1978
Continuous grazing, little bluestem cover (7.8 ha)	83	72	0	Chickasha, Oklahoma	silt loam	76.5[e]	14.7	9.20	4.90	Olness et al., 1980
Rotational grazing, little bluestem cover (9.6 ha)	87	76	0	Chickasha, Oklahoma	silt loam	78.2[e]	4.3	4.72	3.09	Olness et al., 1980
Continuous grazing, little bluestem cover active gullies (11.1 ha)	0	0	0	Chickasha, Oklahoma	silt loam	76.5[e]	10.2	5.19	.76	Olness et al., 1980
Rotational grazing, little bluestem cover (11.0 ha)	0	0	0	Chickasha, Oklahoma	silt loam	78.2[e]	4.3	1.73	.20	Olness et al., 1980

a. Four year median; sediment phase not sufficiently examined
b. Major contribution from underground spring
c. Three year median
d. Four year median
e. Nine year mean

Figure 8a: PHOSPHORUS EXPORT FROM GRAZED AND PASTURED WATERSHEDS

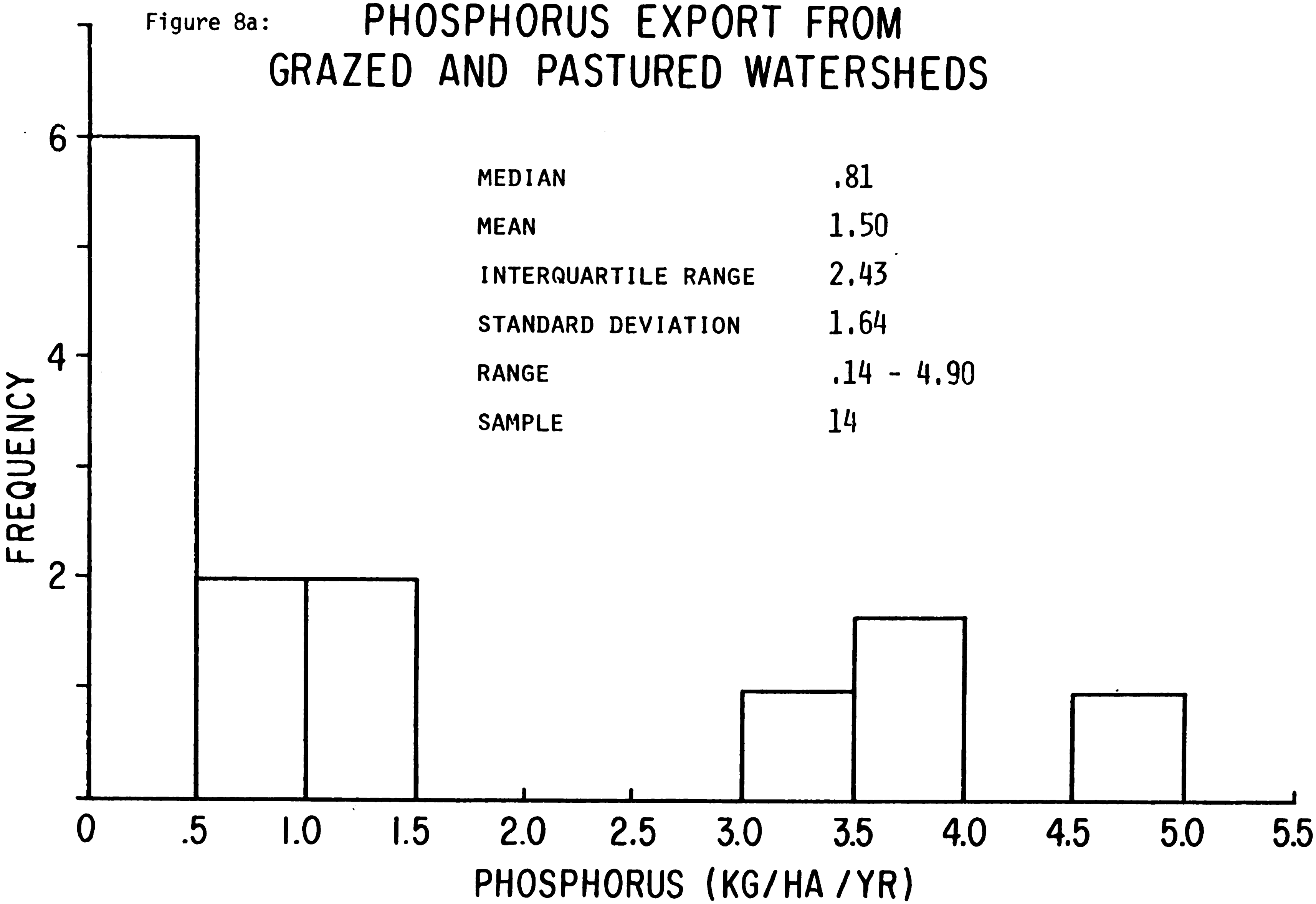
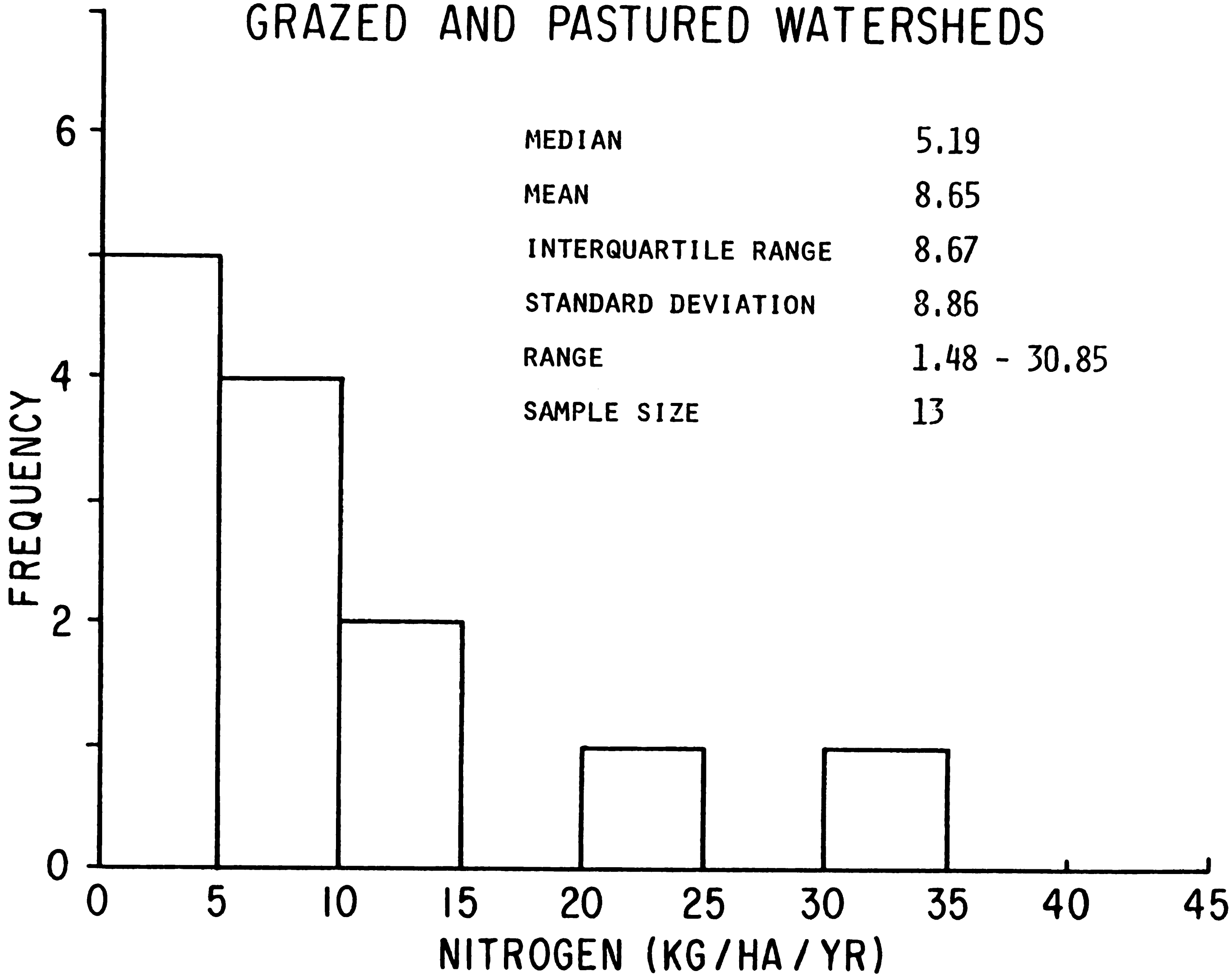


Figure 8b: NITROGEN EXPORT FROM GRAZED AND PASTURED WATERSHEDS



As an example of some of the causative factors determining the magnitude of nutrient export, the reader is referred to Figure 8a, representing phosphorus export. The values on the left represent phosphorus export from those watersheds grazed primarily in summer or on a rotational basis, while those on the right represent export from watersheds with either continuous grazing or forage fertilization. This cause-effect relationship emphasizes the need for proper examination and selection of the coefficients for extrapolation purposes.

Feedlot and Manure Storage

In many areas of the country, significant changes have taken place in livestock production operations. Whereas livestock production was once an operation requiring large tracts of land, centralization is now the trend. Specialization has removed cattle from pasture and grassland resulting in confinement of large numbers of animals in small areas. While livestock production is expected to increase, actual operation numbers and sizes are decreasing thus concentrating livestock density (Loehr, 1970).

Livestock operations have produced other changes related to nutrient budgets. At one time the grain and roughage produced on the farm was used for feed and the manure generated was returned to the land. Now with centralized operations, feed is often imported and even if land is available for manure spreading, the practice becomes, from a profit standpoint, a questionable one in comparison with the use of available commercial fertilizers. Thus an increasing number of

Table 7: Daily Production and Composition of Livestock Manure-Feces and Urine (Upper figure is average; lower figures represent the range given in literature. Dashes indicate data not available or entry not appropriate - g/kg-day live weight).*

	Dairy Cattle	Beef Cattle	Feeder Swine	Poultry	Sheet	Horses	Catfish	People
Manure	85	62	69	53	36	50	--	31.2
	72-90	41-88	50-90	32-67	30-40	40-60		
Total Solids	9.3	8.9	7.2	13.9	9.5	17.5	3.1	3.4
	6.8-13.5	6.0-11.1	6.0-9.0	9.0-17.4	8.4-10.7		2.8-3.5	2.4-4.4
Volatile Solids	6.9	6.9	5.7	10.8	8.0	--	--	2.0
	5.7-7.9	4.8-8.2	4.0-7.0	8.0-12.9	6.0-9.1			1.1-2.6
BOD_5	1.4	1.5	2.3	3.4	0.8	1.4	2.3	1.36
	.8-1.8	1.0-1.8	2.0-2.8	1.6-5.5	.7-.9		1.1-4.9	.6-2.10
COD	8.4	7.9	5.9	12.5	10.0	--	--	3.12
	4.2-13.3	6.6-9.0	4.7-7.1	9.5-15.8	7.5-12.0			1.0-3.5
Total N	.37	.43	.45	.86	.40	.30	1.6	.20
	.29-.51	.30-.58	.20-.70	.45-1.50	.34-.45		.7-2.5	.14-.26
Total P	.069	.090	.17	.40	.075	.12	.25	.024
	.026-.100	.023-.170	.09-.27	.20-.75	.040-.120		.24-.26	
Total K	.20	.23	.25	.35	.32	.25	1.5	.064
	.08-.35	.11-.38	.10-.60	.12-.50	.24-.40		.7-2.4	

*from Wanielista, 1978. p. 9.

livestock producers are faced with the disposal of highly concentrated low volume waste flows in confined areas from either the feedlot or manure storage facility.

While various chemical parameters such as the nutrient content of the accumulated manure will vary depending on the age, weight and animal type (see Table 7 for comparison), most studies to date have focused on beef or dairy cattle. Loehr and Agnew (1967) found that waste production averages approximately 6% of the animal's body weight per day. Reddell et al. (1971) reported that about two tons per year of a semicomposted manure with a 50% moisture content accumulated for each head of cattle in their study feedlot. Much of the total waste generated decomposes on the feedlot surface or is removed by cleaning operations, however, a small proportion (2-10%) may leave the feedlot in surface runoff (Madden and Dornbush, 1971; McCalla et al., 1972; Loehr, 1974; Gilbertson et al., 1975). Under the improper conditions the animal wastes could cause problems comparable to the discharge of untreated municipal sewage.

From an examination of the approved nutrient export data from a number of feedlot/manure storage studies, total nutrient loads were observed to be 2-3 orders of magnitude greater than in runoff draining other agricultural activities (Table 8). Nutrient export variability was also much higher (Figures 9a and 9b).

The most dominant influence of runoff water quality and variability has been linked to the intensity, duration, amount and seasonal distribution of rainfall and snowmelt events. Gilbertson et al. (1975) reported that slurries of undecomposed manure flowed from their

Table 8: Nutrient Export from Animal Feedlots and Manure Storage

Land Use	Location	Soil/Surface Characteristics	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Beef livestock feedlot (4.76 ha)	Brookings, South Dakota	1/2 concrete 1/2 grassed	60.71[a] (53.19 - 61.06)	21.87[a] (8.92 - 28.52)		523.0[a] (145.6 - 749.0)	Dornbush and Madden, 1973
Lamb feedlot (21.32 ha)	Brookings, South Dakota	includes detention pond	54.48[b] (49.96 - 59.0)	2.07[b] (1.96 - 2.18)		26.88[b] (20.16 - 35.84)	Dornbush and Madden, 1973
Lamb feedlot (12.63 ha)	Brookings, South Dakota	includes detention storage culvert	49.96	3.10		21.28	Dornbush and Madden, 1973
Dairy confinement, 45 head of cattle (.13 ha)	Brookings, South Dakota	concrete plus roof runoff	58.01[a] (48.16 - 62.53)	27.18[a] (15.16 - 82.65)		355.0[a] (301.3 - 521.9)	Dornbush and Madden, 1973
Beef and sheep feedlot (.603 ha)	Brookings, South Dakota	concrete surface	58.01[a] (48.16 - 62.53)	15.24[a] (14.40 - 30.35)		222.9[a] (157.9 - 2635.4)	Dornbush and Madden, 1973
Beef feedlot, 300 head of cattle (1.6 ha)	Brookings South Dakota		59.74[b] (55.83 - 63.73)	6.35[b] (3.99 - 8.71)		86.2[b] (29.1 - 142.2)	Dornbush and Madden, 1973
Beef cattle feedlot, 9.29 m^2/cow (.002 ha)	Mead, Nebraska	silty clay loam overlying sand		15.87[b] (14.68 - 17.07)	2923.2[b] (2016.0 - 3830.4)	795.2[b] (291.2 - 1299.2)	McCalla et al., 1972
Beef cattle feedlot, 18.6 m^2/cow (.002 ha)	Mead, Nebraska	silty clay loam overlying sand		17.93[b] (16.59 - 19.28)	1344[b] (1254.4 - 1433.6)	347.2[b] (224.0 - 470.4)	McCalla et al., 1972
Beef cattle feedlot, 18.6 m^2/cow (.002 ha)	Mead, Nebraska	silty clay loam overlying sand		24.94[b] (24.59 - 25.3)	3584[b] (1388.8 - 2195.2)	224[b] (134.4 - 313.6)	Gilbertson et al., 1975
Beef cattle feedlot, 500 - 600 cattle (.25 ha)	Kent Co., Ontario, Canada	concrete	70.7	33.2	3372.27	425	Coote and Hore, 1978
Beef cattle feedlot (.17 ha)	Waterloo Co., Ontario, Canada	paved and unpaved	78.6	17.3	680.52	170	Coote and Hore, 1978

Table 8: (continued)

Land Use	Location	Soil/Surface Characteristics	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Solid manure storage agea (.05 ha)	Elmira, Ontario, Canada	2/3 paved 1/3 unpaved	67.37	20.9	1891.07	172	Coote and Hore, 1978
Manure storage facility (.05 ha)	Burlington, Vermont	crushed limestone	57.7	33.5	7979.9[c]	539.9[c]	Magdoff et al., 1977

a. Three year median
b. Two year mean
c. Derived from original values of kg/cow/yr with permission of authors.

Figure 9a: PHOSPHORUS EXPORT FROM ANIMAL FEEDLOT AND MANURE STORAGE

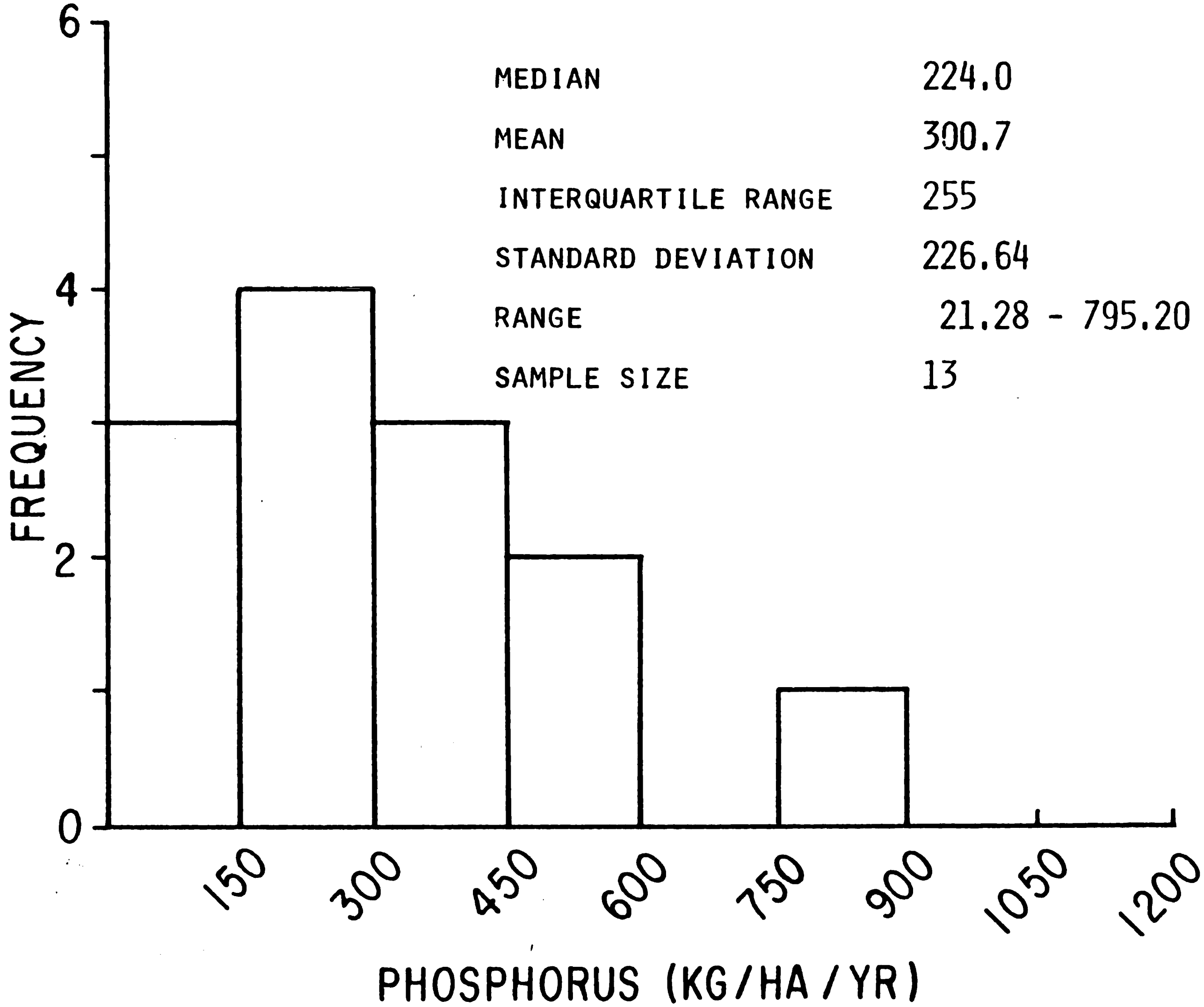
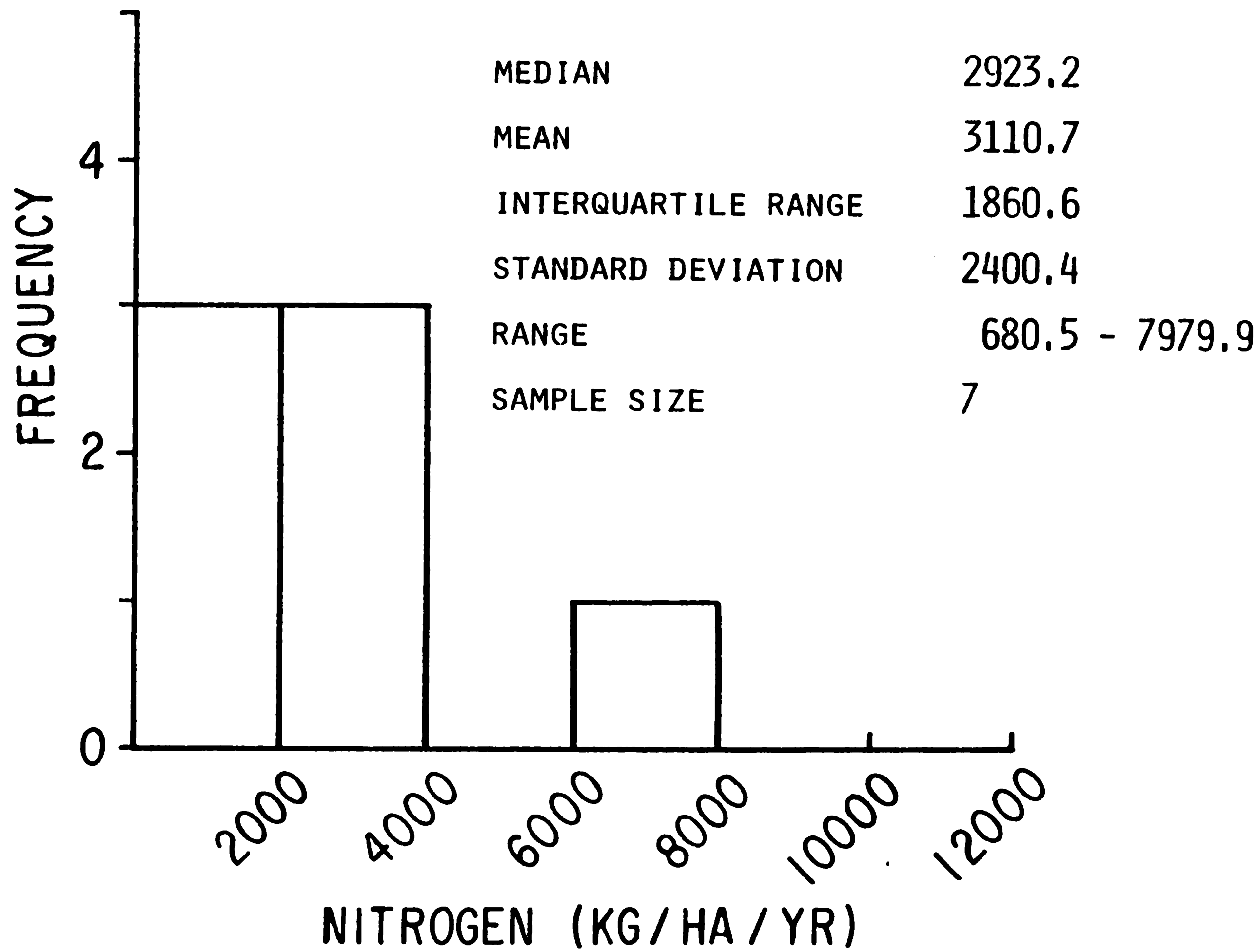


Figure 9b: NITROGEN EXPORT FROM ANIMAL FEEDLOT AND MANURE STORAGE



experimental lot when winter thaws occurred. Dornbush and Madden (1973) observed that although snowmelt runoff accounted for only 27% of the total runoff it carried 33% and 45% of the annual losses of phosphate and nitrogen, respectively.

Edwards et al. (1972) speculated that potential pollution problems in the humid, eastern 1/3 of the U.S. were likely to differ materially from those in the arid west. From an analysis of multi-state data, Clarke et al. (1975) concluded that feedlots in drier areas have less runoff (and nutrient export) from the same amount of precipitation than those in wetter, more humid regions. It is this investigator's suspicion that the more humid conditions a) decrease the water storage capacity causing proportionately more runoff during rainfall events, and b) create more reduced conditions thereby decreasing oxidation-volatilization of animal wastes. With greater accumulation of animal wastes and increased runoff, the potential for greater nutrient export in the humid east is high.

In addition to climatic variation, a number of other factors are suspected of influencing the quantity and quality of runoff. These include:

1. The percent of impervious surfaces: If the percent of paved surfaces is high, the infiltration rate will be low and the runoff and nutrient export will be high. Unsurfaced lots have a soil-manure matrix and indentations from cattle hooves serve as miniature retention basins (Loehr, 1970; Coote and Hore, 1978).
2. Enclosed vs. open facilities (with roofs): If the

facility is enclosed with a roof, rainfall impact energy will be reduced, and runoff and nutrient export will be decreased. (The higher the roof area/feedlot area ratio, the lower the runoff) (Loehr, 1970; Dornbush and Madden, 1973; Coote and Hore, 1978).

3. Animal density: If the animal density is high, the nutrient export can also be high (McCalla et al., 1972; Dornbush and Madden, 1973; Clarke et al., 1975).
4. Detention Basin: If a settling pond or detention basin is present, nutrient export will be decreased (Loehr, 1970; Coote and Hore, 1978).

Watershed Size and Proximity to Lakes and Streams

It should be noted that nearly all the nutrient export coefficients compiled in the tables for row, non row, pasture and feedlot activities were derived from studies dealing with small watersheds. Small watersheds, such as microplots (<0.5 hectares), provide less opportunity for redeposition of suspended sediment (and nutrients) than do large watersheds. Even though a severe storm will scour considerable amounts of deposited nutrients from streambeds--thus probably balancing any loading inequalities between large and small basins--some investigators feel that in the short term, small runoff plots or small watersheds tend to overestimate the mass of nutrients removed by surface runoff.

In addition, Schuman et al. (1973) demonstrated that water samples for all runoff events taken adjacent to the outflow of an agricultural watershed contained considerably more inorganic phosphorus in solution than did samples taken 70-230 meters downstream. This reduction in solution phosphorus was attributed to the adsorption of phosphorus by the additional suspended soil material entering the stream from gully erosion. This decrease in solution phosphorus in the runoff was accompanied by an increase in phosphorus on the sediment transported. Thus total phosphorus loss measured at the two sites agreed relatively well.

Since a major fraction of the nutrients in agricultural runoff is attached to sediments or particulate matter, a significant portion may be filtered from the runoff water by vegetation and soil or settle out during overland flow or in intermittent stream channels (Haith et al., 1976). Similarly, soluble nutrients may be removed from the runoff by vegetation, a phenomenon that is used to some advantage in overland runoff treatment systems for wastewater (Reed, 1972; Pound and Crites, 1973; Burton, 1978).

The magnitude of nutrient export from large watersheds with a diverse mixture of agricultural activities may not be easily determined. This is because nutrient flux produced in one portion of the watershed may be reduced in another area through biological uptake or redeposition of sediments. For large basins consisting of a mosaic of agricultural activities (or for those watersheds far removed from lakes or tributaries), export coefficients from Table 9, entitled "Mixed Agriculture" are offered as a comparison to nutrient flux values describing particular activities.

These tables consist of nutrient export values derived primarily from a number of different agricultural activities. In many cases, one activity, such as continuous corn or grazing land dominates. In others, a small percentage of the watershed is urbanized. Many studies included forested land use. While this mixture of land uses (and climates) makes meaningful comparisons with other watersheds difficult, it is felt that these nutrient coefficients more realistically reflect conditions resulting from the sediment/solution attenuation phenomenon discussed above.

In support of this, it can be observed that both the median phosphorus export value and the range for mixed agricultural watersheds (Figure 10a) are more similar to those for non row crops and pasture than with row crops and feedlots. For nitrogen flux, however, the median and range more closely parallel flux values from row crops. A possible reason for this is that many of the mixed agricultural watersheds have significant amounts of land devoted to leguminous crops (i.e., soybeans, whitebeans) which fix atmospheric nitrogen. The possibility of leaching of the nitrogen enriched soils, and increasing streamwater nitrogen concentrations, is high. Although lack of data does not allow statistical comparison, mixed agricultural watersheds with nitrogen-fixing crops do appear to have higher proportionate water soluble NO_3-N export than do watersheds planted in non-leguminous crops (see Appendix Table A6b).

Table 9: Nutrient Export from Mixed Agricultural Watersheds

Land Use	Fertilizer Application kg/ha/yr N P K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
58% row crops 31% small grain and pasture 6% woods 5% urban (4950 ha)	44	Black Creek watershed, Harlan, Indiana	silt loam, clay, silty clay loam, silty clay	91.0[a] (70 - 112)	19.35[a] (11.2 - 27.5)	28.65[a] (8.6 - 48.7)	3.15[a] (1.1 - 5.2)	Lake and Morrison, 1977
63% row crops 26% small grain and pasture 8% woods 3% urban (942 ha)		Smith-Fry drain, Harlan, Indiana	silt loam, clay, silty clay loam, silty clay	91.0[a] (70 - 112)	20.75[a] (12.4 - 29.1)	31.76[a] (10.3 - 53.2)	3.25[a] (1.1 - 5.4)	Lake and Morrison, 1977
35% row crops 48% small grain and pasture 5% woods 12% urban (714 ha)		Dreisbach Drain, Harlan, Indiana	silt loam, clay, silty clay loam, silty clay	91.0[a] (70 - 112)	18.05[a] (10.1 - 26.0)	25.85[a] (6.6 - 44.1)	3.00[a] (1.00 - 5.00)	Lake and Morrison, 1977
50% pasture 25% rotation cropland 25% hardwood forest (123 ha)		Coshocton, Ohio	silt loam	88.8[b] (77.7 - 92.7)	33.35[b] (26.9 - 34.4)	3.74[b] (1.67 - 10.61)		Taylor et al., 1971
39% corn 46% legumes and grass 9% small grain 2% idle 4% roads (594 ha)	134 46 120	Ottowa, Ontario, Canada	clay loam, sandy loam	95.1[c]		18.6[c] (8.2 - 24.2)	.60[c] (0.1 - 0.8)	Patni and Hore, 1978
60% row crops 40% hay and pasture 2 livestock feedlots (157.5 ha)	127 28	Macedonia, Iowa	silt loam	67.79	10.74	9.64	.648	Burwell et al., 1974

Table 9: (continued)

Land Use	Fertilizer Application kg/ha/yr N P K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Three years, pasture, two years corn (42.9 ha)	343 67	Treynor, Iowa	silt loam	84.71	17.65	14.11	.27	Burwell, et al., 1977
Intensive Agriculture crops and improved pasture (208 ha)	120 33	North Central, Florida	sand	96.5[a] (88 - 105)	16.7[a] (12.1 - 21.3)	4.23[a] (2.10 - 6.36)	1.1[a] (.86 - 1.34)	Campbell, 1978
Active cropping and pasture		South of Washington, D.C.				2.82	.409	Grizzard et al., 1977
At least 80% of watershed devoted to agricultural activities		Southern Ontario, Canada				14.3[d] (.62 - 23.5)	1.29[d] (.05 - 2.30)	Avadhanula, 1979
37.4% soybean and whitebean 27.1% cereal 23% corn (5080 ha)		Thames River, Southern Ontario, Canada	lacustrine clay over till plain over limestone	72.9		16.1	1.28	Coote et al. (ed.), 1978
36.1% woodland 25.0% cereal 22.2% tobacco 10.1% corn 3% pasture and hay (7913 ha)		Big Creek, Southern Ontario, Canada	deep level deltaic sands			6.4	.26	Coote et al. (ed.), 1978
31.3% corn 26.4% cereal 17.9% pasture and hay 12.1% soybean and whitebean 7.5% woodland (6200 ha)		AuSable River Southern Ontario, Canada	level clay till plain over shale	86.0		41.5	.91	Coote et al. (ed.), 1978

Table 9: (continued)

Land Use	Fertilizer Application kg/ha/yr N P K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
37.2% pasture and hay 35.3% cereal 18.7% corn 6.9% woodland (1860 ha)		Grand River, Southern Ontario, Canada	silty clay ground moraine	92.5		20.3	1.00	Coote et al. (ed.), 1978
42.3% corn 22.8% pasture and hay 15.4% woodland 12.2% cereal (3000 ha)		Middle Thames River, Southern Ontario, Canada	calcareous loamy till	101.8		31.1	1.53	Coote et al. (ed.), 1978
33.4% pasture and hay 29.2% woodland 22.3% cereal 12.3% corn		Maitland River, Southern Ontario, Canada	drumlinized loam till	82.3		14.3	.16	Coote et al. (ed.)., 1978
37.4% woodland 28.5% pasture and hay 10.7% cereal 10.4% corn 3.7% tobacco (5645 ha)		Shelter Valley Creek, Southern Ontario, Canada	windblown sand and silt on scoping sandy calcareous till	84.0		3.2	.08	Coote et al. (ed.)., 1978
44.2% pasture and hay 18.4% cereal 17.8% woodland 16.2% corn (3025 ha)		Twenty Mile Creek, Southern Ontario, Canada	lacustrine and reworked clay over dolomite	77.9		15.5	1.53	Coote et al. (ed.), 1978
41.3% pasture and hay 29.0% cereal 11.3% corn 7.5% woodland (2383 ha)		Humber River, Southern Ontario, Canada	stratified clay over shale and limestone	73.7		11.1	.49	Coote et al. (ed.), 1978

Table 9: (continued)

Land Use	Fertilizer Application kg/ha/yr N P K	Location	Soil Type/Texture	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
27.8% vegetables 22.8% corn 10.0% woodland 8.9% cereal 7.9% soybean and whitebean (1990 ha)		Hillman Creek, Southern Ontario, Canada	shallow moraine sand over clay till plain over limestone	77.0		25.2	.91	Coote et al. (ed.), 1978
66.6% pasture and hay 12.1% cereal 9.5% corn 9.4% woodland (4504 ha)		Saugeen River Southern Ontario, Canada	reworked lacustrine clay over clay till	92.4		9.4	.81	Coote et al (ed.), 1978

a. Two year mean
b. Four year median
c. Three year median
d. Estimates based on PLUARG Task C monitoring of selected sites in the Grand and Saugeen River basins.

Figure 10a: PHOSPHORUS EXPORT FROM MIXED AGRICULTURAL WATERSHEDS

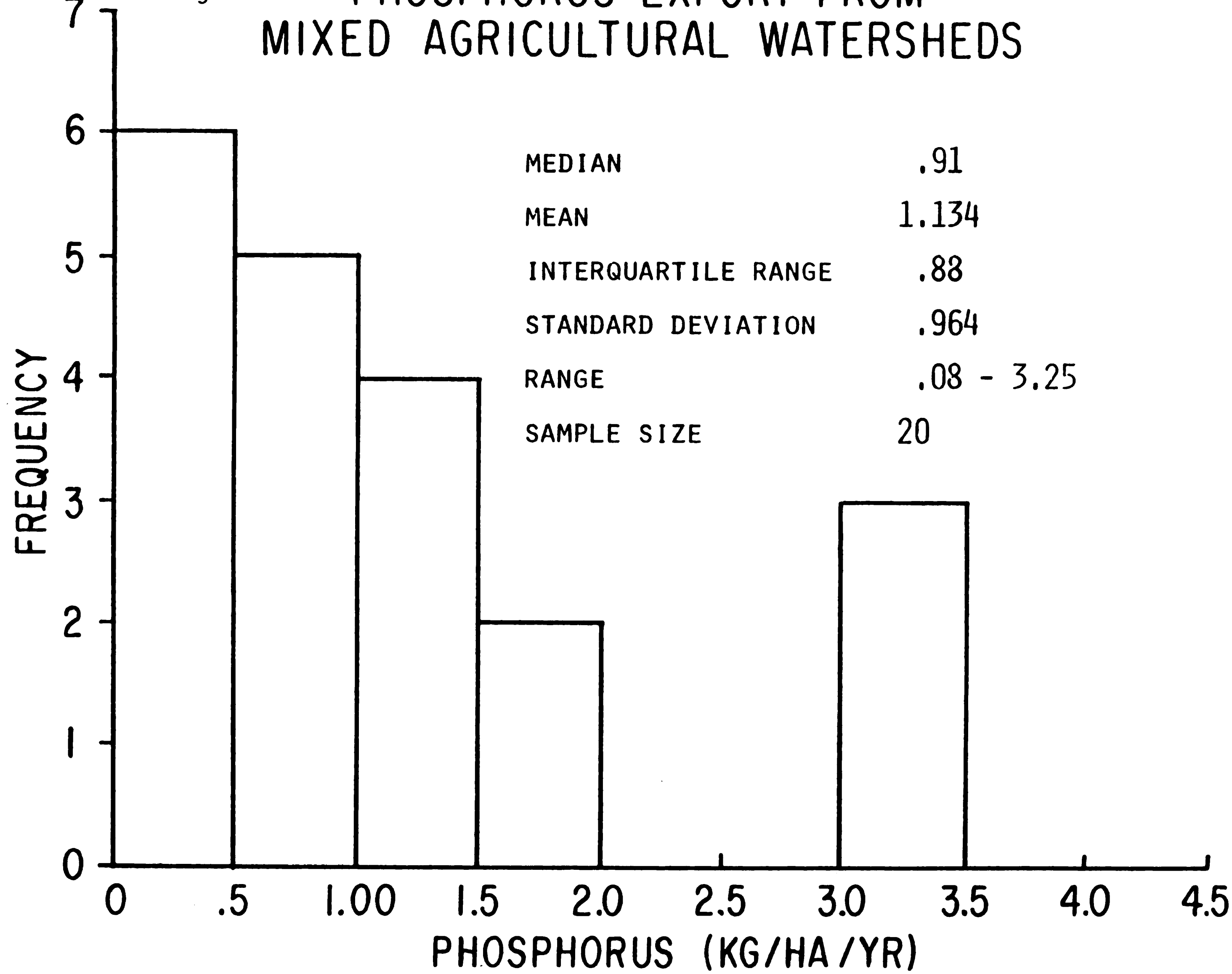
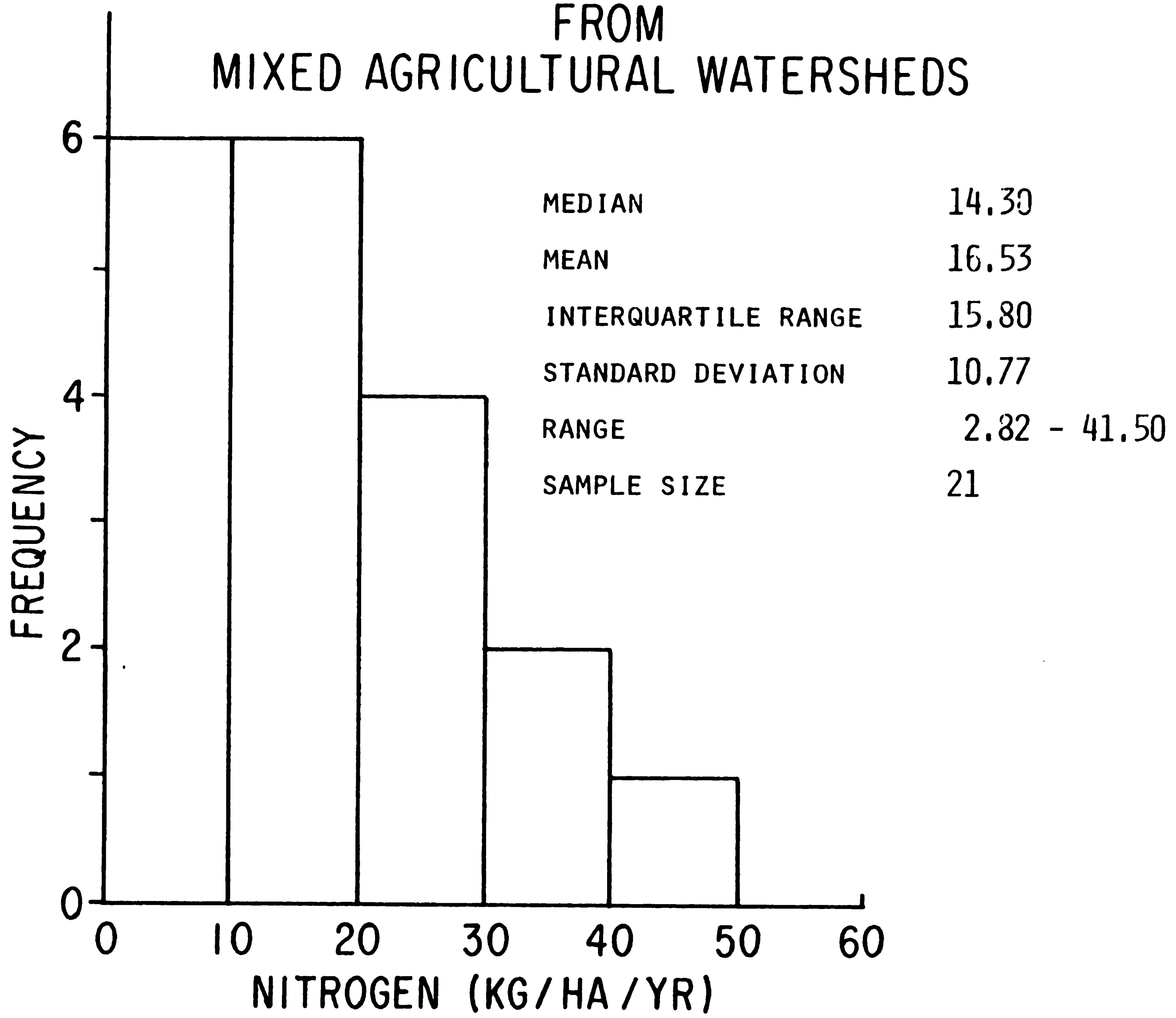


Figure 10b: NITROGEN EXPORT FROM MIXED AGRICULTURAL WATERSHEDS



CHAPTER V

URBAN LAND USE

Introduction

Prior to the mid 1960's, the water quality aspects of urban stormwater studies were generally ignored. This was partially because attention was directed primarily toward the effects of flooding in urban areas. The previously overwhelming emphasis on point source pollution also concealed the impact of diffuse runoff on water quality. Much of this neglect could be attributed to the "dilution is the solution to pollution" philosophy which formed the doctrinal basis for the design of many combined sewer systems in U.S. cities during the first half of this century (Moreau, 1975).

Recent water quality legislation and expanding urban populations have increased public awareness of pollution problems associated with urban stormwater. Gibson et al. (1975) cited a U.S. News and World Report (1972) article that listed approximately 65% of the nation's population as living in metropolitan areas occupying less than 5% of the land. As this trend toward urbanization continues, it is estimated that almost 90% of the nation's population will reside in the urban areas by 1990 (Ward, 1972). With these projections for rapid future growth, both the areas concerned with urban runoff and the attitudes toward contamination problems will likewise continue to expand (Landon, 1977).

The phenomenon of urban runoff begins with the accumulation of contaminants on urban substrates. These substrates include vegetation, automobiles, houses, shopping centers, streets and industries. Both rainfall impact energy and water runoff dislodges and removes some of these contaminants in solution and in suspension, and transports them into gutters and through storm sewers to the nearest natural or man-made watercourse. Since the nature of these contaminants is highly diverse (and potentially nutrient-rich), the impact of this waste source on water quality can be significant.

To more fully consider the cause and effect relationships determining pollutant loadings, consideration must be given to their respective components. To the degree that concentrations are similar, variations in pollutant loadings can be attributable to differences in runoff volume. Likewise, to the degree that the amounts of runoff are similar, pollutant loading variations can be attributed to concentration differences (Konrad et al., 1978).

This dualistic approach to analysis of urban stormwater pollution allows the analyst to separate the many interacting factors into two major categories. The first of these categories includes the hydraulic factors that determines the relative amounts of runoff (e.g., the percentage of impervious cover and nature of the drainage system). The second category is composed of those particular land use/cover activities within the watershed that affect concentration. These include both long and short term events such as highway corridors and construction activities, respectively.

The remainder of this chapter will discuss both the hydraulic factors and land use activities as they relate to nutrient load variability.

Hydraulic Characteristics

The majority of U.S. cities have expanded laterally during the past two decades. As urban development takes place, the response of a watershed to the rainfall input departs from its natural conditions. Due to the increase of impervious areas, the infiltration capacity and rate are sharply reduced. As a result, runoff becomes less dependent on evapo-transpiration and infiltration into the soil (Kao et al., 1973). According to Hollis (1975), the net effects of urbanization "are that a higher proportion of rainfall is translated into runoff, this runoff occurs more quickly and flood flows are therefore higher and 'flashier' than was the case in the catchment before urbanization" (see Chapter 2 for additional information).

In comparisons between urban and natural (undisturbed) basins with similar basin length-slope rations, Yoshino (1975) and Ikuse et al., (1975) note that the lag times of quickflow from urban areas are 1/7 - 1/4 the lag times of the quickflow from the natural basins, respectively. Additionally, the urbanized basins have between 1.5 and 2 times the volume of stormwater runoff of the natural basins.

Accordingly, differences in runoff volume (and infiltration) are related to the percentage of impervious surfaces within the urbanized basin. This is, in turn, dependent on the particular type of urban activity present. Typical land use activities include:

	Land Use	Description
1.	industrial	factories, mills
2.	commercial/business	offices, stores, malls
3.	high density residential	cooperatives, apartment complexes
4.	medium density residential	subdivisions
5.	low density residential	large-lot developments
6.	public lands	parks, playgrounds, cemetaries

From a study within the predominantly residential Occoquan and Bull Run watersheds in the Washington D.C. area, Grizzard et al. (1977) determined the percent impervious surface area for the monitored land activity as:

Land Use	Percentage
Commercial/Office	89-96
High rise residential	47-65
Townhouse/garden apartments	39-48
Medium density single family	34-42
Low density single family	14-19
Rural/agricultural	0-5

Grizzard et al. (1977) observed that when the impervious surface area percentage was used to characterize the land use categories, general trends became evident. For individual rainfall events, nutrient loading rates generally increased with increasing percentages of impervious surface area. In a comparison of northern Florida watersheds in contrasting land use, Burton et al. (1977) notes similar trends. Not only did the urban watershed (containing two large regional shopping centers, a major highway, commercial office buildings, schools, and apartments) have 9.4 times the concentration and 16 times the phosphorus load of a forested-agricultural watershed, but concentration and phosphorus load were also 1.25 and 2 times, respectively, that of the suburban watershed (with low density, residential subdivisions, a school and a riding stable). Konrad et al. (1978) attributes analogous findings in Wisconsin's urbanized Menominee River basin to the "easy washoff and transport of pollutants in curb and gutter storm sewer systems, and the more intensive scour and transport capacities of larger volumes of water."

Conversely, Mattraw and Sherwood (1977) suggest a number of possible explanations for the low nutrient export values exhibited by their residential watershed. These suggestions include:

a. Roofs did not have gutters. Most of the roof runoff was incorporated in sod lawns overlying quartz sand with good permeability.

b. Streets did not have curbs. Drainage water was routed along the road edge and through grassy swale.

c. Low runoff. Only 5-10% of the total rainfall ran off because of flat terrain and high permeability.

Land Use/Cover Activities--Nutrient Sources

Nutrient contaminants in urban stormwater are derived from a number of different sources and activities. Given similar hydrologic response, these sources can influence the concentration and cause significant variations in total nutrient export. Origins of nutrient contaminants include atmospheric deposition from precipitation and dryfall, street surface residues, soil erosion from construction activities and non-storm event related storm sewer contaminants.

Atmospheric Deposition

Industry and motor vehicles are the primary sources of air pollutants and are most heavily concentrated in urban areas. Although Andren and Lindberg (1977) indicate considerable complexity in relating atmospheric quality to source, urban atmospheric inputs of nutrients can be somewhat higher than those for forests (Uttormark et al., 1974; Reckhow et al., 1980). These increases can be attributed primarily to combustion emissions since:

a. Aviation and automotive fuels are known to contain organophosphorus additives to reduce corrosion (Simpson and Hemens, 1978) and to control pre-ignition and spark plug fouling (Klausener and Lee, 1974).

b. Fly ash from oil-fired boilers is estimated to contain 0.9% phosphorus as P_2O_5, and open-hearth furnaces contain up to 0.3% phosphorus pentoxide (Delumyea and Petel, 1977).

c. Approximately 1.2 million kilograms of phosphorus are combusted in fuel each year (Uttormark et al., 1974).

d. Automotive and industrial emissions are believed to be the major source of NO_x, (Robinson and Robins, 1970; Bennett and Linstedt, 1978), and

3. Photo-oxidation and hydrolysis reactions in an atmosphere containing hydrocarbons and oxides of nitrogen apparently

are a major source of nitrites, nitrates and nitric acid in precipitation (Likens, 1972; Likens et al., 1977).

Not only can atmospheric loads be significantly higher in urban areas, but nutrient utilization is essentially eliminated due to the limited vegetation. This contributes to proportionally higher streamwater concentrations. Betson (1978) suggests that efforts to minimize atmospheric pollution will lead to improved water quality generally, and particularly in urban areas.

Street Surface Residues

City and suburban streets and highways act as very effective collectors of dust, dirt and other residues from many activities within an urban area. These materials, which are washed from roads and other impervious surfaces during stormwater runoff events, include:

a. Exhaust and petroleum depositions due to motor vehicles: (including many of the elements listed in the above section on atmospheric deposition).

b. Materials from the road pavement itself: The type (asphalt, cement) and condition of road surface will determine the products of decomposition and aggregate materials (Bennett and Linstedt, 1978).

c. Chemicals from ice control: One special additive to highway salts has been nutritious phosphate, used to inhibit corrosion (Hanes, 1970). It has been estimated that approximately 9 million tons of salt and other deicing chemicals are purchased annually for snow removal purposes (Richardson et al., 1974).

d. Organic vegetation residues, debris, dirt and dust from animal and human activities: In the Washington, D.C. area, an analysis of "pure" materials was undertaken to aid in establishing the origin of pollutants found in roadway deposits. The conclusion was that "Phosphorus was most likely derived from area soils and roadway abrasion. Nitrogen was contributed by soils and plant materials carried onto the roadway by motor vehicles" (Shaeen, 1975).

Erosion

Urbanization typically causes accelerated erosion primarily as a result of construction activities. According to Field et al. (1977), these activities potentially raise sediment yields by two or three orders of magnitude from 10^2-10^3 kg/ha/yr to 10^4-10^5 kg/ha/yr. Studies by Burton et al. (1976) for highway construction and those by Daniel et al. (1979) for residential construction sites, also confirm similar increases for nitrogen and phosphorus loads. Total phosphorus and nitrogen loads for the latter study average 13.6 and 31.6 kg/ha/yr, respectively (primarily associated with high sediment loads).

Non-Event, Storm Sewer Contaminants

In addition to nutrient loads associated with stormwater, storm sewers can also contribute to water pollution between rainfall events.

From an urban study in Lubbock, Texas which focused on dry weather flows, Gibson et al. (1975) observed substantial pollutant concentrations between runoff events resulting from a number of factors. These included runoff from firefighting operations, exterior cleaning of commercial areas, industrial spills and their associated clean-up, illegal discharge of waste waters and waste products, industrial maintenance operations and excessive lawn watering. Litter, trash and discarded grass and leaves can also accumulate and decay in storm sewers and thus contribute to the nutrient load of subsequent sewer flows (Cowen and Lee, 1973; Prasad et al., 1980). Additional considerations potentially leading to increased nutrient concentrations (and loads) are the concentration and type of household pets (Landon, 1977), excessive lawn fertilization (Ellis and Childs, 1973; Prasad et al., 1980), and faulty septic tank-drain fields (Burton et al., 1977; Konrad et al., 1978).

Data Presentation

The nutrient export coefficients for urban land use are presented in Table 10. The range of nutrient loads is relatively wide and reflects the full extent of conditions exhibited from low density residential to industrial activities. This distribution is graphically presented for phosphorus and nitrogen in Figures 11a and b. Note that the median values are comparatively low. This is primarily because the bulk of the export coefficients are derived from studies of suburban-residential watersheds which produce low nutrient export.

Table 10: Nutrient Export from Urban Watersheds

Land Use	Location	Soil/Surface Characteristics	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Residential (50 ha)	Madison, Wisconsin	27% impervious surface	69.93	10.49	5.0	1.1	Kluesener and Lee, 1974
78% industrial 22% commercial (49 ha)	Menominee, Wisconsin	silt and clay loams		24.03[a] (7.88 - 40.18)		2.67[a] (1.06 - 4.28)	Konrad et al., 1978
Commercial (15.8 ha)	Appleton, Wisconsin	clay loam overlying dolomite bedrock	76.5		4.54[b]	.88[b]	Much and Kemp, 1978
Central business district (9.3 ha)	Appleton, Wisconsin	clay loam overlying dolomite bedrock	76.5		38.47[b]	4.08[b]	Much and Kemp, 1978
Industrial (8.1 ha)	Appleton, Wisconsin	clay loam overlying dolomite bedrock	76.5		6.53[b]	.75[b]	Much and Kemp, 1978
Residential (41.7 ha)	Appleton, Wisconsin	clay loam overlying dolomite bedrock	76.5		3.67[b]	.35[b]	Much and Kemp, 1978
Low density residential subdivision, Large lots with complete grass cover and trees (46.82 ha)	Okemos, Michigan	sandy loam, sandy clay loam	77.19		1.52[c]	0.19[c]	Landon, 1977
Low density residential, Extensive grassed areas, small lots, (33.73 ha)	Holt, Michigan	sandy loam, sandy clay loam	77.19		6.9[c]	2.7[c]	Landon, 1977
High density residential townhouse complex, limited open space (7 ha)	East Lansing, Michigan	sandy loam, sandy clay loam	77.19		4.8[c]	1.1[c]	Landon, 1977

Table 10: (continued)

Land Use	Location	Soil/Surface Characteristics	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
High density residential co-operatives, large amounts of open grassed areas (21.63 ha)	Lansing, Michigan	sandy loam, sandy clay loam	77.19		5.5[c]	.56[c]	Landon, 1977
Commercial, Shopping Center (18.19 ha)	Meridian Twp. Ingham Co. Michigan	sandy loam sandy clay loam	77.19		20.5[c]	1.7[c]	Landon, 1977
Commerical, light industry and business (4.19 ha)	Lansing, Michigan	sandy loam, sandy clay loam	77.19		4.0[c]	.66[c]	Landon, 1977
64% residential 13% recreational 12% commerical 6% transportation 1% industrial (958 ha)	Montgomery Creek, Kitchner Ontario, Canada					.757	O'Neill, 1979
Residential and light commercial (11 ha)	Cincinnati, Ohio	37% impervious surface	76.2	28.19	9.97		Weibel et al., 1964
At least 60% of watershed devoted to urban land use	Southern Ontario, Canada				9.48[d] (6.65 - 10.2)	1.63[d] (.73 - 2.05)	Avadhanula, 1979
Industrial and residential (414 ha)	Third Creek Watershed, Knoxville, Tennessee	carbonatic bedrock with shales, 28% impervious surfaces	150.0	84.3	14.95	4.17	Betson, 1978
Commercial (212 ha)	Fourth Creek Watershed, Knoxville Tennessee	soluble dolomitic carbonate rock, 45% impervious surfaces	155.0	41.1	12.78	4.85	Betson, 1978

Table 10: (continued)

Land Use	Location	Soil/Surface Characteristics	Precipitation cm/yr	Water Runoff cm/yr	Total Nitrogen Export kg/ha/yr	Total Phosphorus Export kg/ha/yr	Reference
Suburban (62 ha)	Plantation Hills Residential Area Knoxville, Tennessee	soluble dolomitic carbonate rock 23% impervious surfaces	153.0	9.4	1.56	.43	Betson, 1978
60% residential 19% commercial and industrial 12% institutional 10% unused (432.54 ha)	Durham, North Carolina	29% impervious surfaces	108.2	16.26		1.23	Bryan, 1970
60% residential 19% commercial and industrial 12% institutional 10% unused (432.54 ha)	Durham, North Carolina	29% impervious surfaces		24.64		5.26	Colston, 1974
20% urbanized, large scale residential (47900 ha)	Bull Run Basin, Occoquan Watershed, Virginia	sedimentary sandstones and shales			33.76[e]	1.912[e]	Grizzard et al., 1978
Single family residential (19.2 ha)	Broward Co., Florida	quartz sand, 39% impervious surface	125.6	9.42	1.48	0.21	Mattraw and Sherwood, 1977
67% residential 13% commercial 12% woodland 8% agriculture (792 ha)	Tallahasee, Florida	well drained loamy soils	124.5	21.2		6.23	Burton et al., 1977
Residential (6.8 ha)	Durban, South Africa	quartz sand with some clay content, 20% impervious surface	113.06	18.99	4.0	0.6	Simpson and Hemens, 1978

a. two year mean
b. Estimates based on annual streamflow measurements and nine monitored runoff events during 8 month water quality sampling period
c. Estimates based on annual streamflow measurements and five months water quality sampling
d. Estimates based on PLUARG Task C monitoring of selected sites in the Saugeen and Grand River basins
e. Suspected of having nonurban influences

Figure 11a: PHOSPHORUS EXPORT FROM URBAN WATERSHEDS

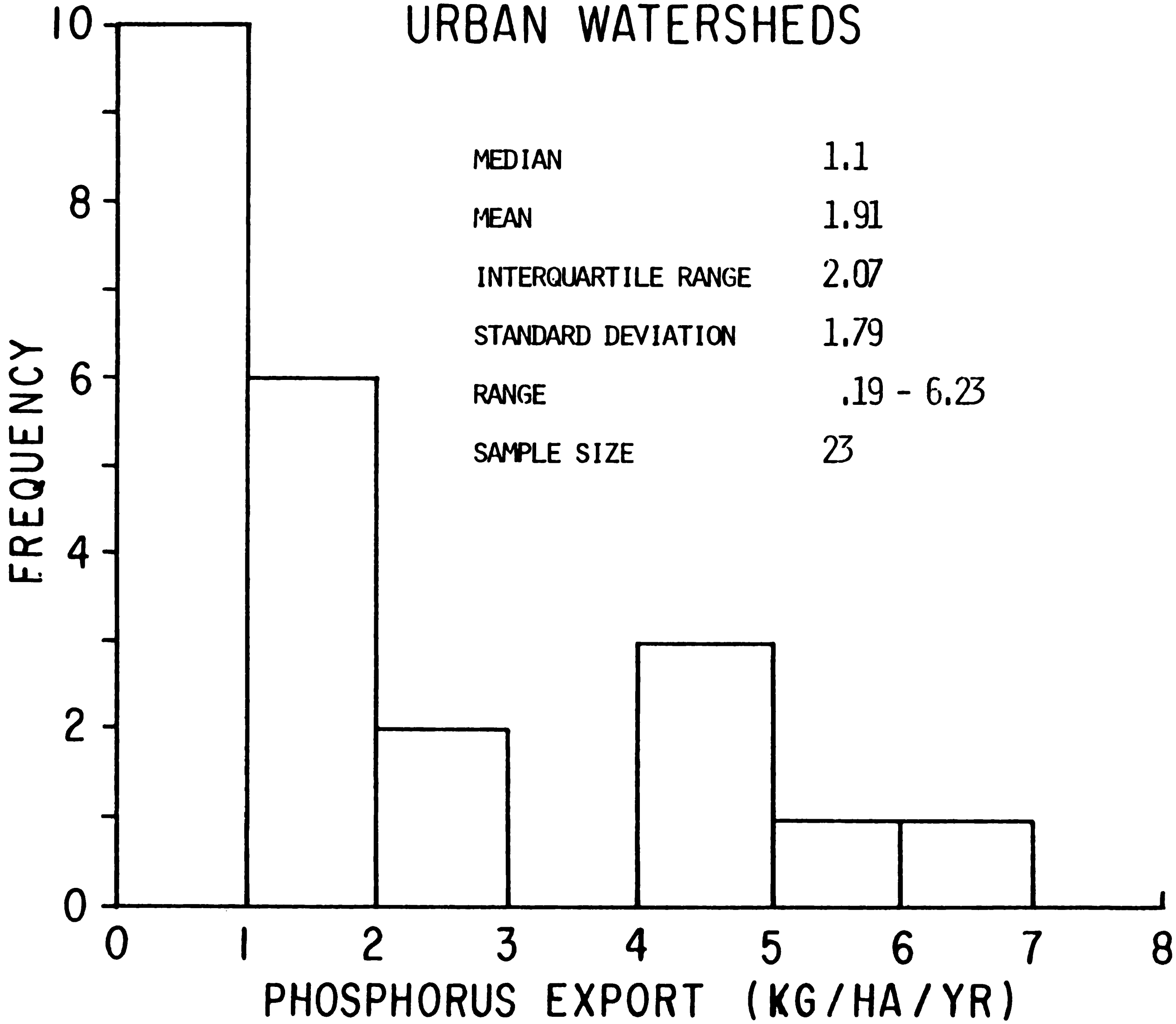
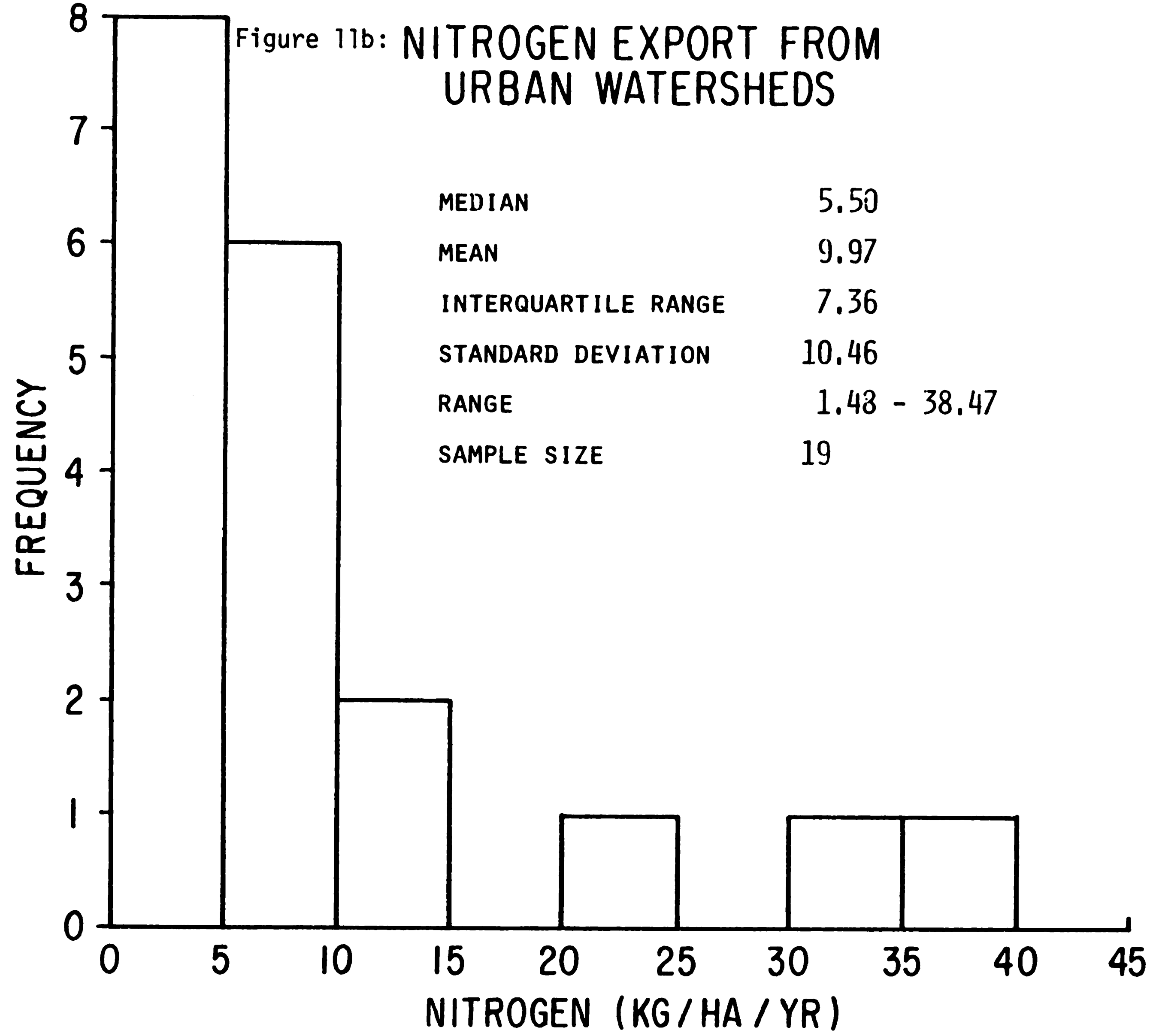


Figure 11b: NITROGEN EXPORT FROM URBAN WATERSHEDS



CHAPTER VI

COMPARISON OF NUTRIENT EXPORT FROM VARIOUS LAND USES

The Phosphorus and Nitrogen Export Coefficients

Summary Tables - Text and Appendix

In Chapter 2, criteria employed in the identification of the export coefficients collected for this study are described. To a great extent, these criteria reflect the importance of good experimental design in the collection of nutrient flux data for the determination of export coefficients. Chapters 3 through 5 include an examination of land use features that contribute to nutrient load variability. The compiled nutrient export coefficients have been tabulated along with many of these land use features in Tables 1 through 10. These tables allow the reader to observe or match the appropriate characteristics with those of an application watershed a) for present nutrient export and water quality prediction purposes, and b) to predict future changes in water quality and proposed land use changes.

To provide the reader with a more complete record of the variability and magnitude of the chemical fractions composing both phosphorus and nitrogen export (i.e., sediment phosphorus, NO_3-N), a breakdown of these chemical fractions is included in the Appendix. These tables include all the nutrient runoff coefficients presented in the text plus some information from studies which did not focus on total nutrient loads. To reduce repetition, most of the watershed characteristics are eliminated if the particular study is adequately described in the text tables.

Frequency Distribution

The effects of watershed characteristics and climatic conditions on nutrient export can be observed from a study of the loading coefficients in the above tables. However, this variability can be more properly assessed through examination of the data in frequency distributions or histograms. The histograms allow the analyst to more readily note the magnitude of the cross sectional variability resulting from different characteristics among watersheds that determine nutrient export. Accordingly, histograms describing nutrient export from the above land uses have been developed and are presented in Figures 5 through 11.

Summary statistics describing these distributions such as the mean, median, standard deviation and interquartile range are also presented. If the data set has a skewed distribution, statistics like the mean and standard deviation can be misleading. For highly skewed distributions, the mean and standard deviation may be overly influenced by an extreme data point, and they will not summarize the rest of the data well. For this reason, some statisticians suggest that certain "robust" statistics be used when the shape of the distribution is either non-normal or uncertain.

Two such robust statistics that should be considered in place of the mean and standard deviation are the median and interquartile range (Mosteller and Tukey, 1977; Reckhow, 1980). Both the median and the interquartile range are functions of order statistics; that is, they are based on an ordering of the data points from low to high values. With this arrangement, the median is the middle value (i.e., at the 50% level), and the interquartile range is the difference between the value at the 75% level and the value at the 25% level.

Box Plots

In addition to the tables and histograms, another useful graphical technique for displaying batches of data is the box plot. This technique is based on order statistics (ordering the data points from low to high value) and the plot itself is constructed from five values from the (ordered) data set. These values are: 1) the median; 2) the minimum value; 3) the maximum value; 4) the 25 percentile value; and 5) the 75 percentile value (see Figure 12).

Visual comparisons of box plots may be enhanced by the incorporation of the statistical significance of the median into the plot. This is achieved by notching the box at a desired confidence level. For example, if the 95% confidence level notches around two medians do not overlap in the display, the medians are roughly significantly different at the 95% confidence level (see McGill et al., 1978; and Reckhow, 1980 for details on confidence limits and other aspects of box-plot construction).

In addition to the above information, the box plots can also include the following (Reckhow, 1980):

1. the interquartile range;
2. the sample range;

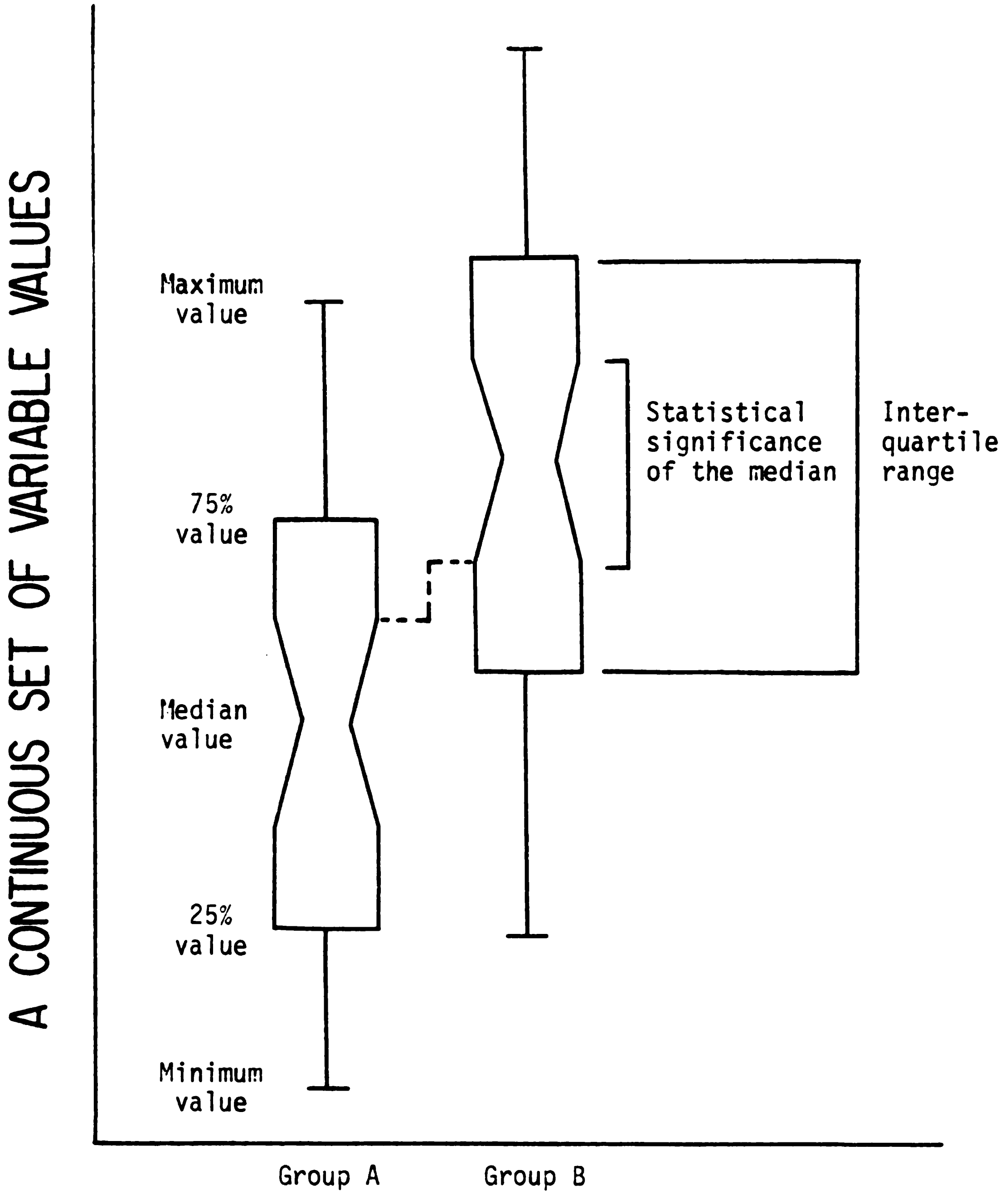


Figure 12: The Basic Configuration of a Box Plot and Comparison of Two Plots Possessing Significantly Different Medians

3. an indication of skew (from a comparison of the symmetry above and below the median); and
4. the size of the data set.

The box plots of the nutrient export coefficients from different land uses can be compared in Figures 13a and b. Note that the nutrient export medians and associated variability for each land use are readily apparent.

The range of nutrient flux values from forested watersheds is quite narrow and the median values for nitrogen and phosphorus are significantly lower than for all other land uses except pasture. A major factor determining the magnitude of phosphorus flux appears to be total annual water flow. Areas of the country with high annual rainfall (and a high percentage of storm events) tend to have high stormwater flow and high phosphorus flux. Variations in the magnitude of nitrogen export from undisturbed forests are more difficult to interpret. Since nitrogen is often the most limiting nutrient (for terrestrial plant growth), it is a more sensitive indicator of biological activity than phosphorus. Because of this sensitivity, readily observable relationships between nitrogen flux and climatic or physiographic factors may be overshadowed by subtle local differences in the supply and demand for nitrogen by growing vegetation.

Watersheds dominated by agricultural activities demonstrate both significantly higher median nitrogen and phosphorus export and wider export variability (with the exception of pastureland) than undisturbed forested watersheds. The general trend within agricultural watersheds indicates that as the soil surface is increasingly disturbed

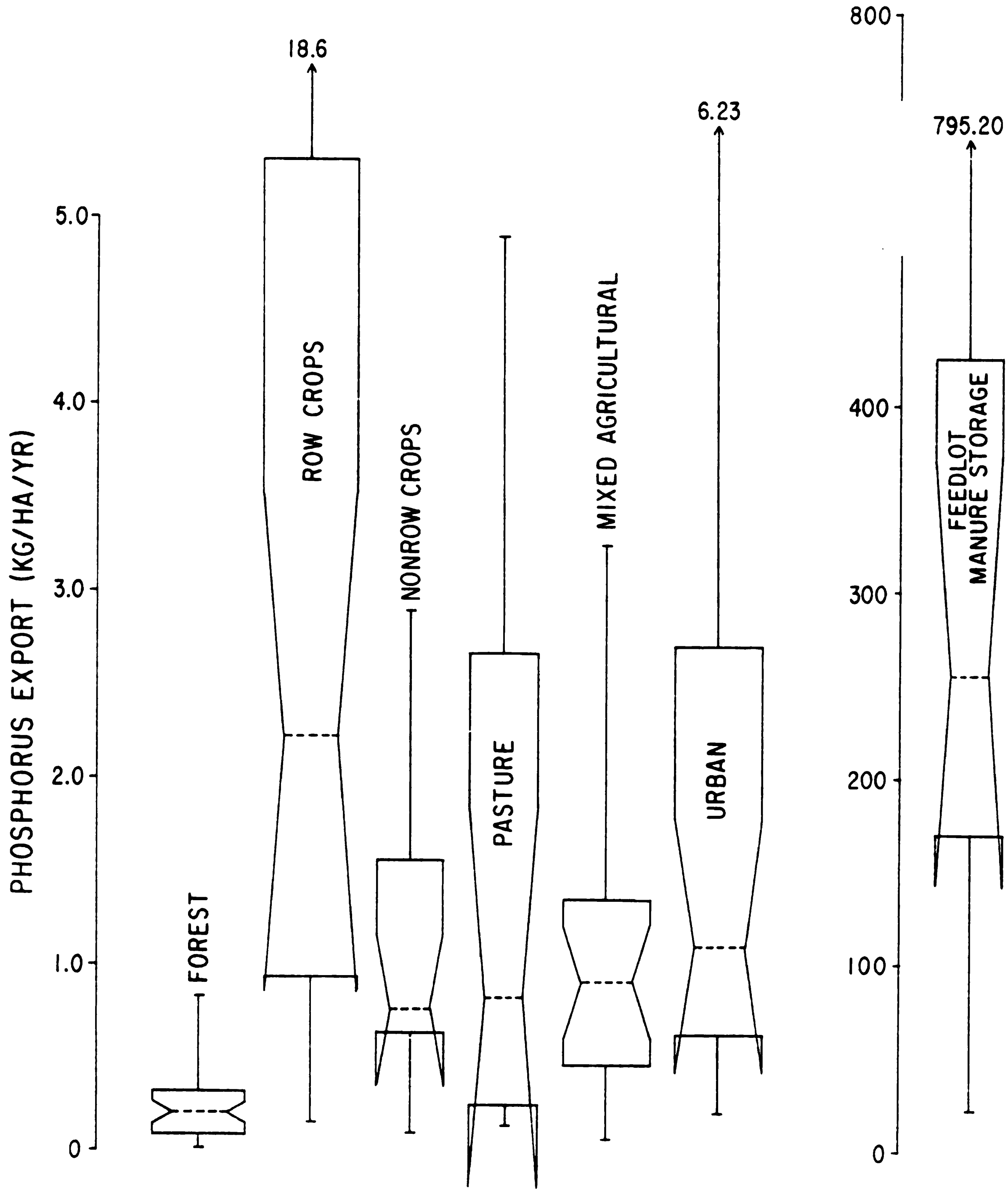
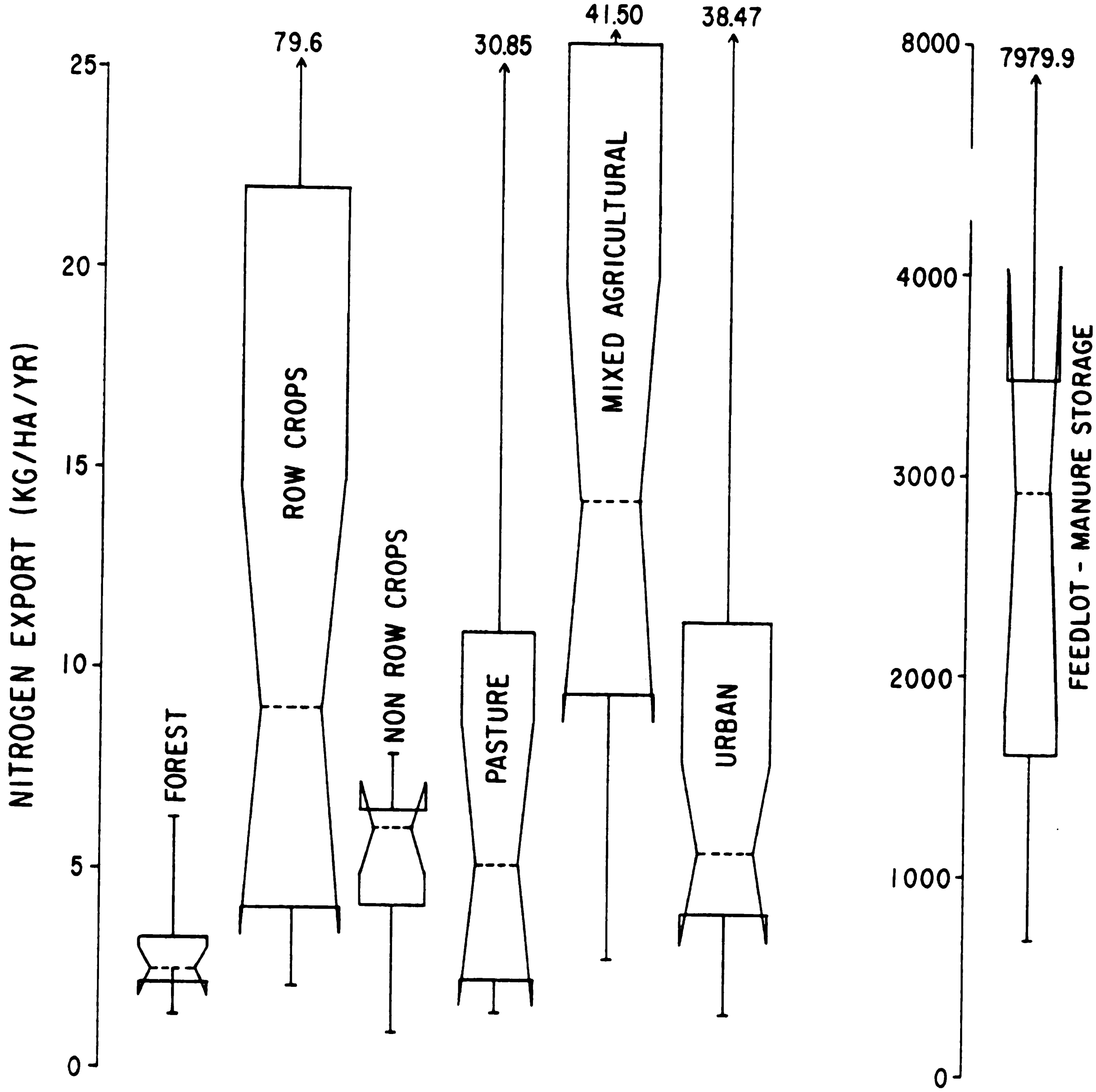


Figure 13a: Box Plots of Phosphorus Export Coefficients from Various Land Uses



Fibure 13b: Box Plots of Nitrogen Export Coefficients from Various Land Uses.

and "exposed to the elements," and increasing amounts of fertilizer nutrients are added, the potential for soil erosion and nutrient export increases. Accordingly, nutrient output from pastureland is not significantly different than output from undisturbed forests. This is primarily because pastures and grazing lands generally have a continuous (if somewhat reduced) annual vegetative cover which 1) reduces the kenetic energy of rainfall impact, and 2) incorporates nitrogen and phosphorus as vegetative biomass.

In contrast to pastureland, row-cropped watersheds undergo considerably more disturbance of the soil surface, and the soil is left barren (fallow) for longer periods than for even the most severely grazed watersheds. The inputs of nutrients from fertilizers are also generally higher than those for pastures. In addition, the planting of crops in rows promotes rapid water runoff (through channelization) and high soil erosion, which cause large quantities of nitrogen and phosphorus to be exported with sediments and particulate matter. Because of these and other interacting factors, total nutrient export from row crops is both high and extremely variable.

Nitrogen and phosphorus export from non row cropped watersheds is not significantly different from either row cropped or pastured watersheds. However, the median and range of nutrient export is lower and narrower, respectively, than nutrient export from row cropped watersheds. Although both fertilizer inputs and length of fallow periods for non row crops are similar to conditions for row crops, plant density (leaf-area index) is usually much higher for non row crops. Therefore, channelization is not a major problem with this activity, and stormwater flux and nutrient export are subsequently reduced.

Feedlot and manure storage activities not only exhibit significantly higher median nutrient export coefficients but in comparison with other land uses, the range of nutrient export is also the most variable. This is because the feedlot or manure storage area is typically devoid of vegetation, the underlying soil is continuously exposed and saturated with nutrients, and the nutrient pool from animal wastes is often inexhaustible. The potential for nutrient flux is therefore very high, especially during storm and snowmelt events.

The box plots displaying nutrient export from mixed agricultural watersheds are difficult to interpret since this general category includes not only varying percentages of all agricultural activities (i.e., pasture, feedlots, etc.), but often small proportions of forest land (i.e., farm woodlots). Phosphorus export from mixed agricultural watersheds is not significantly different from any of the above described agricultural activities. This probably reflects the "homogenized" nature of the various agricultural activities within the watersheds and the lack of influence of any one of these activities on phosphorus flux. Nitrogen flux, however, is significantly higher than export from both pasture and non row crops. This is possibly because of the high percentage of leguminous crops in these mixed agricultural watersheds which could increase streamwater nitrate concentrations, and hence, total nitrogen export.

The box plots representing urban land use activities reflect a mixture of watershed conditions ranging from low density housing to commercial and industrial sites. The low median export coefficients are representative of the large percentage of values derived from suburban and residential watersheds. The wide range of the data results from the few high values obtained from the industrial and commercial sites.

Nutrient Export Variability: Cross Sectional Versus Longitudinal

The information presented thus far has demonstrated that a number of interrelated factors contribute toward variability in nutrient loads. Nutrient load variability contributes toward prediction uncertainty. This uncertainty arises from both measurement and/or estimation error, and natural variability. Natural variability includes both cross-sectional variability, which in part represents various conditions in the nutrient export coefficient watersheds (and can be observed in the frequency distribution and box plots), and longitudinal variability which reflects variability in export from a single watershed over time.

To illustrate longitudinal variability, phosphorus export from two similar adjacent corn-cropped watersheds, one with seven years of identical fertilization rates and the other with five, were combined to create the histogram in Figure 14. Since variation in precipitation runoff is the probable key cause of longitudinal variability, a histogram of water runoff rates was also developed and presented in Figure 15. Note the high degree of similarity between the two distributions.

In most situations, it is likely that longitudinal variability is smaller in magnitude than cross-sectional variability, since the

Figure 14: TOTAL PHOSPHORUS EXPORT FROM TWO CORN CROPPED WATERSHEDS ILLUSTRATING VARIABILITY OVER TIME

(FROM ALBERTS ET AL., 1978)

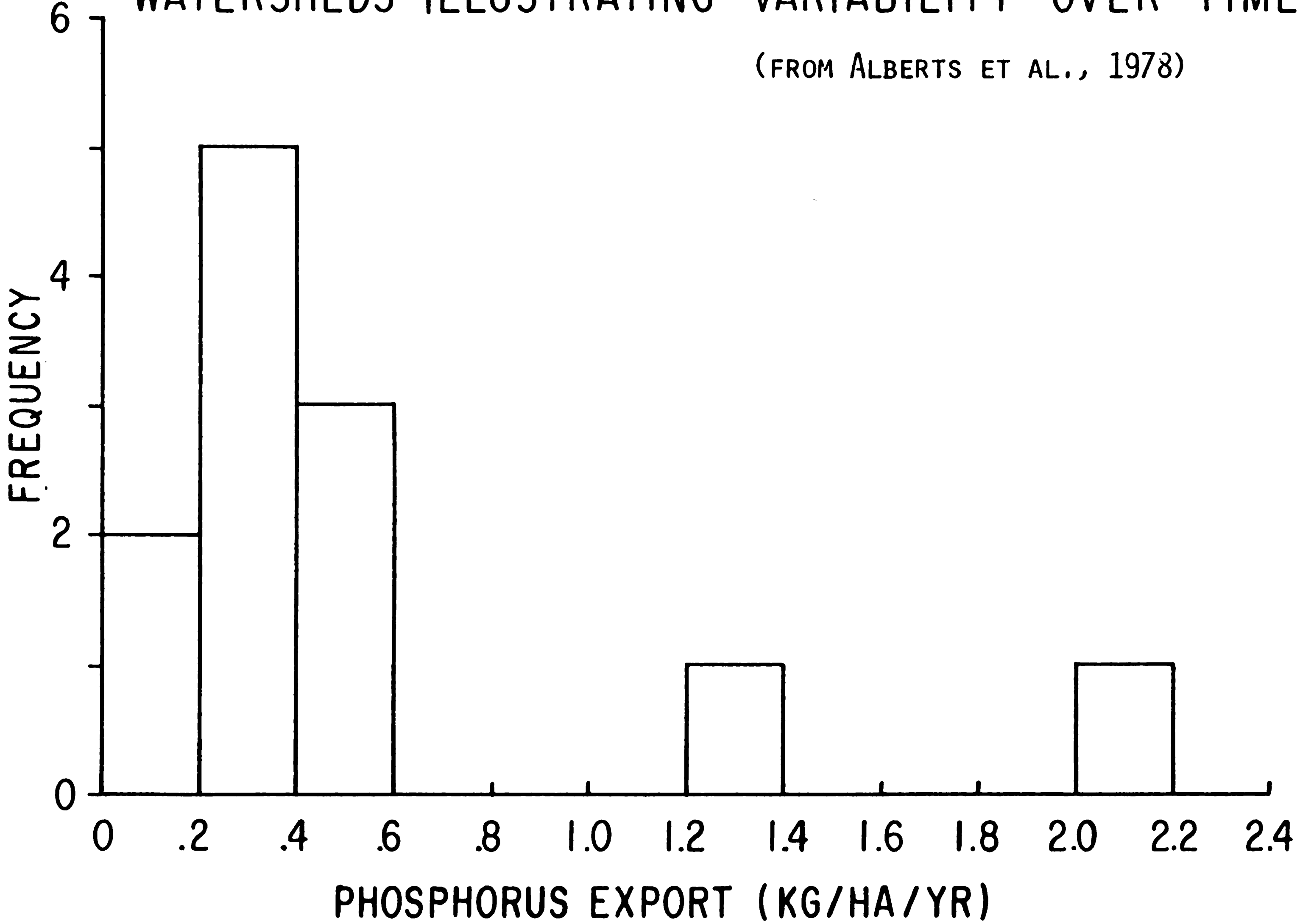
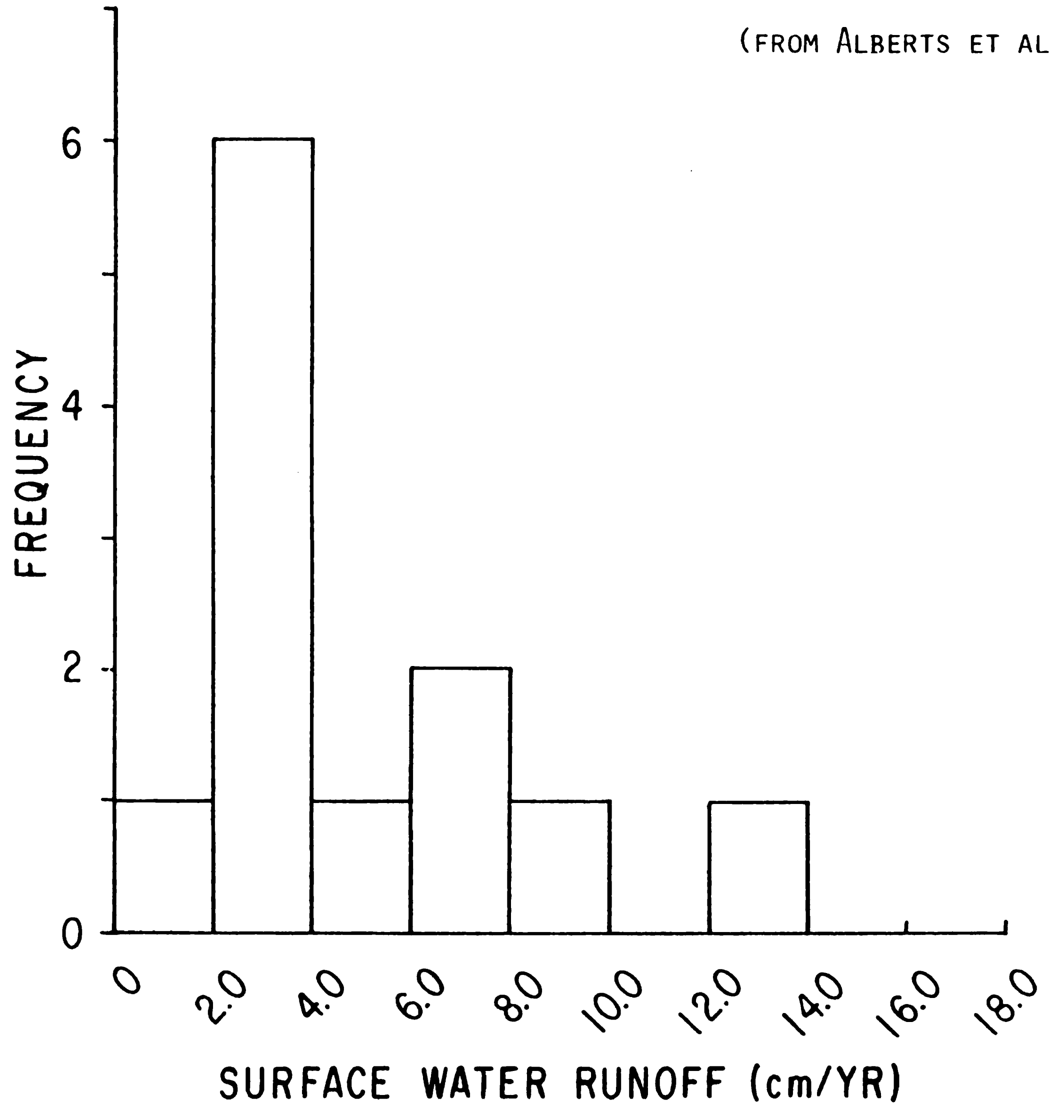


Figure 15: SURFACE WATER RUNOFF FROM TWO CORN CROPPED WATERSHEDS ILLUSTRATING VARIABILITY OVER TIME

(FROM ALBERTS ET AL., 1978)



causative factors for longitudinal variability are relatively homogeneous (in comparison to the causative and cumulative factors for cross-sectional export coefficient variability). Unfortunately, there is little multi-year data on nutrient export in single watersheds, so when needed, the estimation of longitudinal nutrient export variability is necessarily subjective.

CHAPTER VII

AN APPLICATION OF NUTRIENT EXPORT COEFFICIENTS

Introduction

Nutrient loading coefficients, which are associated with watershed land uses, have potentially meaningful application for lake water quality management planning by quantitative investigators. This is because many *in situ* water quality studies are often technically, financially and practically prohibitive to conduct. Planning for proper lake quality management necessitates the prediction of the impact of projected land use on lake quality. Projected or anticipated land use changes, however, cannot be measured. Instead, the information must be extrapolated from other similar watersheds, possibly from the nutrient export coefficients compiled in the previous chapters.

The prediction of quantitative water quality impacts associated with land use changes requires the use of mathematical models. Models have a wide scope of application. However, there are many important restrictions, requirements and tasks associated with model application. One of the most important tasks that the analyst performs in applying modeling methodology to the planning process is selecting the nutrient export coefficients.

Two things must be considered for selecting nutrient export coefficients for effective planning. The first is based on the premise that planning decisions must be based upon reliable information. In the context of this study, the selected export coefficients must carefully match those characteristics of the application lake watershed. Not only must the analyst have comprehensive knowledge of the application lake watershed but he/she must also be aware of those conditions which influence the candidate export coefficients in the literature. This implies that either experience in the application of loading estimates, and/or a thorough knowledge of the ecological mechanisms described in the previous chapters, is a valuable attribute.

The second consideration vital to the planning process is that the reliability of the prediction be estimated. Water quality modelers determine prediction reliability by incorporating uncertainty analysis into the modeling methodology. Assignment of "high," "most likely," and "low" export coefficients represents the uncertainty that the analyst has in his/her estimate of nutrient loading. (The high and low values selected for an application lake watershed are often not as high or low as some of the candidate export coefficients presented in the previous tables. This is because conditions in the application watershed are more certain and may not be equivalent to the extreme conditions that are presented by the range of candidate coefficients.)

According to Reckhow et al. (1980), loading uncertainty may be caused by either variability or bias. "Variability results from 1) natural fluctuations in a characteristic (i.e., streamflow or concentration) or from 2) uncertainty inherent in a statistic summarizing a set of data. Bias results from a number of causes, all associated with the fact that the estimate may not be representative of the characteristics that it was selected to estimate."

He further argues that while "modelers and biologists prefer objective measures of uncertainty, such as the calculated variability in a data set, both the 1) limited available data, and the 2) obviously unmeasurable nature of future projections favor (or necessitates) subjective estimates. Given this subjectivity, and the inexperience of most planners and analysts with nutrient loading estimation, there may be uncertainty in the uncertainty estimates."

Application Lake Watershed

To demonstrate to the reader the usefulness of the compiled nutrient export coefficients and their inherent temporal and spatial variability and subjective application, a hypothetical watershed has been constructed with a wide cross-section of land uses and soil/substrate types (Figure 16). The 5900 ha watershed consists of 60.1% agriculture, 34% forest and 5.9% urban land uses, all of which drains into 1475 ha Beau Lac from a number of large and small tributaries (Table 11). Soil types range from sandy loams in the upper portions of the watershed to silt and clay loams in the "lowlands" and sand-sandy loams surrounding the lake.

Forest land use consists of mixed deciduous hardwoods and pine. The vegetation is well established secondary to tertiary growth between 30-100 years old and uniformly distributed throughout the watershed.

Agricultural land is primarily in corn (65%) with non row crops (25%) and some pasture-grazing activities (10%) also present.

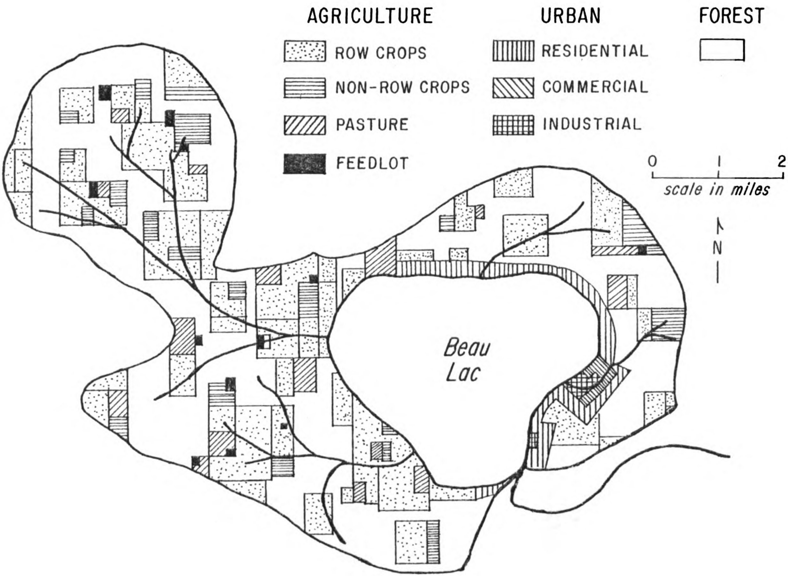


Figure 16: Land use practices for the Beau Lac watershed.

Both conventional and soil conservation practices are equally utilized and evenly distributed throughout the basin. All cropland except wheat is fallow during the months of November through April, and feedlot activities are less than 1% of total agricultural activities.

Urban land use is composed of medium density, full-time residential housing (64.3%) on the eastern and northern shores of the lake. Commercial activities (21.4%) consist of shopping malls, parking lots and other related uses with high impervious surfaces. Industry (14.3%) is comprised of light manufacturing (tubing fabricators, electrical components) and warehouses.

Table 11: Land Use Areas in the Beau Lac Watershed

Land Use	Area (ha)	Percent of Total
Forest	2000	33.9
Row Crops		
corn	2280	38.6
Non-Row Crops		
wheat	350	5.9
hay	350	5.9
alfalfa	200	3.4
Pasture		
continuous	100	1.7
rotational	250	4.2
Feedlot	20	.3
Urban		
residential	225	3.8
commercial	75	1.3
industrial	50	.8
TOTAL	5900	100.1

Total population within the urbanized area is 1820. All homes, businesses and industries are sewered and connected to a sewage treatment facility which uses a trickling filter process. Sewage effluent is directed to a major tributary leading into the lake. Because of the high nutrient load, the lake periodically experiences nuisance blooms of algae. On the advice of a consulting firm, the town is considering the addition of phosphate removal capability (with a 90% efficiency rate) to correct the situation. Of major consideration to the city council is how effective this measure will be in reducing total nutrient loads.

Climatic Variability

Climate (i.e., annual variation in precipitation runoff) is often a major determinant of longitudinal variability of nutrient loads. Longitudinal variability is demonstrated in the Beau Lac Watershed through application of nutrient loading estimates which will reflect two years of rainfall extremes. In other words, "high," "most likely," and "low" nutrient loading estimates for the first year will reflect the range of nutrient loads predicted for below normal annual precipitation amounts. The range of loading estimates predicted for the second year will reflect above normal annual precipitation amounts. For this example, it is assumed that the Beau Lac Watershed is within the southern Great Lakes Basin and exhibits similar climatic conditions.

To arrive at a best guess of typical rainfall-runoff-nutrient load relationships for this geographic area, a ratio of dry to wet year estimates determined by Lake and Morrison (1977) for three sub-watersheds in Ohio's Maumee River Basin will be applied to the application watershed. From their two-year study, a 60% increase in rainfall from 70 cm (dry year) to 112 cm (wet year) increased water runoff, total phosphorus and nitrogen export by 2.5, 4.7 and 5.7 times, respectively.

In order to apply Lake and Morrison's water runoff-nutrient export relationship to the Beau Lac Watershed, "high," "most likely," and "low" nitrogen and phosphorus loading estimates will first be (subjectively) determined for the dry year using coefficients from the appropriate land use tables. Nutrient loading estimates for the wet year will be determined by multiplication of dry year estimates by the approximate increase in nutrient load observed by Lake and Morrison between dry and wet years. For example, wet year phosphorus load = $\sim$4.7 times dry year phosphorus load.

The difference in runoff between the two years is not only reflected in the magnitude of the unit area nutrient export but can also be observed in the lake's limnological characteristics (Table 12).

Selection of Nutrient Loading Coefficients

The location of land use activities relative to tributaries and lakes is not often considered in nutrient budgeting studies. However, the spatial distribution of land uses is likely to have an impact on stream quality.

Uttormark et al. (1974) indicated that agricultural lands immediately bordering a lake or stream are likely to contribute much

Table 12: Beau Lac Summary Statistics

Variable	Estimate	
	dry year	wet year
A_o = Lake surface area	14.75 $10^6 m^2$	14.75 $10^6 m^2$
$\bar{z}$ = Mean depth	6.5 m	7.2 m
V = Lake volume	95.88 $10^6 m^3$	106.20 $10^6 m^3$
Q = Total inflow volume	10.14 $10^7 m^3$/yr	22.33 $10^7 m^3$/yr
T = Hydraulic detention time	.95 yr	.48 yr
q_s = Areal water load	6.85 m/yr	15.11 m/yr

greater quantities of nutrients in runoff to the lake than are more distant lands. Uptake of soluble nutrients and filtering of sediment fractions by intercepting vegetation are often cited as phenomena responsible for reducing the total loads from more removed, non-riparian habitat (see Chapter 4).

In addition, most of the agricultural nutrient loading estimates for specific agricultural activities (i.e., row crops), were determined from small runoff plots. Small plots are likely to yield high export values for certain situations. These values will consist of both high solution fractions and high sediment fractions and will tend to be higher than those reported for larger watersheds (several hectares in size). Multiplication of each agricultural activity by the appropriate nutrient export coefficient can grossly over estimate total nutrient export. Thus, small watershed export coefficients are most applicable to agricultural activities adjacent to a surface water body (tributary streams or the lake).

While admittedly subjective, it is assumed that only 25% of the total agricultural activities in the watershed are adjacent (i.e., within 300 m) to either the lake itself or one of its tributaries. Accordingly, loading coefficients for this fraction of agricultural land will be derived from those tables describing specific activities (i.e., row crops) while the remaining 75% will be extrapolated from the tables compiled for mixed agricultural watersheds. In contrast, nutrient export coefficients for urban activities will be unmodified since 100% of this land use is adjacent to either the lake or tributaries.

The per capita phosphorus load from the sewage treatment facility was estimated from data compiled by Reckhow et al. (1980). They estimate per capita loads at about 1.1 kg phosphorus/capita/yr. For a population of 1820 full-time residents, this is approximately 2000 kg P/yr. For simplicity, other sources of nutrient loading (i.e., precipitation, groundwater, and lake sediments) will not be included.

Results

"High," "most likely" and "low" nutrient export coefficients selected for each land use are presented for both wet and dry years in Tables 13a and 13b. Total overland nutrient export to the lake is presented in Tables 14a and 14b. As can be observed from the tables, the range of both the unit area and total mass loads are relatively narrow within the same year. Estimates between years are significantly different, however, reflecting the initial assumptions made concerning

Table 13a: Phosphorus Export Coefficients for High and Low Precipitation Years. (kg/ha/yr)

Land Use	Area (ha)	High (a)	High (b)*	Mid (a)	Mid (b)	Low (a)	Low (b)
Forest	2000.	.06	.35	.04	.20	.02	.09
Row Crops							
corn	590.	1.1	5.0	.5	2.5	.36	1.7
Non-Row Crops							
wheat	87.5	.7	3.5	.5	2.5	.3	1.5
hay	87.5	.53	2.5	.3	1.6	.2	.9
alfalfa	50.	.6	2.8	.4	1.9	.3	1.2
Pasture							
continuous	25	.9	4.0	.7	3.5	.6	2.8
rotational	62.5	.3	1.4	.2	1.0	.13	.6
Feedlot	5.	63.0	300.0	32.	150.0	10.9	50.0
Mixed agriculture	2662.5	.64	3.0	.34	1.6	.19	.9
Urban							
residential	225	.4	2.0	.21	1.0	.11	.5
commercial	75	.9	4.0	.5	2.5	.21	1.0
industrial	50	1.1	5.0	.64	3.0	.32	1.5

*a = dry precipitation year per unit area loading rate

b = wet precipitation year per unit area loading rate

Table 13b: Nitrogen Export Coefficients for High and Low Precipitation Years. (kg/ha/yr)

Land Use	Area (ha)	High (a)	High (b)*	Mid (a)	Mid (b)	Low (a)	Low (b)
Forest	2000	.63	3.6	.50	2.8	.35	2.0
Row Crops							
corn	590	5.25	30.0	2.6	15.0	1.1	6.0
Non-Row Crops							
wheat	87.5	1.75	10.0	1.05	6.0	.53	3.0
hay	87.5	.79	4.5	.62	3.5	.35	2.0
alfalfa	50	2.45	14.0	1.14	6.5	.53	3.0
Pasture							
continuous	25	2.10	12.0	1.4	8.0	.7	4.0
rotational	62.5	.9	5.0	.61	3.5	.44	2.5
Feedlot	5.	175.0	1000.0	87.5	500.0	43.75	250.0
Mixed agriculture	2662.5	4.4	25.0	3.5	20.0	1.8	10.0
Urban							
residential	225	1.4	8.0	.79	4.5	.44	2.5
commercial	75	2.1	12.0	1.4	8.0	.7	4.0
industrial	50	2.3	13.0	1.6	9.0	.9	5.0

*a = dry precipitation year per unit area loading rate

b = wet precipitation year per unit area loading rate

Table 14a: Total Phosphorus Export for High and Low Precipitation Years (kg/yr)

	High		Mid		Low	
Land Use	(a)	(b)*	(a)	(b)	(a)	(b)
Forest	120.0	700.0	80.0	400.0	40.0	180.0
Row Crops						
corn	649.0	2950.0	295.0	1475.0	212.4	1003.0
Non-Row Crops						
wheat	61.3	306.3	43.8	218.8	26.3	131.3
hay	46.4	218.8	26.3	140.0	17.5	78.8
alfalfa	30.0	140.0	20.0	95.0	15.0	60.0
Pasture						
continuous	22.5	100.0	17.5	87.5	15.0	70.0
rotational	18.8	87.5	12.5	62.5	8.1	37.5
Feedlot	315.0	1500.0	160.0	750.0	53.0	250.0
Mixed Agricultural	1704.0	7987.5	905.3	4260.0	505.9	2396.3
Urban						
residential	90.0	450.0	47.3	225.0	24.8	112.5
commercial	67.5	300.0	37.5	187.5	15.8	75.0
industrial	55.0	250.0	32.0	150.0	16.0	75.0
TOTAL	3179.5	14990.1	1677.2	8051.3	949.8	4669.4
Average Phosphorus Loading Rate (kg/ha/yr)	.54	2.54	.28	1.36	.16	.76

*a = dry precipitation year per unit area loading rate

b = wet precipitation year per unit area loading rate

Table 14b: Total Nitrogen Export for High and Low Precipitation Years. (kg/yr)

Land Use	High (a)	High (b)*	Mid (a)	Mid (b)	Low (a)	Low (b)
Forest	1260.0	7200.0	1000.0	5600.0	700.0	4000.0
Row Crops						
corn	3097.5	17700.0	1534.0	8850.0	649.0	3540.0
Non-Row Crops						
wheat	153.1	870.0	91.9	525.0	49.0	262.5
hay	69.1	393.8	54.3	306.0	30.6	175.0
alfalfa	122.5	700.0	57.0	325.0	36.5	150.0
Pasture						
continuous	52.5	300.0	35.0	200.0	17.5	100.0
rotational	56.3	312.5	38.1	218.8	27.5	156.3
Feedlot	875.0	5000.0	437.5	2500.0	218.8	1250.0
Mixed Agricultural	11715.0	66562.5	9318.8	53250.0	4792.5	26625.0
Urban						
residential	315.0	1800.0	177.8	1012.5	99.0	52.5
commercial	157.5	900.0	105.0	600.0	52.5	300.0
industrial	115.0	650.0	80.0	450.0	45.0	250.0
TOTAL	17988.5	102388.8	12929.4	73837.6	6708.8	37371.3
Average Nitrogen Loading Rate (kg/ha/yr)	3.05	17.35	2.19	12.51	1.14	6.33

*a = dry precipitation year per unit area loading rate

b = wet precipitation year per unit area loading rate

water runoff-nutrient load relationships.

The average N:P mass load ratio of 7.5 for both years indicates potential nitrogen limitation within the lake. Phosphorus, however, is the more manageable of the two nutrients and reduction of its input will eventually cause phosphorus limitation and control of nuisance conditions.

The most easily controlled phosphorus source in the application watershed is from the sewage treatment plant. From the information presented in Table 15a, inputs from sewage treatment effluent range from 40-70% of the total load for dry or low precipitation years and 12-30% for wet years.

To determine the impact of both total (non point source and sewage treatment plant) and reduced (non point source and 90% P removal) loads on the lake, a general loading reference, such as the criteria proposed by Vollenweider (1975), was used. He defined maximum acceptable specific loadings as levels which would result in a steady-state in-lake phosphorus concentration of 10 μg/l. In-lake values of twice that amount, 20 μg/l, were judged to be excessive or dangerous. Although somewhat arbitrary, and negligent of other causative factors such as alkalinity (King, 1970, 1972, 1979), the values of 10 and 20 μg-P/l appear to be reasonable and are supported by general limnological experience (Vollenweider, 1976). One must be aware, however, that certain limnological conditions can occur which cause exceptions to the model and proposed acceptable-excessive classification system.

Using subscripts to indicate in-lake concentrations associated with given loading rates, "maximum acceptable" and "excessive" specific loadings are given by (Vollenweider, 1975):

$$L_{10} = 0.01\ (10 + q_s) \tag{12a}$$

$$L_{20} = 0.02\ (10 + q_s) \tag{12b}$$

For comparison, both total and reduced annual phosphorus mass loads for wet and dry years are expressed as a loading per unit lake surface area per year and are presented in Table 15b. These areal loading estimates are then compared to Vollenweider's "acceptable-excessive" loading rates using the Beau Lac summary statistics in Table 12 and graphically presented in Figure 17.

From the diagram in Figure 17, the wide variation in phosphorus loading resulting from rainfall differences is readily apparent. "Most likely" wet year (total and reduced) phosphorus load estimates are well above excessive loading limits while dry year estimates straddle acceptable loading criteria for the *in situ* limnological conditions.

Phosphorus reduction for dry year conditions necessitates reclassification of the lake from meso- to oligotrophic. In contrast, the trophic status of "most likely" wet year loads remains unchanged. If it is assumed that normal (precipitation) year values fall somewhere between these two extremes, phosphorus removal strategies may well reduce nuisance algae conditions.

In concluding this section, it should be apparent that nutrient load estimation and subsequent lake response prediction depends heavily on the proper selection of nutrient export coefficients. This selection process must involve a careful match between those export coefficients

Table 15: Total Phosphorus Mass Loading from Nonpoint Source (NPS), Sewage Treatment Plant (STP) and with 90% Phosphorus Removal

a) kg phosphorus/watershed/yr

	Dry Year			Wet Year		
	low	mid	high	low	mid	high
NPS	950	1677	3189	4469	8051	14,990
STP	2000	2000	2000	2000	2000	2,000
Total	2950	3677	5189	6569	10051	16,990
with 90% removal	1150	1877	3389	4669	8251	15,190

(b) g phosphorus/m^2 lake surface

NPS	.06	.11	.22	.30	.55	1.02
Total (NPS + STP)	.20	.25	.35	.44	.68	1.15
with 90% removal	.08	.13	.23	.32	.56	1.03

reported in the tables with both watershed surface conditions (i.e., land use) and climate (i.e., annual rainfall).

The above example demonstrates that a eutrophication control strategy relying on point source reduction alone will result in mixed success. If rainfall remains unseasonably high or if high rainfall intensity causes intermittent "plugs" of diffuse nutrients to enter the lake, the end result may be either continuous or periodic nuisance algae blooms.

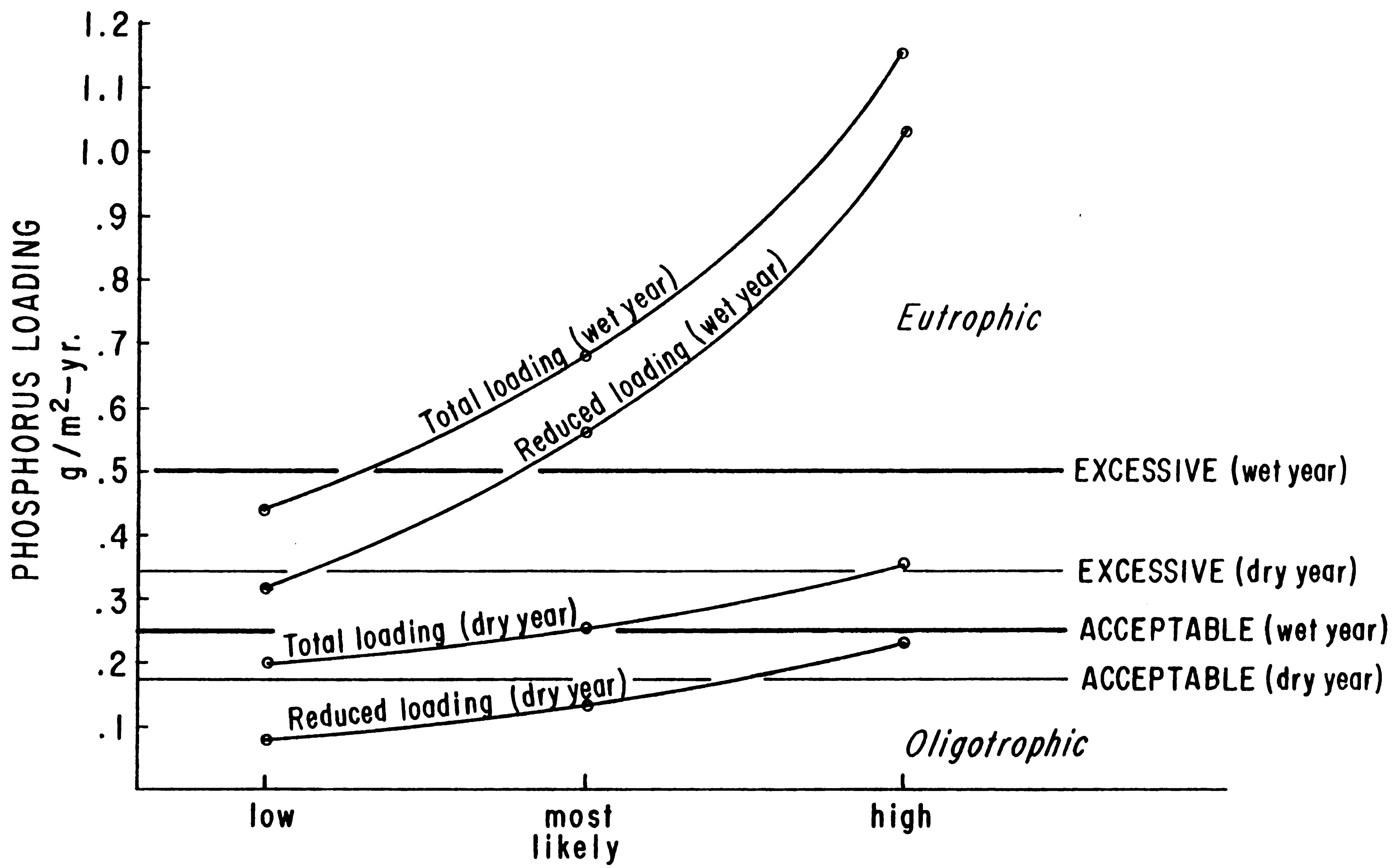


Figure 17: Low, most likely and high phosphorus loading estimates for Beau Lac

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The major focus of this thesis is non point nutrient flux from quickflow (stormwater flow), and the ecological mechanisms within a watershed which influence nutrient variability. Because many of these mechanisms and watershed perturbations are land use specific, the hypothesis, which is central to this study, is that a relationship exists between land use and nutrient flux. To properly characterize the variable nature of diffuse nutrient export, and test this hypothesis:

1. elements of sampling design theory were described,
2. literature studies conforming to the described sampling design criteria were screened and compiled according to land use,
3. biogeochemical factors influencing nutrient flux within each land use were examined, and
4. compiled nutrient coefficients were applied to a hypothetical watershed and the results interpreted.

Sampling Design

The major components of sampling design best describing both temporal and spatial variability of quickflow and diffuse nutrient flux include:

1. Parameters sampled:

   Nitrogen and phosphorus are the two nutrients most commonly accepted as affecting the lake eutrophication process. Of these two nutrients, phosphorus is generally the most limiting factor for plant growth, and most effectively controlled using existing engineering technology and land use management.

   Both nitrogen and phosphorus are collectable in basically two forms: particulate and solution. The soluble inorganic forms are generally readily available for plant utilization. However, there is a high degree of uncertainty concerning what (or when) fractions of particulate inorganic and organic forms are biologically available. Because of the unpredictability of bioavailability, the collection of total (soluble and particulate) nutrient fractions is advised.

2. Sampling frequency:

   The frequency of sampling nutrient flux associated with quickflow is a function of the 1) hydrologic response of the watershed; 2) effect on the precision of the nutrient budget estimate, and 3) associated cost of sampling. Often sampling frequency is based on a random design. Uncertainty can sometimes be reduced and accuracy and precision increased if a stratified random sampling program is employed. The underlying assumption is that the population can be more accurately represented as the sum of sub-populations. The two strata associated with hyrdologic data collection are

1) rainfall and snowmelt induced high flow events, and 2) low flow (baseflow) conditions. If sample size is increased in the high flow stratum, a more precise and accurate estimate of the population average can be obtained. According to Reckhow (1978), more samples should be taken in a stratum if the stratum is: 1) more variable, 2) larger, and/or 3) less costly to sample.

3. Sample collection and flux estimation methods:

   a) Concentration samples:

      Concentration samples are determined by a variety of field collection techniques. Manual (grab) methods are easiest but may not be efficient because storm events which transport a high percentage of the total load are often missed. To correct this problem, automatic samplers should be used. The collection process can be implemented at either equal time intervals or on a flow-weighted basis. Flow-weighted sampling often yields a more precise concentration estimate because high concentrations associated with first flush can be more equitably represented than sampling at equal time intervals.

   b) Flow estimation:

      Flow estimation is determined by one of three methods: 1) continuous flow measurement (i.e., USGS stream gauging stations), 2) instantaneous flow measurement at time of concentration sampling, and 3) an annual flow regression equation developed by the USGS. If USGS stations are not available, the third alternative is probably the most precise for a given cost.

c) Flux estimation:

To estimate flux, a number of mathematical techniques are available. Each is appropriate under certain conditions. The technique chosen depends upon the intended use, fit of the data to the equations, and simplicity of the mathematics.

4. Temporal extent of sampling:

The temporal extent of sampling depends on long-range variability. Seasonal periods of high rainfall or snowmelt runoff creates greater variance in nutrient concentrations and loads than do low runoff or baseflow periods. For a given confidence level (precision) and a margin of error (accuracy), the temporal extent of sampling must include these high and low runoff periods. Therefore, a more informative approach is to sample and report data in yearly increments.

5. Sampling location and watershed design:

The sampling location is determined by the desired (site-specific) representativeness of the sample and research objective. If the objective is to determine nutrient export from a particular land use, then the watershed under study must be exclusive of other land use types.

Comparison of Nutrient Export Coefficients from Differing Land Uses

Local climate and conditions within the watershed contribute to longitudinal and cross sectional variability, and are major influences of the "characteristics and comparative magnitude" of nutrient flux in quickflow and tributary outflow. These influences are analysed and categorized within the context of three land uses: forest, agricultural and urban.

1. Forest watersheds

   In forested systems, the median nutrient export values are significantly lower than for all other land uses except pasture. In addition, the nutrient export variability is small, making it difficult to specify any one factor as the determinant of loading in a particular watershed. Much of the variation among coefficients is probably within the range of experimental or sampling error. To determine if cause-effect relationships existed between certain physiographic and climatic characteristics, the following factors are examined:

   a) Geology:

      While the hypothesis of geologic influences on water quality make theoretical sense (e.g., high phosphorus apatite rocks contribute to high phosphorus loads), little information on specific effects is currently available to verify this phenomenon.

   b) Vegetation type:

      Certain vegetation types cause reduced water flow (e.g., pines have high evapotranspiration rates and interception capacity) and increased nutrient concentrations (i.e., nitrogen fixers). Both can reduce or increase nutrient flux.

c) Ecological succession:

Three popular hypotheses currently exist linking ecological succession with nutrient accumulation and output. However, the collected data contains a mixture of seral stages and many other causative factors, which complicate any conclusive argument.

d) Climate:

A major factor influencing phosphorus flux appears to be climate. Areas of the country that exhibit warm climates with high rainfall (such as the pacific northwest and the southeastern piedmont regions) are also associated with high productivity, high runoff and high phosphorus export.

e) Disturbed forests:

Disturbances within forested watersheds produce increased nutrient flux. Of the three types of disturbances examined, timber harvest operations appear to produce the highest nutrient export.

2. Agricultural watersheds

Agricultural watersheds are shown to have both significantly higher median nutrient export and wider export variability (with the exception of pastureland) than undisturbed forested watersheds. In general, as the soil surface is increasingly disturbed and "exposed to the elements," and increasing amounts of fertilizer nutrients are added, the potential for soil erosion and nutrient export increases. Major factors and activities which influence nutrient flux include soil type, management practices, crop type, pasture and grazing operations, animal feedlots and manure storage facilities.

a) Soils and management practices

i) Soils

Because cropland soils are left fallow for long time periods (i.e., late fall through early spring), the potential for erosion and nutrient flux is high. Of the many soil types, clays and organic soils contribute significantly to high nutrient yields from quickflow.

ii) Fertilizers

The type of fertilizer is not as important to nutrient flux as the time of application. If fertilizers are applied during snowmelt or high rainfall/runoff periods, nutrient export can be high. Excessive fertilization (applied above the recommended rate) will cause increases in nutrient flux. Under-fertilization can also cause similar increases (from soil erosion) since the crop canopy is often reduced which exposes the soil surface for longer time periods.

iii) Tillage practices

Conventional tillage methods, in which the ground is left fallow during non-growing periods and crop residues are removed at harvest, cause soil erosion and high nutrient export. Conservation tillage methods, such as no-till, contour planting or terracing, significantly reduce water, soil and nutrient export.

b) Crop type

Nitrogen and phosphorus export from row and non row cropped watersheds is significantly higher than nutrient export from forested watersheds and significantly lower than export from animal feedlot and manure storage facilities. However, the median and range of nutrient export from non row cropped watersheds is lower and narrower than export from row cropped watersheds. Although management practices for the two crop types are often similar, plant density is usually much higher for non row crops. This reduces channelization, water loss, soil erosion and nutrient export.

c) Pasture and grazing land

Nutrient output from pastureland is not significantly different than output from undisturbed forests. This is because the vegetative cover retains water, soil and nutrients. Of the two general management practices--continuous and rotational--the former will result in higher nutrient export. This occurs primarily because soil compaction and waste loads are increased and protective vegetation is decreased. Fertilization of pastures can also increase nutrient export.

d) Feedlot and manure storage

The nutrient export coefficients for feedlot and manure storage facilities are significantly higher and exhibit the greatest variability of all land use activities. While conditions are highly variable, the feedlot or manure storage area is typically devoid of vegetation, the underlying soil is saturated with nutrients, and the nutrient pool from animal wastes is often inexhaustible. High nutrient export can be expected if the, 1) percentage of paved surfaces is high, 2) roof area/feedlot area ratio is low, 3) animal density is high, and 4) no detention basin is present.

e) Mixed agricultural activities

This general category includes varying percentages of all agricultural activities including some forest land. As a result, phosphorus export from this mixed land use is not significantly different from any of the above described agricultural activities (except feedlots). Nitrogen flux, however, is significantly higher than both export from both pasture and non row crops, possibly because of the greater occurance of nitrogen fixing crops in these mixed watersheds.

3. Urban watersheds

Nutrient export from urban watersheds is not significantly different than export from most agricultural watersheds.

Variations in nutrient export, however, are also large. This results from two basic considerations, a) hydraulic factors which influence runoff volume, and b) land use/cover activities which influence concentration.

a) Hydraulic Factors

Major hydraulic factors include the percentage of impervious cover and nature of the drainage system (i.e., slope and detention basins). As the percentage of impervious surfaces increase, infiltration capacity is reduced, runoff and surface scour is increased, and nutrient flux is also increased. Therefore, commercial areas tend to have higher loads than residential areas.

b) Land Use/Cover Activities

Many local sources or activities increase stormwater nutrient concentrations. These include i) atmospheric emissions, ii) street surface residues (i.e., ice control chemicals, pavement materials, dirt), iii) erosion from construction sites, and iv) non-event, storm sewer contaminants (i.e., industrial spills, illegal discharges of waste waters).

Application of Nutrient Export Coefficients

The nutrient loading coefficients have meaningful application in the water quality planning arena. Planning implies the prediction of future impacts of land use on water quality and requires the use of mathematical models. Projected or anticipated land use changes cannot be measured. Therefore, the information necessary for model inputs must be extrapolated from other similar watersheds such as the nutrient export coefficients compiled in the previous tables.

Two considerations are necessary for selecting nutrient export coefficients. The first is that the selected coefficients must carefully match those characteristics of the application lake watershed. The second consideration is that the reliability (or uncertainty) of the prediction be estimated. Assignment of "high," "most likely" and "low" export coefficients represents the uncertainty that the analyst has in the nutrient loading estimate. "While modelers and biologists prefer objective measures of uncertainty, both the limited available data, and the unmeasurable nature of future projections necessitates subjective estimates" (Reckhow et al., 1980).

To demonstrate the transferability of the compiled nutrient loading coefficients and subjectivity associated with the application process, a hypothetical lake watershed is constructed with a wide range of land uses and two years of annual rainfall. The resulting lake trophic status and lake rehabilitation strategy success are dependent not only on the selection of "high," "most likely" and "low" annual nutrient flux estimates, but also on the year (wet or dry) the estimates were based on. Considering the uncertainty associated with this example, and the previous record of improper use of literature export coefficients, two important conclusions are apparent:

1. For lake management purposes, the use of nutrient loading estimates for predicting present, and future water quality conditions with changing land use, is highly subjective.

To reduce application uncertainty, the user or analyst of these coefficients must be familiar with the biogeochemical processes which influence nutrient flux. Only after careful consideration of watershed and climatic conditions should any attempt be made to match these conditions with literature derived export coefficients.

2. As watersheds become increasingly removed from natural undisturbed conditions and undergo increasing human perturbations, the ecological mechanisms controlling nutrient flux become more complex and less understood. Our ability to accurately predict present or future interactions within the drainage basin and resulting lake response, likewise becomes less precise and more uncertain. Given these circumstances, there is a need to acknowledge our inability to "solve" all water quality planning problems with "inflated" confidence. A real effort must also be made to acquaint the public with these limitations so as not to jeopardize our future creditability as water quality planners.

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APPENDIX

Table Ala: Phosphorus Export from Forested Watersheds

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Dissolved Phosphorus Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
75-100 year old jack pine - black spruce (34 ha)	96.7 80.3 70.1 74.3	29.7 35.4 22.3 23.4				.329 .435 .289 .220	Schindler et al., 1976
Climax hardwoods (125 ha)	126.3	68.0				.090	Schindler and Nighswander, 1970
Jack pine - black spruce				.032	.028	.060	Nicholson, 1977
Jack pine - black spruce				.024	.012	.036	Nicholson, 1977
70% aspen 30% black spruce and alder (10 ha)		17.7 19.2 15.5				.124 .179 .157	Verry, 1979
Aspen - birch (6.48 ha)	82.1 79.48 75.51	21.47 15.56 13.73	.05 .20 .16			.19 .38 .28	Timmons et al., 1977
Maple, birch, beech (15.6 ha)	132.2	83.3		.007	.012	.019	Likens et al., 1977

Table Ala: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Deciduous	85.4	25.3	.035			.035	Taylor et al., 1971
hardwood and	88.9	35.6	.072			.072	
pine (17.6 ha)	92.8	32.0	.035			.035	
Mixed deciduous						.070	Dillon and Kirchner,
forests, sandy						.047	1975
soils - igneous						.067	
formation						.075	
						.046	
						.050	
						.037	
						.025	
						.060	
						.072	
						.030	
						.052	
						.025	
						.035	
						.037	
						.077	
						.048	
						.038	
						.027	
						.041	
Mixed deciduous						.145	Dillon and Kirchner,
forests, loam						.092	1975
soils, sedimen-						.122	
tary formation						.067	
Mixed deciduous forest (.01 ha)	129.0	84.3				.090	Singer and Rust, 1975

Table Ala: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr): Dissolved Phosphorus				Reference
			PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	
Oak hickory forest (97.5 ha)	139.5 128.2 187.5 174.7	74.5 71.0 114.8 116.1		.01 .02 .03 .03		.01 .02 .03 .03	Henderson et al., 1977
Oak, maple, yellow poplar, black cherry, beech (34 ha)						.18 .14 .08	Aubertin and Patric, 1974
Mixed pine and hardwood (40 ha)	164.0	48.7		.265	.010	.275	Krebs and Golley, 1977
Mixed mature hardwoods, Coweeta hydrologic lab, North Carolina (12.1 - 61.1 ha)			.02 .02 .02 .03 .02 .02 .03				Swank and Douglas, 1977
Mixed pine and hardwood						.20	Correll et al., 1977
99% mixed forest 1% developed (6495 ha)		7.3				.212	Bedient et al., 1978

Table A1a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus				Reference
			PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	
Loblolly and slash pine Mississippi							
(2.81 ha)	189.08	39.48	.04				Schreiber et al., 1976
(1.93 ha)	189.08	46.40	.05				
(2.39 ha)	189.08	37.88	.04				
(1.64 ha)	189.08	30.26	.04				
(1.49 ha)	189.08	39.63	.05				
Loblolly and slash pine							
(2.81 ha)	205.0	36.90		.094	.187	.281	Duffy et al., 1978
(1.93 ha)	205.0	38.95		.110	.196	.306	
(2.39 ha)	205.0	34.85		.097	.260	.357	
(1.64 ha)	205.0	30.75		.083	.238	.321	
(1.49 ha)	205.0	32.55		.055	.171	.226	
Douglas fir and western hemlock							
(47139.5 ha)						.830	Sylvester, 1960
(32376.0 ha)						.360	
Douglas fir and western hemlock (10.1 ha)	215.0	135.0				.520	Fredriksen, 1972
Douglas fir and western hemlock		158.0	.08			.180	Fredriksen, 1979

Table Ala: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
Douglas fir and western hemlock		76.0	.47			.680	Fredriksen, 1979

Table Alb: Nitrogen Export from Forested Watersheds

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	Dissolved NH_4-N	Dissolved TKN-N	Dissolved ORG-N	Dissolved Total-N	Particulate/Sediment Nitrogen NO_3-N	Particulate NH_4-N	Particulate TKN-N	Particulate ORG-N	Particulate Total-N	Total Nitrogen	Reference
75-100 year old	96.7	29.7											6.45	Schindler et al.,
jack pine-	80.3	35.4											7.32	1976
black spruce	70.1	22.3											6.07	
(34 ha)	74.3	23.4											5.69	
Climax hard-woods (125 ha)	126.3	68.0	1.26											Schindler and Nighswander, 1970
Jack pine - black spruce			.108	.126			2.028					.342	2.37	Nicholson, 1977
Jack pine - black spruce			.171	.037			1.22					.164	1.384	Nicholson, 1977
70% aspen		17.7	.20	.23		1.83							2.26	Verry, 1979
30% black spruce		19.2	.05	.10		2.21							2.37	
and alder (10 ha)		15.5	.33	.37		1.34							1.74	
Aspen-birch	82.1	21.47	.17	.16		2.13							2.46	Timmons et al.,
(6.48 ha)	79.48	15.56	.19	.47		2.63							3.29	1977
	75.51	13.73	.09	.19		1.64							1.92	
Sugar maple, yellow birch, beech, red spruce, balsam fir and paper birch. New Hampshire (607 ha)			6.6	.04										Martin, 1978

Table A1b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Maple, birch, beech (15.6 ha)	132.2	83.3				3.90						.11	4.01	Likens et al., 1977
Deciduous hardwood and pine (17.6 ha)	84.4	25.3	.80										1.37	Taylor et al., 1971
	88.9	35.6	1.60										3.16	
	92.8	32.0	.70										2.82	
Oak-hickory forest (97.5 ha)	136.0	70.7	.40	1.10		1.60	3.10						3.10	Henderson and Harris, 1973
Oak hickory forest (97.5 ha)	189.5	114.8	.1	.3	2.1		2.2						2.2	Henderson et al., 1977
	174.7	116.1	.2	.2	1.5		1.7						1.7	
Oak, maple, yellow poplar, black cherry, beech (34 ha)			.45	1.52										Aubertin and Patric, 1974
			.60	.84										
			.86	.86										
Mixed mature hardwoods, Coweeta hydrologic lab., North Carolina (12.1 - 61.1 ha)			.03	.03										Swank and Douglas 1977
			.06	.05										
			.05	.05										
			.35	.10										
			.05	.07										
			.05	.06										
			.15	.07										
Mixed pine and hardwood													1.50	Correll et al., 1977

Table Alb: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
99% mixed forest 1% developed (6495 ha)		7.3	.286											Bedient et al., 1978
Loblolly and slash pine, Mississippi														
(2.81 ha)	189.08	39.48	.33	4.40										Schreiber et al., 1976
(1.93 ha)	189.08	46.40	.39	5.26										
(2.39 ha)	189.08	37.88	.30	3.16										
(1.64 ha)	189.08	30.26	.24	1.86										
(1.49 ha)	189.08	39.63	.33	2.07										
Douglas fir and western hemlock (47139.5 ha)													3.32	Sylvester, 1960
Alpine forest, New Mexico														Gosz, 1978
91.4% pine 8.6% pinion-juniper (116 ha)			.004	.03		.06								
56% mixed conifer 44% spruce-fir (180 ha)			.06	.13		.23								

Table Alb: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr): Dissolved Nitrogen					Particulate/Sediment Nitrogen					Total Nitrogen	Reference
			NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N		
68.3% spruce-fir 14.0% aspen 11.0% mixed conifer 6.7% pine (164 ha)			.05	.12										Gosz, 1978 (continued)
64% spruce-fir 23% subalpine grassland 13% aspen (100 ha)			.25	.40										
Aspen (3.4 ha)			.14	.32										
48.9% aspen 39.0% subalpine grassland 11.1% spruce-fir 1.0% alpine tundra (415 ha)			.13	.28		.82								
84.4% spruce-fir 15.6% aspen (122 ha)			.08	.25										
75.5% spruce-fir 24.5% alpine tundra (163 ha)			.55	.43		.99								
Douglas fir and western hemlock (10.1 ha)	251.0 215.0	170.0 135.0					.58 .38							Fredriksen, 1972

Table Alb: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Douglas fir and western hemlock		158.0	.07		.70		.77							Fredriksen, 1979
Douglas fir and western hemlock		76.0	.02		.71		.73							Fredriksen, 1979
Alder and douglas fir Western Oregon														Brown et al., 1973
68% alder 32% douglas fir (203.14 ha)			35.04 37.40 28.45 24.95											
68% alder 32% douglas fir 25% patch cut (303.32 ha)			31.46 25.40 28.42 24.54											

Table A2a: Phosphorus Export from Row Crops

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	Reference
			PO_4-P	Total P			
Corn continuous planting (.004 ha)	77.6 77.0 65.76	10.7 8.51 21.95				1.22 1.49 1.22	Minshall et al., 1970
Corn continuous planting fresh manure winter applied (.004 ha)	77.6 77.0 65.76	12.26 5.97 19.41				5.77 1.03 2.00	Minshall et al., 1970
Corn continuous planting fermented manure spring applied (.004 ha)	77.6 77.0 65.76	11.51 5.59 15.32				.96 .75 .68	Minshall et al., 1970
Corn continuous planting, liquid manure spring applied (.004 ha)	77.6 77.0 65.76	12.45 5.61 15.60				1.18 .95 .76	Minshall et al., 1970
Corn continuous planting, no manure (.004 ha)		8.71 14.33				1.00 1.60	Hensler et al., 1970

Table A2a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Dissolved Phosphorus Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Corn continuous planting, fresh manure winter applied (.004 ha)		7.11 11.53				5.66 1.13	Hensler et al., 1970
Corn continuous planting, fermented manure spring applied (.004 ha)		7.11 10.52				.73 .90	Hensler et al., 1970
Corn continuous planting, liquid manure, spring applied (.004 ha)		8.10 10.79				.91 .97	Hensler et al., 1970
Corn continuous (.009 ha)	62.6	8.6	.3	.4	18.2	18.6	Young and Holt, 1977
Corn (.009 ha)	65.7	10.1	.1	.3	13.7	14.0	Young and Holt, 1977
Corn surface spread manure (.009 ha)	65.7	3.8	.4	.5	8.1	8.6	Young and Holt, 1977

Table A2a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
Corn plowdown manure (.009 ha)	65.7	4.0	.2	.4	9.4	9.8	Young and Holt, 1977
Corn rotation planting (.009 ha)	57.2	4.57	.11	.17	2.97	3.14	Burwell et al., 1975
Corn continuous planting (.009 ha)	57.2	8.03	.18	.33	5.22	5.55	Burwell et al., 1975
Corn continuous contour planting (30 - ha)	79.79	6.41		.19	.306	.496	Alberts et al., 1978
	80.04	5.47		.085	.948	1.033	
	73.8	12.57		.237	1.881	2.118	
	86.2	3.86		.04	.554	.594	
	105.95	6.64		.175	.104	.279	
	63.07	1.37		.019	.073	.092	
	78.25	2.63		.043	.244	.287	
Corn continuous contour planting (33.6 - ha)	80.11	5.93		.094	.163	.257	Alberts et al., 1978
	78.29	3.86		.046	.477	.523	
	74.08	9.76		.189	1.099	1.288	
	86.45	3.81		.028	.426	.454	
	104.59	7.5		.205	.048	.253	
	62.16	1.52		.026	.057	.083	
	78.65	2.11		.052	.301	.353	

Table A2a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Dissolved Phosphorus Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Corn continuous terraced (60 - ha)	52.8	.70		.081	.009	.09	Alberts et al., 1978
	73.12	.35		.009	.015	.024	
	76.41	1.75		.059	.228	.287	
	95.24	10.71		.119	.494	.613	
	102.46	8.49		.238	.161	.399	
	53.81	.66		.018	.032	.050	
	73.76	2.9		.128	.131	.259	
Corn continuous planting (1.29 ha)	107.7	13.0	.25	.54	1.67	2.21	Smith et al., 1978
Corn 6 replications (.001 ha)	87.39					.40	Bradford, 1974
Soybeans two crops/yr. conventional till (.01 ha)	118.0	28.3		.025			McDowell et al., 1978
	169.2	83.2		.25	17.5	17.75	
Soybeans two crops/yr. no till (.01 ha)	118.3	13.0		1.2			McDowell et al., 1978
	169.2	42.8		1.8	1.1	2.9	

Table A2a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
Cotton, continuous planting (17.9 ha)	97.3	24.1		2.18	9.34	11.52	Menzel et al., 1978
	72.7	8.8		.68	1.70	2.38	
	88.1	12.6		.86	2.68	3.54	
	74.4	13.6		1.06	4.01	5.07	
Cotton, continuous planting (12.1 ha)	96.3	24.8		1.67	9.08	10.75	Menzel et al., 1978
	73.1	8.0		.51	1.56	2.07	
	88.2	11.9		.70	2.80	3.5	
	72.9	13.5		.98	4.68	5.66	
Soybeans - corn two crops/yr. no till (.01 ha)	118.3	21.5		1.3			McDowell et al., 1978
	169.2	88.2		.5	6.3	6.8	
Corn - soybeans two crops/yr. no till (.01 ha)	118.3	66.2		0.8			McDowell et al., 1978
	169.2	50.5		2.2	2.2	4.4	
Corn silt loam soils Aurora, New York (.32 ha)	98.1	8.9	.21				Klausner et al., 1974
Citrus grove surface tillage, sand soil, Gainesville, FL (9 ha)	163.5	.17	.01				Rogers et al., 1976
	146.1	.23	.01				

Table A2a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
Citrus grove surface tillage, sand soil, Gainesville, FL (9 ha)	163.5 146.1	9.68 4.43	.37 .15				Rogers et al., 1976
Citrus grove surface tillage, sand soil, heavy lime application Gainesville, FL (9 ha)	163.5 146.1	8.89 6.60	.32 .23				Rogers et al., 1976

Table A2b: Nitrogen Export from Row Crops

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Corn, continuous planting (.004 ha)	77.6	10.7											5.53	Minshall, et al., 1970
	77.0	8.51											3.61	
	65.76	21.95											3.96	
Corn, continuous planting, fresh manure, winter applied (.004 ha)	77.6	12.26											26.88	Minshall et al., 1970
	77.0	5.95											3.05	
	65.76	19.41											7.97	
Corn, continuous planting, fermented manure, spring applied (.004 ha)	77.6	11.51											5.32	Minshall et al., 1970
	77.0	5.59											3.35	
	65.76	15.32											3.38	
Corn, continuous planting, liguid manure, spring applied (.004 ha)	77.6	12.45											2.81	Minshall et al., 1970
	77.0	5.61											2.88	
	65.76	15.60											5.07	
Corn, continuous planting, no manure (.004 ha)		8.71											4.08	Hensler et al., 1970
		14.33											4.58	
Corn, continuous planting, fresh manure, winter applied (.004 ha)		7.11											26.06	Hensler et al., 1970
		11.53											4.44	

Table A2b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Corn, continuous planting, fermented manure, spring applied (.004 ha)		7.11 10.52											3.68 4.76	Hensler et al., 1970
Corn, continuous planting, liquid manure, spring applied (.004 ha)		8.10 10.79											4.07 3.70	Hensler et al., 1970
Corn, continuous (.009 ha)	62.6	8.6	2.4				4.0	.0				75.6	79.6	Young and Holt, 1977
Corn (.009 ha)	65.7	10.1	2.7				4.8	.0				39.4	44.2	Young and Holt, 1977
Corn, surface spread manure (.009 ha)	65.7	3.8	.6				3.2	.0				24.7	27.9	Young and Holt, 1977
Corn, plowdown manure (.009 ha)	65.7	4.0	1.2				2.5	.0				30.5	33.0	Young and Holt, 1977
Corn, rotation planting (.009 ha)	57.2	4.57	.44	.18	.33			.21			13.08		14.24	Burwell et al., 1975

Table A2b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Corn, continuous planting (.009 ha)	57.2	8.03	1.11	.37		.72		.36			21.18		23.63	Burwell et al., 1975
Corn, continuous contour planting (30 ha)	79.79	6.41	2.3	.54						5.85			8.69	Alberts et al., 1978
	80.04	5.47	1.45	.42						34.73			36.60	
	73.80	12.57	1.31	2.10						69.06			72.47	
	86.20	3.86	.65	.29						23.42			24.36	
	105.95	6.64	2.03	.33						5.19			7.55	
	63.07	1.37	1.04	.08						1.08			2.20	
	78.25	2.63	.53	.08						4.43			5.04	
Corn, continuous contour planting (33.6 ha)	80.11	5.93	1.45	.95						2.96			5.36	Alberts et al., 1978
	78.29	3.86	.53	.34						25.15			26.02	
	74.08	9.76	.95	1.46						41.30			43.71	
	86.45	3.81	.49	.14						27.22			27.85	
	104.59	7.5	.60	.22						2.02			2.84	
	62.16	1.52	.31	.70						.68			1.69	
	78.65	2.11	.32	.03						3.99			4.34	
Corn, continuous terraced (60 ha)	52.8	.70	.24	.12						.31			.67	Alberts et al., 1978
	73.12	.35	.14	.03						.52			.69	
	76.41	1.75	.16	.59						7.03			7.78	
	95.24	10.71	3.26	.36						23.08			26.70	
	102.46	8.49	2.56	.33						4.19			7.08	
	53.81	.66	.54	.01						.55			1.10	
	73.76	2.9	.80	.19						1.11			2.10	

Table A2b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Corn, continuous planting (1.29 ha)	107.7	13.0	.86	1.48	5.90				.85	5.66			12.42	Smith et al., 1978
Corn, 6 replications (.001 ha)	87.39		.078	.55									3.29	Bradford, 1974
Soybeans, two crops/yr., conventional till (.01 ha)	118.0	28.3	.70	1.5										McDowell et al., 1978
	169.2	83.2	1.0	2.8								42.7	46.5	
Soybeans, two crops/yr., no till (.01 ha)	118.3	13.0	1.2	2.1										McDowell et al., 1978
	169.2	42.8	0.6	1.6								2.3	4.5	
Cotton, continuous planting (17.9 ha)	97.3	24.1											11.49	Menzel et al., 1978
	72.7	8.6											4.99	
	88.1	12.6											9.79	
	74.4	13.6											8.82	
Cotton, continuous planting (12.1 ha)	96.3	24.8											14.84	Menzel et al., 1978
	73.1	8.0											5.18	
	88.2	11.9											10.03	
	72.9	13.5											12.19	
Soybeans - corn two crops/yr., no till (.01 ha)	118.3	21.5	3.0	2.2										McDowell et al., 1978
	169.2	88.2	3.0	3.8								17.0	23.8	

Table A2b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Corn - soybeans two crops/yr., no till (.01 ha)	118.3 169.2	66.2 50.2	8.1 8.9	3.1 6.7								 5.9	 21.3	McDowell et al., 1978
Corn, silt loam soils, Aurora, New York (.32 ha)	98.1	8.9	1.16	.42										Klausner et al., 1974
Citrus grove surface tillage, sand soil, Gainesville, FL (9 ha)	163.5 146.1	.17 .23	.01 .02											Rogers et al., 1976
Citrus grove surface tillage, sand soil, Gainesville, FL (9 ha)	163.5 146.1	9.68 4.43	.69 .25											Rogers et al., 1976
Citrus grove surface tillage, sand soil, heavy lime application, Gainesville, FL (9 ha)	163.5 146.1	8.89 6.60	.82 .44											Rogers et al., 1976

Table A3a: Phosphorus Export from Non-Row Crops

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr): Dissolved Phosphorus PO_4-P	Dissolved Phosphorus Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Alfalfa no fertilization (.004 ha)	105.4	8.2				.75	Converse et al., 1976
	107.8	14.2				.76	
	108.8	18.5				2.40	
Alfalfa fall applied manure (.004 ha)	105.4	5.2				1.24	Converse et al., 1976
	107.8	7.8				1.20	
	108.8	9.0				8.09	
Alfalfa winter applied manure (.004 ha)	105.4	8.2				.64	Converse et al., 1976
	107.8	10.3				.58	
	108.8	12.8				6.09	
Alfalfa spring applied manure (.004 ha)	105.4	6.7				2.39	Converse et al., 1976
	107.8	10.1				.55	
	108.8	15.0				1.81	
Alfalfa and bromegrass two plots (3.55 - 4.10 ha)	57.91	2.69	.24	.73		.97	Harms et al., 1974
Wheat continuous planting (5.2 ha)	96.5	20.8		.61	2.73	3.34	Menzel et al., 1978
	72.9	7.0		.19	.51	.80	
	87.7	10.5		.36	.60	.96	
	73.1	5.5		.13	2.19	2.32	

Table A3a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Dissolved Phosphorus Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Wheat continuous planting (5.3 ha)	96.6	23.0		.52	3.77	4.29	Menzel et al., 1978
	73.1	5.5		.09	.50	.59	
	87.9	9.3		.26	.53	.79	
	72.9	5.4		.11	2.21	2.32	
Spring wheat and summer stubble two year rotation (4 - 5 ha)		62.5	0.3			0.6	Nicholaichuk and Read, 1978
		7.0	0.1			0.1	
Spring wheat and summer fallow two year rotation (4 - 5 ha)		98.0	0.9			2.3	Nicholaichuk and Read, 1978
		19.0	0.1			0.4	
Spring wheat and fall fertilized summer fallow (4 - 5 ha)		49.0	2.3			5.6	Nicholaichuk and Read, 1978
		7.0	0.2			0.2	
Millet six replications (.001 ha)	87.39					0.44	Bradford, 1974

Table A3a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Oats Rotation Planting (.009 ha)	57.2	6.89	.09	.22	.43	.65	Burwell et al., 1975
Hay Rotation Planting (.009 ha)	57.2	14.2	.31	.60	.04	.64	Burwell et al., 1975
Wheat Aurora, New York (.32 ha)	98.1	10.7	.20				Klausner et al., 1974

Table A3b: Nitrogen Export from Non Row Crops

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen					Particulate/Sediment Nitrogen					Total Nitrogen	Reference
			NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N		
Alfalfa	105.4	8.2	1.36	1.27									6.28	Converse et al.,
no fertilization	107.8	14.2	1.14	.98									5.66	1976
(.004 ha)	108.8	18.5	2.02	3.86									14.67	
Alfalfa	105.4	5.2	1.24	2.63									6.10	Converse et al.,
fall applied	107.8	7.8	.78	3.41									6.63	1976
manure (.004 ha)	108.8	9.0	1.50	8.92									23.09	
Alfalfa	105.4	8.2	1.51	1.71									7.82	Converse et al.,
winter applied	107.8	10.3	.79	1.17									5.88	1976
manure (.004 ha)	108.8	12.8	1.88	13.12									38.22	
Alfalfa	105.4	6.7	2.69	3.58									6.43	Converse et al.,
spring applied	107.8	10.1	.98	.85									4.07	1976
manure (.004 ha)	108.8	15.0	1.73	2.75									11.42	
Alfalfa and	57.91	2.69											.10	Harms et al.,
bromegrass														1974
two plots														
(3.55 - 4.10 ha)														
Wheat	96.5	20.8											6.12	Menzel et al.,
continuous plant-	72.9	7.0											3.77	1978
ing (5.2 ha)	87.7	10.5											5.63	
	73.1	5.5											7.12	

Table A3b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Wheat continuous plant- ing (5.3 ha)	96.6 73.1 87.9 72.9	23.0 5.5 9.3 5.4											8.95 2.89 4.31 8.74	Menzel et al., 1978
Spring wheat and summer stubble, two year rotation (4 - 5 ha)		62.5 7.0	0.2 0.1		1.1 0.1									Nicholaichuk and Read, 1978
Spring wheat and summer fallow, two year rotation (4 - 5 ha)		98.0 19.0	0.7 0.6		6.5 0.9									Nicholaichuk and Read, 1978
Spring wheat and fall fertilized summer fallow, (4 - 5 ha)		49.0 7.0	0.4 0.2		7.7 0.5									Nicholaichuk and Read, 1978
Millet six replications (.001 ha)	87.39		0.10	0.50									3.04	Bradford, 1974
Oats, rotation planting (.009 ha)	57.2	6.89	1.57	.29		.71		.03			1.89		4.22	Burwell et al., 1975
Hay, rotation planting (.009 ha)	57.2	14.2	.63	1.41		1.67		.01			.17		4.09	Burwell et al., 1975

Table A3b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Wheat (.32 ha) Aurora, New York	98.1	10.7	.79	.56										Klausner et al., 1974
coastal bermuda grass light manure fertilization, sandy loam soil, Alabama (.04 ha)	134.8 108.9 191.2	42.0 10.8 38.6	3.6 1.0 2.1	1.0 .8 1.2										Long, 1979
Coastal burmuda grass, heavy manure fertilization, sandy loam soil, Alabama (.04 ha)	134.8 108.9 191.2	41.9 10.0 33.6	26.0 4.6 3.4	3.2 1.2 0.8										Long, 1979

Table A4a: Phosphorus Export from Pastured and Grazed Watersheds

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr): Dissolved Phosphorus PO_4-P	Dissolved Phosphorus Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Moderate dairy grazing, bluegrass cover (1.88 ha)	106.8	20.2				.15	Kilmer et al., 1974
	104.3	22.5				.16	
	105.5	12.3				.13	
	119.8	24.6				.12	
Heavy dairy grazing, bluegrass cover (1.38 ha)	106.8	26.0				.70	Kilmer et al., 1974
	104.3	26.9				.18	
	105.5	19.9				.11	
	119.8	31.8				.12	
Pasture (6.28 ha)	58.4	4.44				.25	Harms et al., 1974
Winter grazed and summer rotation (1 ha)	108.0	12.94		3.0	.15	3.6	Chichester et al., 1979
Summer grazed (1 ha)	108.0	2.92		.40	.0	.85	Chichester et al., 1979
Rotation grazing (42.9 ha)	77.83	4.39		.193	.058	.251	Schuman et al., 1973
	73.30	.94		.064	.017	.081	
	75.40	3.86		.386	.126	.512	
Pasture for brood cattle (10 ha)	164.0	61.8		1.269	.076	1.345	Krebs and Golley, 1977

Table A4a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Dissolved Phosphorus Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Continuous grazing with some supplementary winter feeding some hay production (351.2 ha)	114.7					3.8	Correll et al., 1977
Continuous grazing little bluestem cover, active gullies (11.1 ha)	105.0 77.8 98.7 50.7	28.4 12.6 17.6 2.02		.14 .07 .03 .01	3.72 .99 1.83 .26	3.86 1.06 1.86 .26	Menzel et al., 1978
Rotation grazing little bluestem cover, good cover (11.0 ha)	109.1 77.3 99.4 52.4	17.8 4.2 7.7 .35		.10 .02 .02 .00	1.34 .22 .25 .02	1.44 .24 .27 .02	Menzel et al., 1978
Continuous grazing little bluestem cover (7.8 ha)	76.5	14.7		3.27	1.63	4.90	Olness et al., 1980
Rotational grazing, little bluestem cover (9.6 ha)	78.2	4.3		2.43	0.66	3.09	Olness et al., 1980

Table A4a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
Continuous grazing, little bluestem cover active gullies (11.1 ha)	76.5	10.2		.01	.75	.76	Olness et al., 1980
Rotational grazing, little bluestem cover (11.0 ha)	78.2	4.3		.02	.18	.20	Olness et al., 1980

Table A4b: Nitrogen Export from Pastured and Grazed Watersheds

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr): Dissolved Nitrogen NO_3-N	Dissolved Nitrogen NH_4-N	Dissolved Nitrogen TKN-N	Dissolved Nitrogen ORG-N	Dissolved Nitrogen Total-N	Particulate/Sediment Nitrogen NO_3-N	Particulate/Sediment Nitrogen NH_4-N	Particulate/Sediment Nitrogen TKN-N	Particulate/Sediment Nitrogen ORG-N	Particulate/Sediment Nitrogen Total-N	Total Nitrogen	Reference
Moderate dairy	106.8	20.2	2.97	.47									3.44	Kilmer et al.,
grazing,	104.3	22.5	2.63	.44		.77							3.83	1974
gluegrass cover	105.5	12.3	1.68	.18		.55							2.41	
(1.88 ha)	119.8	24.6	2.14	.21		1.15							3.47	
Heavy dairy grazing,	106.8	26.0	16.10	1.95									18.05	Kilmer et al.,
bluegrass cover	104.3	26.9	10.79	.61		1.32							12.71	1974
(1.88 ha)	105.5	19.9	7.20	.19		.99							8.31	
	119.8	31.8	7.28	.32		1.46							9.26	
Pasture (6.28 ha)	58.4	4.44	.40		1.12								1.52	Harms et al., 1974
Winter grazed and summer rotational (1 ha)	108.0	12.94	5.75			7.8						8.25	30.85	Chichester et al., 1979
Summer grazed (1 ha)	108.0	2.92	0.5			0.6						0	21.85	Chichester et al., 1979
Rotation grazing	77.83	4.39	1.14	.66						.52			2.32	Schuman et al.,
(42.9 ha)	73.30	.94	.17	.09						.21			.47	1973
	75.40	3.86	.96	.43						2.89			4.26	
Continuous grazing,	105.0	28.4											6.84	Menzel et al.,
little bluestem cover,	77.8	12.6											5.43	1978
active gullies	98.7	17.6											9.23	
(11.1 ha)	50.7	2.02											1.33	

Table A4b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr): Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Rotation grazing, little bluestem cover, good cover (11.0 ha)	109.1 77.3 99.4 52.4	17.8 4.2 7.2 .35											2.02 .95 2.30 .15	Menzel et al., 1978
Continuous grazing, little bluestem cover (7.8 ha)	76.5	14.7						.68[a]	4.18[a]	8.52[a]			9.20	Olness et al., 1980
Rotational grazing, little bluestem cover (9.6 ha)	78.2	4.3						.31[a]	3.67[a]	4.41[a]			4.72	Olness et al., 1980
Continuous grazing, little bluestem cover, active gullies (11.1 ha)	76.5	10.2						.34[a]	.16[a]	4.85[a]			5.19	Olness et al., 1980
Rational grazing, little bluestem cover (11.0 ha)	78.2	4.3						.20[a]	.12[a]	1.53[a]			1.73	Olness et al., 1980

a. Consists of both soluble and non-soluble fractions.

Table A5a: Phosphorus Export from Animal Feedlot and Manure Storage

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Beef livestock feedlot (4.76 ha)	61.06 60.71 53.19	28.52 8.92 21.87				523.0 145.6 749.3	Dornbush and Madden, 1973
Lamb feedlot (21.32 ha)	59.0 49.96	1.96 2.18				35.84 20.16	Dornbush and Madden, 1973
Lamb feedlot (12.63 ha)	49.96	3.10				21.28	Dornbush and Madden, 1973
Dairy confinement, 45 head of cattle (.13 ha)	62.53 58.01 48.16	15.16 82.65 27.18				521.9 355.0 301.3	Dornbush and Madden, 1973
Beef and sheep feedlot (.603 ha)	62.53 58.01 48.16	15.24 30.35 14.40				2635.4 222.9 157.9	Dornbush and Madden, 1973
Beef feeding (1.6 ha)	63.73 55.83	3.99 8.71				29.1 142.2	Dornbush and Madden, 1973
Beef cattle feedlot 9.29 m^2/cow (.0019 ha)		17.07 14.68				1299.2 291.2	McCalla et al., 1972

Table A5a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Beef cattle feedlot, 18.6 m^2/cow (.0019 ha)		16.59 19.28				470.4 224.0	McCalla et al., 1972
Beef cattle feedlot, 18.6 m^2/cow (.0019 ha)		24.59 25.30				313.6 134.4	Gilbertson et al., 1975
Beef cattle feedlot, 500-600 cattle (.245 ha)	70.7	33.2	163.0			425.0	Coote and Hore, 1978
Beef cattle feedlot (.165 ha)	78.6	17.3	73.0			170.0	Coote and Hore, 1978
Solid Manure storage area (.05 ha)	67.37	20.9	86.0			172.0	Coote and Hore, 1978
Manure storage facility (.047 ha)	57.7	33.5				539.9	Magdoff et al., 1977
Barnlot runoff, 370 cows/ha, Ohio (.17 ha)		31.9 27.9		14.11 19.98			Edwards et al., 1972

Table A5b: Nitrogen Export from Animal Feedlot and Manure Storage

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Beef livestock	61.06	28.52								1332.8[a]				Dornbush and
feedlot (4.76 ha)	60.71	8.92								577.9[a]				Madden, 1973
	53.19	21.87								1196.2[a]				
Lamb feedlot	59.0	1.96								32.48[a]				Dornbush and
(21.32 ha)	49.96	2.18								53.76[a]				Madden, 1973
Lamb feedlot	49.96	3.10								64.96[a]				Dornbush and
(12.63 ha)														Madden, 1973
Dairy confinement,	62.53	15.16								705.6[a]				Dornbush and
45 head of cattle	58.01	82.65								1561.28[a]				Madden, 1973
(.13 ha)	48.16	27.18								1154.70[a]				
Beef and sheep	62.53	15.24								973.3[a]				Dornbush and
feedlot	58.01	30.35								433.4[a]				Madden, 1973
(.603 ha)	48.16	14.40								287.84[a]				
Beef feeding	63.73	3.99								99.68[a]				Dornbush and
(1.6 ha)	55.83	8.71								975.40[a]				Madden, 1973
Beef cattle feedlot,		17.07											3830.4	McCalla et al.,
9.29 m^2/cow		14.68											2016.0	1972
(.0019 ha)														

Table A5b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	Dissolved NH_4-N	Dissolved TKN-N	Dissolved ORG-N	Dissolved Total-N	Particulate/Sediment Nitrogen NO_3-N	Particulate NH_4-N	Particulate TKN-N	Particulate ORG-N	Particulate Total-N	Total Nitrogen	Reference
Beef cattle feedlot 18.6 m^2/cow (.0019 ha)		16.59 19.28											1254.4 1433.6	McCalla et al., 1972
Beef cattle feedlot, 18.6 m^2/cow (.0019 ha)		24.59 25.30											1388.8 2195.2	Gilbertson et al., 1975
Beef cattle feedlot, 500-600 cattle (.245 ha)	70.7	33.2						6.27	862.0	2504.0			3372.27	Coote and Hore, 1978
Beef cattle feedlot (.165 ha)	78.6	17.3						1.42	138.0	541.0			680.52	Coote and Hore, 1978
Solid manure storage area (.05 ha)	67.37	20.9						2.07	776.0	1112.0			1891.07	Coote and Hore, 1978
Manure storage facility (.047 ha)	57.7	33.5							5831.0[a]				7979.9	Magdoff et al., 1977
Barnlot runoff 370 cows/ha Ohio (.17 ha)		31.9 27.9	6.45 3.04				66.86 107.09							Edwards et al., 1972

a. Consists of both dissolved and particulate fractions.

Table A6a: Phosphorus Export from Mixed Agricultural Watersheds

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr): Dissolved Phosphorus PO_4-P	Dissolved Phosphorus Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
58% row crops	112.0	27.5				5.2	Lake and Morrison,
31% small grain	70.0	11.2				1.1	1977
and pasture							
6% woods							
5% urban (4950 ha)							
63% row crops	112.0	29.1	.14	.24	5.20	5.4	Lake and Morrison,
26% small grain	70.0	12.4	.06	.09	.98	1.1	1977
and pasture							
8% woods							
3% urban (942 ha)							
35% row crops	112.0	26.0	.34	.46	4.5	5.0	Lake and Morrison,
48% small grain	70.0	10.1	.18	.22	.73	1.0	1977
and pasture							
5% woods							
12% urban (714 ha)							
50% pasture	77.7	26.9		.031			Taylor et al., 1971
25% rotation	88.6	34.4		.080			
cropland	88.9	33.9		.067			
25% hardwood	92.7	32.8		.077			
forest (123 ha)							
39% corn	99.0					0.10	Patni and Hore,
46% legumes and	93.5					0.80	1978
grass, 9% small	92.7					0.60	
grain, 2.6% idle							
4% roads (594 ha)							

Table A6a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
60% row crops 40% hay and pasture two livestock feedlots (157.5 ha)	67.79	10.74		.319	.329	.648	Burwell et al., 1974
Three years pasture and two years corn (42.9 ha)	84.71	17.65		.19	.08	.27	Burwell et al., 1977
Intensive agricultural crops and improved pasture (202 ha)	105.0 88.0	21.3 12.1	1.21 .63			1.34 .86	Campbell, 1978
Active cropping and pasture						.409	Grizzard et al., 1977
At least 80% of watershed devoted to agricultural activities				.233		1.29	Avadhanula, 1979

Table A6a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
37.4% soybean and whitebean 27.1% cereal 23% corn (5080 ha)	72.9			.21		1.28	Coote et al., 1978
36.1% woodland 25.0% cereal 22.2% tobacco 10.1% corn 3% pasture and hay (7913 ha)				.06		.26	Coote et al., 1978
31.3% corn 26.4% cereal 17.9% pasture and hay 12.1% soybean and whitebean 7.5% woodland (6200 ha)	86.0			.50		.91	Coote et al., 1978
37.2% pasture and hay 35.3% cereal 18.7% corn 6.9% woodland (1860 ha)	92.5			.33		1.00	Coote et al., 1978

Table A6a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
42.3% corn 22.8% pasture and hay 15.4% woodland 12.2% cereal (3000 ha)	101.8			.43		1.53	Coote et al., 1978
33.4% pasture and hay 29.2% woodland 22.3% cereal 12.3% corn (5472 ha)	82.3			.07		.16	Coote et al., 1978
37.4% woodland 28.5% pasture and hay 10.7% cereal 10.4% corn 3.7% tobacco (5645 ha)	84.0			.03		.08	Coote et al., 1978
44.2% pasture and hay 18.4% cereal 17.8 Woodland 16.2% corn (3025 ha)	77.9			.51		1.53	Coote et al., 1978

Table A6a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
41.3% pasture and hay 29.0% cereal 11.3% corn 7.5% woodland (2383 ha)	73.7			.20		.49	Coote et al., 1978
27.8% vegetables 22.8% corn 10.0% woodland 8.9% cereal 7.9% soybean and whitebean (1990 ha)	77.0			.36		.91	Coote et al., 1978
66.6% pasture and hay 12.1% cereal 9.5% corn 9.4% woodland (4504 ha)	92.4			.36		.81	Coote et al., 1978

Table A6b: Nitrogen Export from Mixed Agricultural Watersheds

Table A6b: Nitrogen Export from Mixed Agricultural Watersheds

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
58% row crops	112.0	27.5											48.7	Lake and Morrison,
31% small grain	70.0	11.2											8.6	1977
and pasture														
6% woods														
5% urban (4950 ha)														
63% row crops	112.0	29.1											53.2	Lake and Morrison,
26% small grain	70.0	12.4											10.3	1977
and pasture														
8% woods														
3% urban														
(942 ha)														
35% row crops	112.0	26.0											44.1	Lake and Morrison,
48% small grain	70.0	10.1											6.6	1977
and pasture														
5% woods														
12% urban (714 ha)														
50% pasture	77.7	26.9											1.67	Taylor et al.,
25% rotation crop-	88.6	34.4											3.11	1971
land,	88.9	33.9											10.61	
25% hardwood forest	92.7	32.8											4.38	
(123 ha)														
39% corn	49.0							12.3[a]		6.3[a]			18.60	Patni and Hore,
46% legumes and grass	93.5							8.3[a]		16.0[a]			24.20	1978
9% small grain	92.7							5.6[a]		2.6[a]			8.20	
2.6% idle														
4% roads (594 ha)														

a. Consists of both dissolved and particulate fractions.

Table A6b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
60% row crops 40% hay and pasture two livestock feedlots (157.5 ha)	67.79	10.74	1.19	1.37					7.08				9.64	Burwell et al., 1974
Three years pasture and two years corn (42.9 ha)	84.71	17.65	11.68	.40								2.03	14.11	Burwell et al., 1977
Intensive agriculture crops and improved pasture (208 ha)	105.0 88.0	21.3 12.1	.37 .09	.68 .09		5.3 1.92							6.36 2.10	Campbell, 1978
Active cropping and pasture													2.83	Grizzard et al., 1977
At least 80% of watershed devoted to agricultural activities			8.86										14.3	Avadhanula, 1979
37.4% soybean and whitebean 27.1% cereal 23% corn (5080 ha)	72.9							10.7		5.3			16.1	Coote et al., 1978

Table A6b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
36.1% woodland 25.0% cereal 22.2% tobacco 10.1% corn 3% pasture and hay (7913 ha)								4.3		2.2			6.4	Coote et al., 1978
31.3% corn 26.4% cereal 17.9% pasture and hay 12.1% soybean and whitebean 7.5% woodland (6200 ha)	86.0							37.4		4.2			41.5	Coote et al., 1978
37.2% pasture and hay 35.3% cereal 18.7% corn 6.9% woodland (1860 ha)	92.5							14.9		5.4			20.3	Coote et al., 1978
42.3% corn 22.8% pasture and hay 15.4% woodland 12.2% cereal (3000 ha)	101.8							24.1		7.1			31.1	Coote et al., 1978

Table A6b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
33.4% pasture and hay 29.2% woodland 22.3% cereal 12.3% corn (5472 ha)	82.3							11.3		2.9			14.3	Coote et al., 1978
37.4% woodland 28.5% pasture and hay, 10.4% corn 10.7% cereal 3.7% tobacco (5645 ha)	84.0							2.1		1.1			3.2	Coote et al., 1978
44.2% pasture and hay 18.4% cereal 17.8% woodland 16.2% corn (3025 ha)	77.9							7.0		8.5			15.5	Coote et al., 1978
41.3% pasture and hay 29.0% cereal 11.3% corn 7.5% woodland (2383 ha)	73.7							8.3		2.0			11.1	Coote et al., 1978

Table A6b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
27.8% vegetables 22.8% corn 10.0% woodland 8.9% cereal 7.9% soybean and whitebean (1990 ha)	77.0							21.0		4.2			25.2	Coote et al., 1978
66.6% pasture and hay 12.1% cereal 9.5% corn 9.4% woodland (4504 ha)	92.4							5.4		4.1			9.4	Coote et al., 1978

Table A7a: Phosphorus Export from Urban Watersheds

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr): Dissolved Phosphorus PO_4-P	Dissolved Phosphorus Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Residential (50 ha)	69.93	10.49	.64			1.10	Kluesener and Lee, 1974
78% industrial 22% commercial		7.88 40.18				1.06 4.28	Konrad et al., 1978
Commercial (15.8 ha)	76.5		.64			.88	Much and Kemp, 1978
Central business district (9.3 ha)	76.5		3.58			4.08	Much and Kemp, 1978
Industrial (8.1 ha)	76.5		.62			.75	Much and Kemp, 1978
Residential (41.7 ha)	76.5		.27			.35	Much and Kemp, 1978
Low density residential (46.82 ha)	77.19					0.19	Landon, 1977
Low density residential (33.73 ha)	77.19					2.7	Landon, 1977

Table A7a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
High density residential (7 ha)	77.19					1.1	Landon, 1977
High density residential (21.63 ha)	77.19					.56	Landon, 1977
Commercial (18.19 ha)	77.19					1.7	Landon, 1977
Commercial (4.19 ha)	77.19					.66	Landon, 1977
64% residential 13% recreational 12% commercial 6% transportation 1% industrial (958 ha)						.757	O'Neill, 1979
Residential and light commercial (11 ha)	76.2	28.19		.90			Weibel et al., 1964

Table A7a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
At least 60% of watershed devoted to urban land use				.107		1.63	Avadhanula, 1979
Industrial and residential (414 ha)	150.0	84.3	2.39			4.17	Betson, 1978
Commercial (212 ha)	155.0	41.1	.87			4.85	Betson, 1978
Suburban (62 ha)	153.0	9.4	.36			.43	Betson, 1978
60% residential 19% commercial and industrial 12% institutional 10% unused	108.2	16.26				1.23	Bryan, 1970
60% residential 19% commercial and industrial 12% institutional 10% unused		24.64				5.26	Colston, 1974
20% urbanized large scale residential (47900 ha)						1.91	Grizzard et al., 1978

Table A7a: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus				Reference
			PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	
Single family residential (19.2 ha)	125.6	9.42				0.21	Mattraw and Sherwood, 1977
67% residential 13% commercial 12% woodland 8% agricultural (792 ha)	124.5	21.2	.18	.22		6.23	Burton et al., 1977
Residential (6.8 ha)	113.06	18.99	.17	.22		.60	Simpson and Hemens, 1978
74.7% residential 12.6% institutional 7.4% industrial 5.3% commercial (2261 ha) Tulsa, Oklahoma	94.61	15.14		.92			AVCO, 1970

Table A7b: Nitrogen Export from Urban Watersheds

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen					Particulate/Sediment Nitrogen					Total Nitrogen	Reference
			NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N		
Residential (50 ha)	69.93	10.49	.67	.50									5.00	Kluesener and Lee, 1974
Commercial (15.8 ha)	76.5							1.74[a]	.59[a]	2.80[a]			4.54	Much and Kemp, 1978
Central Business district (9.3 ha)	76.5							10.36[a]	6.98[a]	28.11[a]			38.47	Much and Kemp, 1978
Industrial (8.1 ha)	76.5							2.04[a]	2.36[a]	4.49[a]			6.53	Much and Kemp, 1978
Residential (41.7 ha)	76.5							1.19[a]	.72[a]	2.48[a]			3.67	Much and Kemp, 1978
Low density residential (46.82 ha)	77.19							.82[a]		.70[a]			1.52	Landon, 1977
Low density residential (33.73 ha)	77.19							2.9[a]		4.0[a]			6.9	Landon, 1977
High density residential (7 ha)	77.19							2.0[a]		2.8[a]			4.8	Landon, 1977

Table A7b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
High density residential (21.63 ha)	77.19							2.2[a]		2.3[a]			5.5	Landon, 1977
Commercial (18.19 ha)	77.19							12.0[a]		8.5[a]			20.5	Landon, 1977
Commercial (4.19 ha)	77.19							1.8[a]		2.2[a]			4.0	Landon, 1977
Residential and light commercial (11 ha)	76.2	28.19											9.97	Weibel et al., 1964
At least 60% of watershed devoted to urban land use			3.05										9.48	Avadhanula, 1979
Industrial and residential (414 ha)	150.0	84.3						5.62[a]	.83[a]		8.5[a]		14.95	Betson, 1978
Commercial (212 ha)	155.0	41.1						3.14[a]	.44[a]		9.2[a]		12.78	Betson, 1978
Suburban (62 ha)	153.0	9.4						.47[a]	.11[a]		.98[a]		1.56	Betson, 1978

Table A7b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen					Particulate/Sediment Nitrogen					Total Nitrogen	Reference
			NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N		
60% residential 19% commercial and industrial 12% institutional 10% unused (432.54 ha)		24.64								6.83				Colston, 1974
20% urbanized large scale residential (47900 ha)													33.76	Grizzard et al., 1978
Single family residential (19.2 ha)	125.6	9.42											1.48	Mattraw and Sherwood, 1977
67% residential 13% commercial 12% woodland 8% agricultural (792 ha)	124.5	21.2	.24	.17										Burton et al., 1977
Residential (6.8 ha)	113.06	18.99											4.0	Simpson and Hemens, 1978
74.7% residential 12.6% institutional 7.4% industrial 5.3% commercial (2261 ha) Tulsa, Oklahoma	94.61	15.14				2.16								AVCO, 1970

a. Consists of both dissolved and particulate fractions.