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MODELING PHOSPHORUS LOADING AND LAKE RESPONSE
UNDER UNCERTAINTY
A MANUAL AND COMPILATION OF EXPORT COEFFICIENTS

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ABSTRACT

A procedure is proposed that may be used to quantify the relationship between land use and lake trophic quality. This methodology, based on an input-output phosphorus lake model, is presented in a step-by-step manner and illustrated through example An important part of this procedure is a section describing the estimation of nonparametric prediction intervals. These intervals quantify the total prediction uncertainty which is a measure of information value contained in a prediction.

When the methodology is employed to predict the impact of projected land use changes, it is necessary to use phosphorus export coefficients extrapolated from other points in time and/or space. These coefficients represent the mass loading of phosphorus to a surface water body per year per unit of source (e.g., per hectare of forested land) A substantial portion of this document is devoted to a presentation of carefully screened nutrient export coefficients. These values are intended for inclusion in the modeling/uncertainty analysis methodology To that end, criteria are described that will aid the analyst in the selection of appropriate export coefficients and in the interpretation of the results of an application of this methodology

CONTENTS

FIGURES

APPENDIX FIGURES

TABLES

APPENDIX TABLES

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Chapter 1

INTRODUCTION

The planner or engineer concerned with the issue of lake trophic quality management must be conversant across several disciplines. Eutrophication is fundamentally a problem in chemical and biological limnology, so the analyst must be familiar with the natural sciences Methods and processes for managing watershed characteristics and human activities that determine water quality have an engineering basis with strong economic and sociologic features. Finally, techniques that project the link between the engineered management strategies and the limnological water quality are in the planning arena yet require a good foundation in statistics and mathematics. It is this latter set of planning methods, with a firm basis in the statistical understanding and description of empirical relationships, that is the focus of this manual.

Lake eutrophication is both a natural and culturally-induced phenomenon. Natural eutrophication is a slow, largely irreversible process associated with the gradual accumulation of organic matter and sediments in lake basins Cultural eutrophication is an often rapid, possibly reversible process of nutrient enrichment and high biomass production stimulated by cultural activities causing nutrient transport to lakes. Eutrophication is a complex process, and hence the reference is made above to the importance of chemical and limnological knowledge for proper lake management. Each lake is unique, and a study and understanding of the unique features are essential for good planning Yet there are also characteristics of watershed and lake behavior that are, if not universal, certainly shared by many lake systems. The planner can exploit this commonality in management studies, providing he/she is aware of where the commonality ends and the uniqueness begins. In fact, to the degree that planning studies must surely depend upon the efficient use of resources, all planning is probably a compromise between unique and common features.

This manual is based on the aforementioned premise of similar trophic behavior among lakes. This is both a strength and a weakness. Its strength lies in the fact that the methodologies are not necessarily lake-specific, so that models and data are transferrable, keeping analysis costs low. Its weakness is that the ease of application of the methodology and statistics can foster inappropriate use of the techniques described herein and incomplete study of the unique features of a lake. This lowers planning costs but increases risks associated with poor planning decisions. Again, the lesson is to know the limitations of the general methodology.

The techniques presented in this manual for lake trophic management planning are based on control of the nutrient phosphorus. There are two reasons for this reliance on phosphorus:

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 management

In general terms, with phosphorus as the controlling mechanism, the reasons suggest that proper management of human activities in the watershed can often be effective in the maintenance of desirable biomass levels in the lake.

Figure 1 presents a schematic diagram of the watershed and lake ecosystem as viewed from the perspective of phosphorus movement. Human activities (including land use), watershed characteristics, and climate are the general determinants of phosphorus mass transport to lakes. The phosphorus loading to a lake is empirically related to the phosphorus concentration in a lake as a function of the hydrologic and geomorphologic characteristics of the lake. Phosphorus concentration, in turn, is causally linked with biomass levels, water clarity, dissolved oxygen concentrations, and fish populations, which are all empirically interrelated.

The methodology presented herein is based on the phosphorus flow schematic in Figure 1. Historically, it is derived from the work of Vollenweider (1968, 1975) on the phosphorus loading concept. Vollenweider's contribution to this field was the recognition of the similiarities among lakes in trophic response to nutrient input. He defined nutrient loading criteria for lakes as a function of selected hydrologic and geomorphologic characteristics (e.g., mean depth or areal water loading). Vollenweider and others (Dillon and Rigler, 1975, Larsen and Mercier, 1976, Chapra, 1977, Walker, 1977, and Reckhow, 1979c) modified Vollenweider's initial approach and empirically derived simple input-output models for phosphorus One of these cross-sectional empirical phosphorus lake models (Reckhow, 1979d) is incorporated in the procedure described in the next chapter.

The empirical phosphorus lake model mathematically describes the sections of Figure 1 from phosphorus loading to lake phosphorus concentration. The appropriate method for determination of the phosphorus loading depends in part upon whether the application is primarily descriptive or predictive. Descriptive use of the model implies an assessment of current lake and watershed conditions. Direct measurement of the phosphorus loading would therefore be possible. Alternatively, predictive use of the model suggests the estimation of the impact of projected land use on lake water quality.

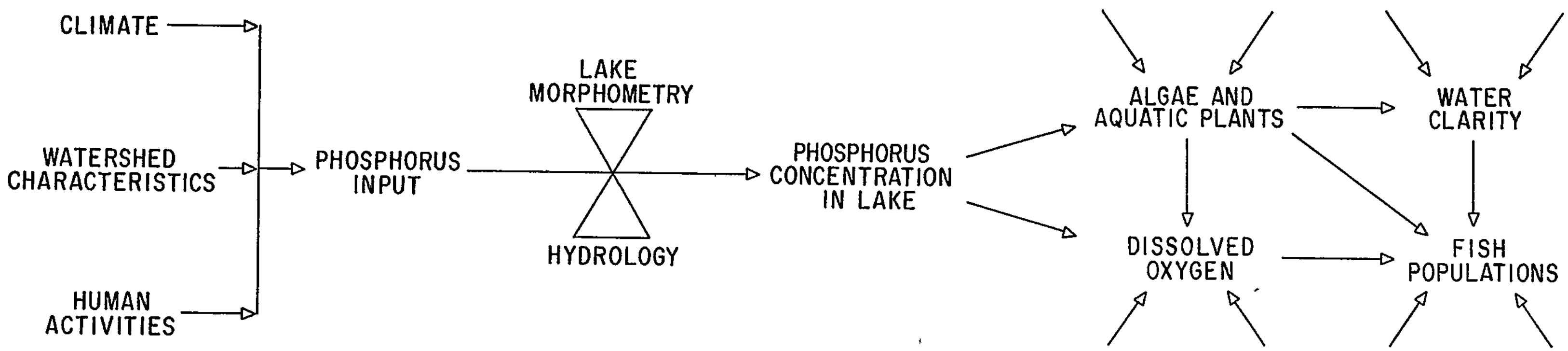


Figure 1. A Schematic Illustrating Phosphorus Loading Determinants and Lake Response

Here direct measurement is obviously impossible, so phosphorus loading information must be extrapolated from other, similar watersheds It is for the predictive function of empirical phosphorus lake models that this manual is designed, although the methodology is equally applicable to descriptive applications (with perhaps an increase in planning risks, see Reckhow and Chapra, 1980, Chapter 1).

A significant portion of this manual is devoted to a discussion and presentation of the phosphorus export coefficients that are used to estimate phosphorus loading for the predictive mode of the modeling methodology The phosphorus export coefficients presented are taken largely from a comprehensive study (Beaulac, 1980) of the literature on the phosphorus mass transported to surface water bodies from various land uses. An earlier survey of this topic (Uttormark et al., 1974) has been frequently cited in lake nutrient loading studies. However, the paucity of well-designed phosphorus export studies pre-dating Uttormark's thorough compilation resulted in the unavoidable inclusion of inaccurate export values in Uttormark's work. Cognizant of this problem, Beaulac screened the now considerable literature on phosphorus export to water bodies for accurate and reliable sampling designs. The result is a set of phosphorus export coefficients that are generally representative of the watershed conditions described. They are presented in Chapter 3 and in the Appendix with watershed descriptions (location, precipitation, soil type, fertilizer application, etc.) designed to facilitate selection of the appropriate export coefficients for lake phosphorus loading.

The concern expressed above for representative export coefficients is grounded in the emphasis in this manual on uncertainty. For planning to be effective, it must be based upon reliable information. Predictive models provide information for planners, so it is vital to the planning process that the reliability of this predictive information be estimated Without a reliability measure, the planner has no basis for weighing model predictive information against other planning information. Inefficient and unpopular decisions can be the result.

Fortunately, it is possible to incorporate an uncertainty analysis into the modeling methodology. This is presented in a step-by-step manner, along with the phosphorus lake model, in Chapter 2. The end product is an estimate of total prediction uncertainty, which should be extremely useful to a planner as a measure of the value of the information provided by the model.

It must be underscored that the estimation of uncertainty does not obviate the need for consideration of the limitations of the modeling/error analysis methodology and for care in the selection of the phosphorus export coefficients. Geomorphologic and climatic constraints on the phosphorus lake model are mentioned in Chapter 2 These limitations are associated with the general rule that empirical models are developed for only a subpopulation of lakes represented by the model development data set. Application of the methodology to lakes not belonging to this subpopulation can increase uncertainty and prediction bias. Since there is no mechanism for the inclusion of this additional error term in the existing methodology, hidden planning risks may result.

The description of the modeling/uncertainty analysis methodology in Chapter 2 offers guidance on the selection of phosphorus export coefficients. Failure to adhere to the criteria for export coefficient choice or failure to carefully match the application lake watershed characteristics with the candidate export coefficient watershed characteristics (described in the tables in Chapter 3 and the Appendix) can again lead to hidden error and bias. This, too, may increase planning risks

This manual is organized around the modeling/error analysis methodology in Chapter 2. The phosphorus export coefficients are presented in Chapter 3 and in the Appendix. This is accompanied by criteria used by Beaulac (1980) in the selection of published coefficients and criteria to be employed by users of this methodology when the export coefficients are selected and applied. At the end, some concluding thoughts are offered in Chapter 4 on the use of this manual for lake trophic management planning.

Chapter 2

THE PHOSPHORUS LAKE MODELING AND UNCERTAINTY ANALYSIS METHODOLOGY

2. 1 Introduction

The lake modeling/uncertainty analysis procedure presented below is a variation of the methodology developed by Reckhow and Simpson (1980) Because of the emphasis attached to uncertainty, the analyst is urged to follow the directions carefully. Further, it is suggested that the analyst read Chapter 1 (and possibly Chapter 4) before beginning the modeling, and read Chapter 4 before preparing a final report documenting the methodology and the application. These chapters offer valuable guidance on modeling, error analysis, and the interpretation of results for lake quality management planning.

2. 2 The Phosphorus Lake Model

In order to plan for the management of phosphorus in a lake watershed, mathematical models describing phosphorus loading and lake trophic response can be quite useful. Given the state of knowledge regarding phosphorus cycles, and the limited funds available to most planning agencies, often the most practical mathematical model for phosphorus management is the simple input/output or "black box" empirical model (Reckhow and Chapra, 1980) This type of model contains terms for the input, the output, and the settling (to the lake bottom) of phosphorus, but it does not explicitly include any biological or chemical reactions. The term "black box" is employed because the model treats the lake like a magician's black box, one is aware only of objects that enter and exit the box, as the contents and internal processes remain a mystery

The left side of Figure 1 (Chapter 1) is a schematic of a "black box" phosphorus model and represents the conceptual foundation for the mathematical model used in this procedure. The figure shows that phosphorus input (loading) to a lake is a result of climate, watershed characteristics, and human activities. This input is modified by environmental factors and yields an output: the lake's average phosphorus concentration.

The mathematical model proposed herein was developed by Reckhow (1979d) from 47 north temperate lakes included in the Environmental Protection Agency's National Eutrophication Survey This model expresses phosphorus concentration (P, in mg/l) as a function of phosphorus loading (L, in g/m^2-yr), areal water loading (q_s, in m/yr), and apparent phosphorus settling velocity (v_s, in m/yr) in the form:

$$P = \frac{L}{v_s + q_s} \tag{1}$$

Using least squares regression, it was found that the apparent settling velocity could be fit using a weak function of q_s. This resulted in the fitted model:

$$P = \frac{L}{11.6 + 1.2q_s} \tag{2}$$

A few limitations on the use of this model should be mentioned now. Since the model was constructed only from lakes within the north temperate climatic zone, it should be applied only to lakes within this zone. Furthermore, the model should not be applied to a lake with variable values more than the maximum values, or less than the minimum values, specified in Table 2. This is because an empirical model should not be used on lakes different from those used to develop the model, without prior testing. Finally, the model may be used to predict the average phosphorus concentration throughout a lake during the growing season. It cannot be used, as developed, to predict nearshore or short-term concentrations.

An important yet often overlooked aspect of the application of models is the fact that the model itself is a simplification of the real world, and thus the prediction from a model is inherently uncertain. Therefore, quantification of the prediction uncertainty should be a required step when a mathematical model is applied. This estimate of the prediction uncertainty could then be used by a modeler or planner as a weight indicating the value of the information contained in the prediction.

Uncertainty, or error, in this modeling exercise may arise from three primary sources: the model, the model parameters, and the model variables Errors in the model and model parameters are derived from the procedure (regression analysis) used to empirically fit the model. For the phosphorus lake model (Equation 2), the model error (s_{mlog}) for the log transformed model is .128; parameter error was found to be quite small for most applications so it was ignored. Model variables uncertainty is estimated for the application lake, and Steps 2 and 4 in the procedure presented herein illustrate the necessary calculations. The separate error terms are combined for an estimate of total prediction uncertainty in Step 4

Once phosphorus concentration is predicted through the application of the empirical model, it is useful to interpret this prediction in the context of expected water quality characteristics in the lake of interest. One example of a trophic state ranking scheme or index was proposed by Chapra and Reckhow (1979) based on average phosphorus concentration. In an earlier work, Dillon and Rigler (1975) also devised a trophic classification scheme which related general water quality and lake use features to the traditional trophic states. These two indices are combined in Table 1 to link phosphorus concentration to potential lake use.

Table 1: Proposed relationships among phosphorus concentration, trophic state, and lake use for north temperate lakes. (Adapted from Chapra and Reckhow, 1979; Dillon and Rigler, 1975).

Phosphorus Concentration (mg/l)	Trophic State	Lake Use
< 0.010	Oligotrophic	Suitable for water based recreation and propagation of cold water fisheries, such as trout Very high clarity and aesthetically pleasing
0.010 - 0.020	Mesotrophic	Suitable for water-based recreation but often not for cold water fisheries. Clarity less than oligotrophic lake.
0.020 - 0.050	Eutrophic	Reduction in aesthetic properties diminishes enjoyment from body contact recreation. Generally very productive for warm water fisheries.
> 0.050	Hypereutrophic	A typical "old aged" lake in advanced succession. Some fisheries, but high levels of sedimentation and algae or macrophyte growth may be diminishing open water surface area.

2. 3 The Modeling/Uncertainty Analysis Procedure

The method proposed herein has as its basis a procedure developed by Dillon and Rigler (1975) that may be used to calculate the capacity of a lake for development based upon the relationship between phosphorus input and water quality. The procedure presented below has two major improvements over that of Dillon and Rigler. First, the most important improvement is the addition of an error estimation procedure. This permits the quantification of prediction uncertainty, and it indicates to the user how valuable (certain) the information is that is provided by the model. Second, the phosphorus lake model imbedded in this procedure has a wider range of applicability than does the Dillon-Rigler model. Dillon and Rigler derived their model from a highly homogeneous set of lakes, the model development data set for the model presented herein includes a fairly wide range of lake types (see Table 2).

In order to facilitate understanding of the impact assessment procedure, it is presented in conjunction with an application to Higgins Lake in Michigan. It should not be inferred from this that the procedure, as presented, is applicable only to Higgins Lake On the contrary, the procedure is quite general and can be easily applied to most lakes (subject to north temperate location and data set constraints such as those in Table 2) simply by substituting the appropriate lake data for the Higgins Lake data in the example.

Higgins Lake, located in the northern, lower peninsula of Michigan, is a deep, cool, oligotrophic lake with a well-oxygenated hypolimnion. The lake has a maximum depth of 41 meters and a mean depth of 15 meters. Some agricultural activity occurs in the watershed but most of the area is forested.

For the sake of this example, assume that an estimate of average lake phosphorus concentration in Higgins Lake, along with an assessment of water quality and recreation potential, is needed for a planning study A measure of prediction uncertainty is also needed to evaluate the results and to compare them with alternative studies.

The method presented below will be used to solve this problem. Recall that the model is

$$P = \frac{L}{11.6 + 1.2q_s}$$

This analysis is structured so that the variables are estimated in the following order: Step 1) areal water loading (q_s), Step 2) areal phosphorus loading (L), Step 3) lake phosphorus concentration (P), and Step 4) phosphorus prediction uncertainty (s_T).

Step 1: Estimation of q_s (areal water loading)

The estimation of q_s involves the solution of two equations;

$$Q = (A_d \times r) + (A_o \times Pr) \tag{3}$$

$$q_s = \frac{Q}{A_o} \tag{4}$$

where:

q_s	= Areal water loading	(m/yr)
Q	= Inflow water volume to lake	(m^3/yr)
A_d	= Watershed area (land surface)	(m^2)
A_o	= Lake surface area	(m^2)
r	= Total annual unit runoff	(m/yr)
Pr	= Mean annual net precipitation	(m/yr)

Ideally, Q should be determined from direct measurement of inflow or outflow, since use of any equation like Equation 3 will result in uncertainty in the predicted variable. When data for Q are not available, it becomes necessary to estimate A_d, A_o, r, and Pr and substitute them into Equation 3 to find Q.

Step 1A: Estimation of A_d (area of the watershed)

The highest points of lake and the lake outlet bound the watershed. In many situtations, all the precipitation that falls on the watershed, and is not evapotranspired, runs off or becomes groundwater and eventually reaches the lake. A topographical map enables one to locate the highest points of land surrounding a lake. Topographical maps are printed by the United States Geological Survey and must be ordered by quadrangle number or name at a U.S.G.S. office. The highest points of land may be outlined and A_d calculated by planimetry. Equation 3 requires that A_d be expressed as m^2 which may require adjustment of the units.

Step 1B: Estimation of r (annual unit runoff)

Average annual areal runoff has been mapped for many regions and again, the U.S.G.S. is a valuable source of information. Note that r must be expressed in m/yr ($m^3/m^2/yr$), and note that it does not include ground water.

When A_d and r are multiplied together an estimate of the average inflow of water from surface runoff is obtained.

Step 1C: Estimation of A_o (area of lake)

The estimation of lake area requires the use of a good map or areal photograph of a known scale. The most accurate method for calculating this area is by planimetry. Note that A_o must also be expressed in m^2.

Step 1D Estimation of Pr (precipitation)

An estimation of the average annual net precipitation (taking into account losses by evaporation) is also needed for Equation 3. This information can be obtained from the U.S.G S or the U.S. Weather Service. Note that Pr must be expressed in m/yr.

The statistics required to solve Equation 3 and 4 for the Higgins Lake example are presented in Table 3 Therefore, the necessary variables are

i) Total annual inflow volume of water to Higgins Lake:

$$Q = (A_d \times r) + (A_o \times Pr)$$
$$= 30.863\ 10^6 m^3/yr$$

ii) The areal water loading:

$$q_s = \frac{Q}{A_o}$$
$$= 0.804\ m/yr$$

Step 2: Estimation of L (areal phosphorus loading)

Every watershed has a unique pattern of land use within its boundaries and each use makes a unique contribution, by way of diffuse sources, to the phosphorus loading of a lake. Technical, financial and practical constraints prohibit most water quality endeavors from conducting "in situ" studies. Therefore, many quantitative investigations rely on the application of phosphorus export coefficients derived from other studies. A compiled survey of coefficients screened according to acceptable criteria (see Chapter 3 and the Appendix) is located in Tables 6 through 12.

Table 2: Minimum and maximum value for the data set used to develop the phosphorus model (from Reckhow, 1979d)

Variable	Minimum	Maximum
P	.004 mg/l	.135 mg/l
L	.07 g/m^2-yr	31 4 g/m^2-yr
q_s	0.75 m/yr	187. m/yr

Table 3: Higgins Lake data necessary for the estimation of q_s

Variable	Estimate
A_d = Watershed area	87 41 $10^6 m^2$
r = Total annual unit runoff	0.2415 m/yr
A_o = Lake surface area	38.4 $10^6 m^2$
Pr = Mean annual net precipitation	.254 m/yr

Table 4: Land use areas in the Higgins Lake Watershed (Liebeskind et al., 1978)

Land Use	Area (hectares)	Area ($10^6 m^2$)
Agriculture	16	0.16
Forest	8347	83 47
Urban	378	3 78

In practical applications it is recommended that high, most likely, and low export coefficients be selected for some of the phosphorus source categories. This allows the calculation of high, most likely, and low total loading estimates, which ultimately represent the uncertainty that the analyst has in his/her estimates of phosphorus loading. The high and low loading estimates represent the additional phosphorus loading error that must be added to the model error for the calculation of total prediction uncertainty. It is important that the high and low loadings represent only those characteristics described in the steps below. This is because to a great extent, the error in the phosphorus loading estimates is already contained in the model error. Additional loading error for an application lake must be included only when the loading is estimated (using the procedure herein) in a different (and less precise) manner than it was estimated for the model development data set. These differences are described in the following steps.

The selection of appropriate phosphorus export coefficients is a difficult task. Since a critical aspect of this modeling exercise is the estimation of prediction errors, the analyst should realize that poor choice of export values contributes to an increase in error. This contribution may be explicit or implicit in the analysis, depending upon whether or not the analyst is aware of all of the uncertainty introduced by his/her choice of phosphorus export coefficients. Clearly, experience in the application of this modeling approach is a valuable attribute.

The estimates of phosphorus loading error are based on high, most likely, and low phosphorus export coefficients selected by the analyst. Loading uncertainty may be caused by either variability or bias. Variability may result from natural fluctuations inherent in a characteristic (e.g., natural variations in streamflow or stream phosphorus concentration), or from uncertainty inherent in a statistic summarizing a set of data. Bias may result from a number of causes, all associated with the fact that the estimate may not be representative of the characteristic that it was selected to estimate. For example, some uncertainty due to possible bias is appropriate to situations where phosphorus export coefficients generated in one watershed are applied in another watershed. As the analyst becomes more uneasy about a selected export coefficient, he/she should express this uneasiness through increased uncertainty and a greater range between high and low export coefficients.

At different points in the procedure presented below, the analyst is alerted to possible sources of bias. These result from the difference between conditions in the model development data set lakes and application lakes. When the characteristics of these two lake groups differ substantially, it is possible that a procedure appropriate for analysis of one group is inappropriate for analysis of the other This is the justification for Table 2, which presents the limitations on the basic model variables, as defined by the model development data set. Now, when the allocation of phosphorus loading sources differs between the two lake groups, there is probably no need to restrict the use of the model, which is insensitive to the source of phosphorus. However, the error analysis (but not the mean prediction) may be affected because the loading estimation errors vary from source to source Therefore, warnings of possible bias are stated herein when the application lake phosphorus loading allocation differs substantially from that for the model development data set. These warnings should be addressed, when appropriate, by the inclusion of a bias uncertainty addition to the high and/or low loading estimates.

The total annual mass flow of phosphorus to a lake is estimated by summing the annual phosphorus contribution from each of the nonpoint sources plus any additional point source input within the watershed. Total mass loading (M) may be expressed as (in kg/yr):

$$M = (Ec_f \times Area_f) + (Ec_{ag} \times Area_{ag}) + (Ec_u \times Area_u) + (Ec_a \times A_o) + (Ec_{st} \times \# \text{ of capita-years} \times (1 - S.R.)) + PSI \tag{5}$$

where:

Ec_f = Export coefficient for forest land (kg/ha/yr)

Ec_{ag} = Export coefficient for agricultural land (kg/ha/yr)

Ec_u = Export coefficient for urban area (kg/ha/yr)

Ec_a = Export coefficient for atmospheric input (kg/ha/yr)

Ec_{st} = Export coefficient to septic tank systems impacting the lake (kg/(capita - yr) - yr)

$Area_f$ = Area of forest land (ha)

$Area_{ag}$ = Area of agricultural land (ha)

$Area_u$ = Area of urban land (ha)

A_o = Area of lake (ha)

# of capita-years = # of capita-years in watershed serviced by septic tank/tile field systems impacting the lake

S.R. = Soil retention coefficient (dimensionless)

PSI = Point source input (kg/year)

In order to facilitate the understanding and estimation of the variables contained in Equation 5, Step 2 has been broken into 7 sub-steps.

Step 2A: Estimation of $Area_f$, $Area_{ag}$, and $Area_u$ (watershed areas).

Recall that the watershed area was determined in Step 1. This area must now be subdivided into agricultural, forest, and urban lands. The area for each must be determined and expressed in hectares. Table 4 identifies the existing land uses and areas in the Higgins Lake watershed. When the objective of this analysis is the projection of future conditions, high and low area estimates are needed to reflect the uncertainty in the land use projections.

Step 2B: Estimation of Ec_f, Ec_{ag}, Ec_u, Ec_a and Ec_{st} (export coefficients)

This substep requires that an export coefficient (Ec_x) be chosen for each of the phosphorus source categories found in the watershed. Candidate export coefficients with a respective summary of watershed characteristics (e.g., soil type, % impervious surface, etc) are found in Tables 6 through 12 Values for atmospheric loading are located in Table 13. These coefficients represent the expected annual phosphorus input to a lake or stream per unit of source.

It is important to understand that Ec_{st} differs from the other export coefficients in that it represents the expected annual amount of phosphorus transported not to the lake, but from households to on-site septic systems. A range of export coefficients that describes per capita export of phosphorus from households to septic systems is presented in Table 14.

After the analyst estimates the amount of phosphorus received by septic systems the next logical step is to determine how much of that phosphorus is being retained in the tile field soils (i.e., how much is exported to the lake). Phosphorus retention is addressed in substep 2C.

The high and low export coefficients selected should reflect the modeler's confidence in the extrapolation of literature export values to the application lake watershed. For example, in cases where the modeler knows that the "most likely" export coefficient chosen was determined under a good sampling program on a watershed quite similar to the application lake watershed, the high and low values should be selected to represent little uncertainty. A single precipitation loading figure (the "most likely" value) is probably adequate for most conditions. Only when the precipitation loading is deemed substantial (perhaps 25% of the total loading) should it be necessary to include possible precipitation loading error bias.

When the objective is future projection, the area estimates and export coefficients should be combined according to· high area with high export, most likely area with most likely export, and low area with low export This calculation is to be made in Step 2F.

For the Higgins Lake example, various documents were consulted, including a study conducted by the U.S. Environmental Protection Agency (USEPA, 1975), in order to familiarize the investigators with the watershed. Phosphorus flux reports from other area lakes were also surveyed. Despite the existence of pertinent literature, the selection of application phosphorus export coefficients is still an unavoidably subjective task. This, of course, is the nature of the technique and consequently affirms the importance of the associated uncertainty analysis.

The forestland within the Higgins Lake watershed consists primarily of coniferous species with some deciduous trees and constitutes the major land use. Agriculture is rather limited and consists chiefly of grazing and pasture. The urban areas are mainly residential/recreational and all units are serviced by septic systems.

For demonstration purposes, high, most likely, and low export coefficients were chosen (based on the phosphorus export coefficients presented in Chapter 3) to reflect phosphorus source conditions found in the Higgins Lake watershed. The selected coefficients are presented in Table 5 . Note that the high and low values selected for Higgins Lake are not as high or

Table 5: High, most likely, and low export coefficients selected for Higgins lake

Source	High	Most Likely	Low
Forest	.30 kg/ha/yr	.20 kg/ha/yr	.10 kg/ha/yr
Agriculture (pasture and grazing land)	1.30 kg/ha/yr	.40 kg/ha/yr	.20 kg/ha/yr
Urban (residential)	2.70 kg/ha/yr	.90 kg/ha/yr	.35 kg/ha/yr
Precipitation	.50 kg/ha/yr	30 kg/ha/yr	.15 kg/ha/yr
Input to septic tanks	1.0 kg/capita/yr	0.6 kg/capita/yr	0.3 kg/capita/yr

as low as some of the candidate export coefficients presented in Chapter 3 This is because conditions in the Higgins Lake watershed were judged to be not equivalent to the extreme conditions that are represented by the ranges in candidate coefficients.

The Ec_{st} export coefficients were selected to take into account Michigan's ban on the sale of phosphorus-based detergents. Thus, the selected coefficients are on the lower side of the range exhibited in Table 14 Likewise, note that Ec_a is also on the lower side of the presented atmospheric export coefficient range This is because little agricultural and industrial activity take place in the Higgins Lake area, which probably results in small quantities of air-born phosphorus.

Step 2C· Estimation of S.R (soil retention coefficient)

On-site septic tank-tile field systems may or may not be effective in trapping phosphorus and preventing it from entering a lake via groundwater transport. The soil retention coefficient is an estimate of how well the systems immobilize phosphorus. This coefficient may range from 0 to 1 0. For example, if it is assumed that all phosphorus transported to septic systems eventually reaches the lake, then a soil retention coefficient value of 0 would be selected. If it is assumed that no phosphorus reaches the lake, then S R = 1 0.

Rodiek (1979) notes that effective tile drainage fields involve both physical and chemical processes. Chemical fixation reactions require effluent-to-soil contact of sufficient time length for chemical reactions or adsorption to occur. There are four major aspects of watershed soils (within the lake impacting zone) that influence contact duration time and phosphorus immobilizing capabilities and thus should be considered when selecting S.R. These factors are. 1) phosphorus adsorption capacity,

2) natural drainage, 3) permeability and, 4) slope. As one might expect, all of these factors are closely related and of a dynamic nature. They are discussed in depth in Chapter 3.

In addition to the above soil characteristics, there are four general mechanisms of phosphate removal in soils. 1) rapid removal or adsorption, 2) slow mineralization and insolubilization, 3) plant uptake, and 4) biological immobilization (Tofflemire and Chen, 1977). The most important of the phosphorus immobilization mechanisms in septic systems are the formation of insoluble iron and aluminum phosphate compounds and the adsordtion of phosphate ions onto clay lattice structures (Tilstra et al., 1972)

Assessment of the factors discussed above is useful in determining S.R. However, because of the complexities involved, the modeler's estimation of S.R. still must be based on his/her knowledge of the soil conditions present in the application watershed, past experience with similar watersheds and his/her professional intuition When the model is used to predict future conditions, it is often sufficient to use a single estimated soil retention coefficienc. Only when the estimated loading from septic systems is thought to be substantial (perhaps 25% of the total loading), should it be necessary to employ low, most likely, and high soil retention coefficients. It is possible, however, that the error analysis may be biased when the septic tank loading becomes a sizeable fraction of the total loading.

For the Higgins Lake example, it was found that sandy/gravel soils of moraines and till plains predominate in the watershed, which tend to permit rapid infiltration and transmission of water. Nearby Houghton Lake is surrounded by various soils posessing moderate to poor phosphorus adsorbing capacities (Ellis and Childs, 1973). Based on this evidence, soil retention of phosphorus was estimated to be on the poor side A "most likely" S R. coefficient of .25 a "low" coefficient of .50 and a "high" coefficient of

.05 were selected to represent the soils surrounding Higgins Lake Since evidence (USEPA, 1975) suggests that phosphorus loading from septic systems may be a substantial fraction of the total loading, three (not one) soil retention coefficients were chosen for Higgins Lake, as specified in the instructions above.

Step 2D. Estimation of # of capita-years

The number of persons contributing to septic systems that impact a lake must be estimated and expressed in capita-years. To ascertain this figure, the analyst must first determine the size of the impact zone. Often this is a strip, perhaps 20-200 meters wide, surrounding the lake Sometimes the analyst may include border strips along tributary streams when conditions suggest that these remote areas may be important. Conditions that dictate the size and location of the impact zone include drainage patterns, water tables, and slopes

When the model is used to assess current conditions, population surveys are quite useful for the estimation of the phosphorus loading from septic tanks. When the goal is the prediction of future conditions, population projections must be consulted For most lakes, the high and low loading estimates for septic systems should then be based solely on the uncertainty in the population projections (the source of possible bias). The total number of capita-years may be calculated by adding together permanent resident capita-years and seasonal resident capita-years This is described in Equation 6 below.

Permanent capita-year

$$\text{Total \# of capita-years} = \text{average \# of persons per living unit} \times \frac{\text{\# days spent at unit per year}}{365} \times \text{\# of living units}$$

$$+ \tag{6}$$

Seasonal capita-year

$$\text{average \# of persons per living unit} \times \frac{\text{\# days spent at unit per year}}{365} \times \text{\# of living units}$$

In this particular example, it was assumed that septic systems of only lakeside dwellings impact Higgins Lake. According to the EPA National Eutrophication Survey (USEPA, 1975) there are an estimated 1,000 seasonal dwellings on the Higgins Lake shoreline and all are served by septic systems A facilities plan study estimated that each seasonal unit is occupied by an average of 3.5 people who spend 60 days a year at their residence (Progressive Engineering Consultants, 1976). This information may be inserted in Equation 6 to estimate the number of capita-years impacting the lake.

$$\text{Total \# of capita-years} = \underbrace{0}_{\text{Permanent}} + \underbrace{3.5 \times \frac{60}{365} \times 1000}_{\text{Seasonal}}$$

$$= 575.3$$

Step 2E: Estimation of PSI (point source input)

If the effluent from an industry, sewage treatment facility or other point source is deposited within the watershed, the impact must be assessed and expressed in kg phosphorus/yr.

At the present time there are no known point sources of phosphorus in the Higgins Lake watershed. Thus, PSI = 0 kg/yr. However, if point sources exist in the application lake watershed, or are projected for the future, then the uncertainty in the phosphorus loading from this source is represented by the uncertainty in the size of the projected population to be served An example of phosphorus loads from sewage treatment plants is presented in Table 15.

As a final note on the phosphorus loading sources, it is possible that the lake sediments may be a non-negligible source. Internal phosphorus loading is most probable in shallow lakes that possess anoxic bottom waters. This condition can promote an appreciable rate of phosphorus transport from the sediment/water interface to overlying waters. In shallow lakes this sediment phosphorus may reach the photic zone and be used by the aquatic plants. If this is thought to be so for an application lake, then high, most likely, and low loading estimates should be used for the prediction and prediction error (see Reckhow, 1979b for suggested values), to reflect this source of possible bias in the uncertainty analysis.

Step 2F Calculation of M (total phosphorus mass loading)

When Steps 2A through 2E are complete, Equation 5 may be solved to yield high, most likely, and low phosphorus mass loading estimates based on high, most likely, and low phosphorus export and soil retention coefficients.

Thus, for the Higgins Lake example

high

$$M_{(high)} = (.30 \times 8347) + (1.30 \times 16) + (2.7 \times 378) + (.50 \times 3840) + (1.0 \times 575.3 \times (1 - 0.05)) + 0$$

$$= 6012.04 \text{ kg/yr}$$

most likely

$$M_{(ml)} = (.20 \times 8347) + (.40 \times 16) + (.90 \times 378) + (.30 \times 3840) + (0.6 \times 575.3 \times (1 - 0.25)) + 0$$

$$= 3426.9 \text{ kg/yr}$$

low

$$M_{(low)} = (.1 \times 8347) + (.20 \times 16) + (.35 \times 378) + (\ 15 \times 3840) + (0.3 \times 575.3 \times (1 - .50)) + 0$$

$$= 1632.5 \text{ kg/yr}$$

Step 2G: Calculation of L (annual areal phosphorus loading)

In order to be used in this model, annual phosphorus input must be expressed as a loading per unit lake surface area. This is accomplished by dividing M by the lake surface area, A_o.

$$L = \frac{M}{A_o} \qquad (7)$$

The units are then converted so that this areal phosphorus loading term is expressed in grams per square meter of lake surface area per year. Thus, for Higgins Lake:

high

$$L_{(high)} = \frac{6012.0\ kg/yr}{38.4 \times 10^6 m^2} = 157 \times 10^{-6}\ kg/m^2/yr = .157\ g/m^2/yr$$

most likely

$$L_{(ml)} = \frac{3426.9\ kg/yr}{38.4 \times 10^6 m^2} = 89 \times 10^{-6}\ kg/m^2/yr = .089\ g/m^2/yr$$

low

$$L_{(low)} = \frac{1632.5\ kg/yr}{38.4 \times 10^6 m^2} = 43 \times 10^{-6}\ kg/m^2/yr = 043\ g/m^2/yr$$

Step 3. Calculation of P (lake phosphorus concentration)

The model may now be solved for high, most likely, and low phosphorus concentrations by substituting in values of q_s and L (high, ml, and low)

$$P_{(high)} = \frac{L\ (high)}{11.6 + 1.2q_s}$$

$$P_{(ml)} = \frac{L\ (ml)}{11\ 6 + 1.2q_s}$$

$$P_{(low)} = \frac{L\ (low)}{11.6 + 1.2q_s}$$

For Higgins Lake.

high

$$P_{(high)} = \frac{0.157}{11.6 + 1.2\ (0.804)} = 0.0125\ mg/l$$

most likely

$$P_{(ml)} = \frac{0\ 089}{11.6 + 1.2\ (0.804)} = 0.0071\ mg/l$$

low

$$P_{(low)} = \frac{0.043}{11.6 + 1.2\ (0.804)} = 0.0034\ mg/l$$

Step 4: Estimation of s_T (prediction uncertainty)

In order to estimate the uncertainty associated with a prediction calculated using the phosphorus model, estimates are needed for the error, or uncertainty, in all terms in the model, and in the model itself. However, it has been shown by Reckhow (1979d) that for most applications of this model, the error in the parameter v_s is small. Further, error in q_s is primarily a function of flow measurement error and hydrologic variability, which also affect L. Since L and q_s are in the numerator and denominator, respectively, in the model, the errors affecting both tend to cancel when they are combined to yield the resultant error in P. In addition, hydrologic variability is unimportant in lakes with low flushing rates. Therefore, it is assumed here that the prediction error is a function only of model error and of aspects of phosphorus loading uncertainty that are identified in Step 2. If the application lake flushes rapidly and is subject to great variations in year-to-year precipitation, then the modeler is urged to include hydrologic variation in the error analysis using the error propagation equation (see the Appendix for instructions)

The model error is represented by s_{mlog} in the equations below and is expressed in logarithmic units of phosphorus concentration error. The loading error, s_L, on the other hand, is expressed in untransformed units of phosphorus loading error. Therefore, to combine these two values for an estimate of total prediction uncertainty, some calculations are necessary.

The procedure presented below is based on first order error analysis (Benjamin and Cornell, 1970). In this particular application, three assumptions are of some importance.

1. Model error, expressed in log-transformed concentration units, is appropriately combined with variable error terms after the transformation is removed.

2. The "range" ("high" minus "low"), for phosphorus loading error, is approximately two times the standard deviation. This is based loosely on the characteristics of the Chebyshev inequality identified below, where about 90% of the distribution is contained within ± 2 standard deviations of the mean.
3. The individual error components are adequately described by their variances (standard deviations).

In order to relax a previously imposed (Reckhow, 1979a) yet tenuous normality assumption, the confidence intervals constructed below are based on a modification of the Chebyshev inequality (Benjamin and Cornell, 1970). Therefore, it is no longer required that the total error term be normally distributed Instead its distribution must only be unimodel and have "high order contact" with the abscissa in the distribution tails. These are achievable assumptions under almost all conditions, and it is recommended (Reckhow and Chapra, 1979) that this type of nonparametric approach be adopted until the distributions have been adequately studied and characterized

Step 4A: Calculation of log $P_{(ml)}$

Take the logarithm of the most likely phosphorus concentration, $P_{(ml)}$.

For Higgins Lake:

$$\log P_{(ml)} = \log 0.0071$$
$$= -2.149$$

Step 4B: Estimation of s_m+ ("positive" model error)

The model error, (s_{mlog}), was determined to be 0.128. Add s_{mlog} to log $P_{(ml)}$ and take the antilog of this value. Now calculate the difference between this antilog value and $P_{(ml)}$. Label this difference s_m+, it represents the "positive" model error.

$$s_m+ = \text{antilog}\ [\log P_{(ml)} + s_{mlog}] - P_{(ml)} \tag{8}$$

For Higgins Lake:

$$s_m+ = \text{antilog}\ (-2.149 + 0.128) - 0.0071$$
$$= 0.0024 \text{ mg/l}$$

Step 4C: Estimation of s_m- ("negative" model error)

Subtract s_{mlog} from log $P_{(ml)}$ and take the antilog of this value. Now calculate the difference between this antilog and $P_{(ml)}$, and label this difference s_m-.

$$s_m- = \text{antilog}\ [\log P_{(ml)} - s_{mlog}] - P_{(ml)} \tag{9}$$

For Higgins Lake:

$$s_m- = \text{antilog}\ (-2.149 - 0.128) - 0.0068$$
$$= 0.0015 \text{ mg/l}$$

Step 4D Estimation of s_L+ ("positive" loading error)

Now, one must convert the loading error estimate into units compatible with the model error. Use the $P_{(high)}$ concentration estimated in Step 3 and calculate the difference between $P_{(high)}$ and $P_{(ml)}$, then divide this difference by 2. Label this value s_L+; it represents the "positive" loading error contribution.

$$s_L+ = \frac{P_{(high)} - P_{(ml)}}{2} \tag{10}$$

For Higgins Lake

$$s_L+ = 0.0027 \text{ mg/l}$$

Step 4E: Estimation of s_L- ("negative" loading error)

Repeat Step 4D substituting the low concentration value $P_{(low)}$ for $P_{(high)}$. Label the resultant value s_L-, it represents the "negative" loading error contribution.

$$s_L- = \frac{P_{(ml)} - P_{(low)}}{2} \tag{11}$$

For Higgins Lake:

$$s_L- = 0.0019 \text{ mg/l}$$

Step 4F: Estimation of s_T+ (total "positive" uncertainty)

Total positive prediction uncertainty is calculated using the equation:

$$(s_T+)^2 = (s_m+)^2 + (s_L+)^2 \tag{12}$$

or:

$$s_T+ = \sqrt{(s_m+)^2 + (s_L+)^2} \tag{13}$$

For Higgins Lake:

$$= \sqrt{(0.0024)^2 + (0.0027)^2}$$

$$s_T+ = 0.0036 \text{ mg/l}$$

Step 4G: Estimation of s_T- (total "negative" uncertainty)

Total negative prediction uncertainty is calculated using the equation

$$(s_T-)^2 = (s_m-)^2 + (s_L-)^2 \tag{14}$$

or:

$$s_T- = \sqrt{(s_m-)^2 + (s_L-)^2} \tag{15}$$

For Higgins Lake:

$$= \sqrt{(-0.0015)^2 + (0.0019)^2}$$

$$s_T- = 0.0024 \text{ mg/l}$$

Step 4H: Calculation of confidence limits

The prediction uncertainty may be expressed in terms of "confidence limits" which represent the prediction plus or minus the prediction uncertainty.

Confidence limits have a definite meaning in classical statistical inference, they define a region in which the true value will lie a pre-specified percentage of the time.

Using the modification of the Chebyshev inequality (Benjamin and Cornell, 1970), the confidence limits may be written as:

$$\text{Prob } [(P_{(ml)} - hs_T-) \leq P \leq (P_{(ml)} + hs_T+)] \geq 1 - \frac{1}{2.25h^2} \quad (16)$$

Equation 16 states that the probability that the true phosphorus concentration lies within certain bounds, defined by a multiple, h, of the prediction error, is greater than or equal to $1 - 1/2.25h^2$. (This relationship loses its significance as h drops much below one.) Substituting values for h into Equation 16 reveals that a value of one for h corresponds to a probability of about 55% (.556 to be exact), and a value of two for h corresponds to a probability of about 90% (.889 to be exact). Thus the 55% confidence limits are

$$\text{Prob } [(P_{(ml)} - s_T-) \leq P \leq (P_{(ml)} + s_T+)] \geq .55 \quad (17)$$

Substituting the Higgins Lake data this becomes

$$\text{Prob } [(0.0071 - 0.0024) \leq P \leq (0\ 0071 + 0.0036)] \geq \ 55$$

$$\text{Prob } [0.0047 \text{ mg/l} \leq P \leq 0.0107 \text{ mg/l}] \geq .55$$

Now that specific values for the prediction error have been inserted into the confidence limits expression, its interpretation changes somewhat. It is: "about 55% of the time (that confidence limits are estimated), one can expect that the actual average phosphorus concentration will lie within the bounds defined by the prediction plus or minus the prediction uncertainty " This same interpretation format applies when the confidence limits are widened to the 90% level (h = 2), and the Higgins Lake data are inserted:

$$\text{Prob } [(P_{(ml)} - 2s_{T}-) \leq P \leq (P_{(ml)} + 2s_{T}+)] \geq .90 \qquad (18)$$

Inserting the data yields:

$$\text{Prob } [(0.0071 - (2)\ (0.0024)) \leq P \leq (0.0071 + (2)\ (0.0036))] \leq .90$$

$$\text{Prob } [0.0023 \text{ mg/l} \leq P \leq 0.0143 \text{ mg/l}] \geq .90$$

2. 4 Application Summary

The application of the technique and model to Higgins Lake resulted in a "most likely" phosphorus concentration of 0.0071 mg/l (Step 3), with 55% confidence limits bounding the "true" phosphorus concentration between 0.0047 mg/l and 0.0107 mg/l.

Relating back to the trophic classification in Table 2, Higgins Lake is probably:

1) oligotrophic
2) clear, and suitable for water-based recreation and a cold water fishery.

These predicted trophic conditions in fact describe the present observed conditions in Higgins Lake. A median phosphorus concentration value of .006 mg/l was determined for Higgins Lake by the Environmental Protection Agency's National Eutrophication Survey (USEPA, 1975).

Chapter 3

NUTRIENT EXPORT COEFFICIENTS

3.1 Introduction

In Chapter 1, a distinction was made between descriptive and predictive use of the modeling methodology Planning for proper lake quality management necessitates the prediction of the impact of projected land use on lake water quality. Measurement of a yet-to-be realized impact is clearly impossible. Instead, the planner must extrapolate impact assessments from other, similar watersheds, possibly in the form of annual export coefficients Thus nutrient loading estimates associated with watershed land uses are necessary for lake trophic quality management planning.

In this chapter, annual nutrient export coefficients, identified in the comprehensive literature survey by Beaulac (1980), are presented in tabular and graphical form The criteria employed in the identification of these "approved" export coefficients 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. Also discussed in some detail are recommended criteria to be considered by users of this methodology in the selection of export coefficients To facilitate this selection process, the tabulated nutrient export coefficients are presented along with data on related characteristics These include watershed location, precipitation, soil type, and other site-specific features that might affect nutrient runoff. The user may then match these qualities with the characteristics of the application lake watershed so that reliable export coefficients are chosen

3.2 Criteria Employed in the Selection of Export Coefficients for this Manual

In screening nutrient export coefficients reported in the literature, Beaulac (1980) established certain acceptance criteria. To a considerable degree, these criteria are reflective of good experimental design employed in watershed studies. So that the analyst may understand the approximate reliability that can be attached to the tabulated export coefficients (presented below and in the Appendix), important screening criteria are discussed. For elaboration of this topic, see the Appendix

1. Accuracy In statistical terms, accuracy exists when the expected value for an estimator lies close to the true value Inaccuracy in a study frequently results from faulty experimental design. Therefore, to evaluate accuracy, one must have a good conceptual knowledge of the characteristic of concern. This includes an understanding of causal relationships as well as temporal and spatial variability if relevant. For nutrient export coefficients, accuracy is likely if the researcher a) employed design controls for extraneous variables not of immediate interest, b) incorporated into the analysis all causal factors not removed from influence, and c) used good statistical sampling design (see the Appendix) As an example, if the researcher is interested in agricultural row crop runoff, he/she must either exclude all other runoff sources from the test watershed, or include consideration of the additional sources when analyzing the results. If it is known that row crop runoff is quite dependent upon major storms and that particulate material is important, then the design must reflect these factors.

2. Precision Like accuracy, precision is a statistical term. An estimate is precise if it is estimated with low error Good sampling design (see the Appendix) is a necessary but not sufficient condition for precision Precision is also affected by the number of samples taken and the amount of useful information acquired per sample. Therefore, in screening literature export coefficients, Beaulac (1980) looked for accurate experimental designs including frequent sampling (particularly if the observations are dependent).
3. Representativeness For the nutrient export coefficients to contribute to reliable lake trophic management planning, the analyst must carefully match the characteristics of candidate export coefficient watersheds with the application lake watershed (see section 3.3). This requires comprehensive information on the export coefficient watersheds. Therefore, Beaulac (1980) looked for information on characteristics such as geographic location, precipitation, watershed size, soil type, fertilizer application (when appropriate) and other important land use features This is vital to the watershed matching process which dictates export coefficient choice.
4. Temporal Extent of Sampling Nutrient budgets and input-output lake models are generally based on yearly increments so that the meterologically-induced annual variations in nutrient export and lake quality are effectively removed from analysis. Since weather and climate have a similar effect on export coefficients, only yearly values were accepted by Beaulac. The alternative, extending values

reported for fractions of a year, must be rejected because of methodological problems

5. Nutrient Flux Estimation There is no "best" method for combining concentration and flow data to estimate mass flux. However, the short discussion in the Appendix on sampling design and flux estimation describes preferred techniques. Only export coefficients estimated under documented methods deemed relatively unbiased are reported herein.

6. Concentration and Flow Data Since flow is the prime determinant of nutrient mass flux, as a rule only those export coefficients estimated with continuous flow data are reported. Most lake models and nutrient loading criteria are based on total nutrient concentrations Therefore, preferred studies were those that reported total nutrient concentrations. Beyond that, since bioavailability (see the Appendix) is an issue receiving increasing attention, fractional forms of the nutrients are provided herein when reported in the original study.

3.3 Export Coefficient Selection Criteria for the Modeler

Probably the most important task that the analyst performs in applying the methodology in Chapter 2 is selecting the phosphorus export coefficients. Most of the other steps are quite explicit in the description of the task to be conducted and in the associated uncertainty (if any). Export coefficient choice, on the other hand, benefits from the experience of the analyst in the general topic of land use-nutrient flux relationships. The problem associated with faulty export coefficient selection is one of supplemental, or hidden, uncertainty. This refers to prediction uncertainty that is unknown to the analyst and thus is not part of the uncertainty accounting process. Hidden uncertainty results from inexperience, the analyst believes that a choice of high and low export coefficients covers the true phosphorus loading when in fact it does not. This leads to bias in the prediction and additional risk in planning. Knowledge of the causal factors behind nutrient flux from land use activities and thoughtfulness in matching the application watershed with candidate export coefficient watersheds can significantly reduce supplemental uncertainty.

There are two important issues to consider when selecting export coefficients. First, one must try to match the application lake watershed and candidate export coefficient watersheds as closely as possible on the basis of causal determinants of phosphorus loading. Second, the range of export coefficients selected (i.e., the high and low values) should reflect the total uncertainty for that characteristic. Factors important in watershed matching are outlined in detail after a short discussion of phosphorus loading uncertainty.

Uncertainty in phosphorus export may arise from 1) natural variability, 2) error and bias associated with the measurement and estimation of the export coefficient, 3) error and bias associated with the representation of phosphorus export in the application watershed by an export coefficient estimated at another point in space and/or time, and 4) uncertainty in land use, population, etc., projections. It was noted in Chapter 2 that the phosphorus model standard error contains some phosphorus loading estimation error associated with the model development data set. As a result, the description of export coefficient selection--for the purpose of loading error estimation--is quite specific. Thus not all uncertainty components identified above are necessarily included in each set-of-three (high, most likely, and low) export coefficients choice.

One point should be made concerning the first item listed above. natural variability. The nutrient export coefficient tables exhibit natural variability (in addition to measurement and estimation error) among the export coefficients presented. This is cross-sectional variability which in part represent various, and different, conditions in the nutrient export coefficient watersheds. This must be distinguished from natural longitudinal variability, which reflects variability in export from a single watershed over time (see section 3.4 for histograms exhibiting cross-sectional and longitudinal variability). It is likely that longitudinal variability is smaller in magnitude than cross-sectional variability, since the causative factors for longitudinal variability are relatively homogeneous (in comparison to the causative factors for cross-sectional export coefficient variability). Since export coefficients are chosen for single watersheds (over time), it is longitudinal export variability that is important (in addition to extrapolation error and bias). 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.

The second issue mentioned above for consideration in selecting export coefficients is the process of matching the application lake watershed and candidate export coefficient watersheds according to causal determinants of nutrient export. To facilitate this matching process, an outline is presented below listing important causative nutrient export factors according to land use activity.

1. <u>Forest Land Use</u>

   The range of phosphorus export coefficients is very narrow (.019 - .830 kg/ha/yr), and it is 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.

a. Species Type

i. Pine-coniferous softwoods have demonstrated higher rainfall interception capacity and evapotranspiration rates than have hardwoods. A number of investigators report that annual streamflow was reduced about 20% below that expected for the hardwood cover, 15 years after experimental watersheds in the Southern Appalachians had been converted from a mature deciduous hardwood cover to white pine (Swank and Douglass, 1977, 1974; Swank et al., 1972; Swank and Miner, 1968). Therefore higher nutrient loads could develop from tributaries draining hardwoods than from tributaries draining softwoods.

ii. Some hardwoods such as alder (Alnus sp.) are nitrogen fixers. Brown et al. (1973) reported both higher nitrate concentrations and higher nitrogen loads from alder watersheds than from those streams that drained primarily douglas fir and western hemlock (for streams in western Oregon).

b. Soil Type, Bedrock, and Parent Material

Dillon and Kirchner (1975) observed that forested watersheds with sandy soils overlying granitic igneous formation had one-half the phosphorus output than did forested watersheds with loam soils overlying sedimentary formations. Loam soils are higher in nutrients and more erodable than sands and gravels, sedimentary formations have higher leachability and erodability. Therefore soils and substrate types such as these (loams and sedimentary formations) may cause shifts toward the higher end of the phosphorus export range.

c. Vegetation Age

Maturity is a function of species type (among other characteristics). This factor is important only in very young, newly vegetated forests. In this sense, "young" refers to trees of less than five years of age. Woodlots of this age do not have a canopy developed enough to reduce rainfall impact energy. Therefore soil in young forests are more disrupted than soils in mature forests (see Disturbed Watershed, below). The result is higher runoff and greater sediment phosphorus flux from young forests.

d. Climate

This appears to be the major determinant of export of phosphorus from forests. Areas of the country that exhibit warm climates with high rainfall (such as the pacific northwest and southeastern piedmont regions) are associated with high productivity, high runoff, and high phosphorus export.

e. Disturbed Watersheds

i. Deforestation/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; 2) raises forest floor temperature; 3) increases the frequency of drying and wetting (weathering); 4) increases microbial activity; and 5) increases the nutrient pool by contribution of dead organic material (slash). Therefore, nutrient output is increased. (The amount of increase depends on the extent of the watershed under cultivation.)

ii. Forest fire

Nutrient export due to fires can increase over the normal range of export for undisturbed forests, but this will depend upon the severity of the burn (% watershed burned) and the type of fire (crown vs. brush (understory) fire) (Wells, 1971; Pritchett, 1979).

iii. Fertilization

Nutrient export will increase only if fertilizers are applied directly on the stream. This practice is currently not very common nationwide. Increases in nutrient export will last only for a short time period (one or two runoff periods), and will depend on the extent of areal coverage of the fertilizer and fertilizer type (nitrogen or phosphorus). (Moore, 1970, 1975; Fredriksen et al, 1975; Stay et al., 1978).

2. Agricultural Land Use. Crops

a. Soils

Because soils are exposed for long time periods (late fall, winter, early spring), they will influence the magnitude of the phosphorus load released from the watershed.

i. Sandy/gravel soils 1) do not erode easily, 2) have a low cation content, and 3) cause a general downward flow of water to the groundwater (high infiltration capacity). Thus phosphorus export via runoff is low.

ii. Clay soils (clay loams, silt loams etc.) have a 1) high cation content (high phosphorus adsorption capacity), 2) high erodability, and 3) low infiltration capacity. Therefore phosphorus export via runoff is high.

iii. Organic soils have 1) limited phosphorus retention capacity, 2) low infiltration capacity, and 3) high nutrient content. As this soil is used for cultivation, it decomposes rapidly. Therefore phosphorus export via runoff is high.

b. Fertilizer Type and Amount

i. The type of fertilizer is not as significant as the time of application. Partially because of this, manure-type fertilizers are thought to often cause high phosphorus export because manure is frequently applied on frozen soils in winter or early spring. When combined with snowmelt and high rainfall/runoff periods, the result is very often high export of phosphorus and nitrogen. If application is followed with soil incorporation, phosphorus and nitrogen export is substantially reduced (Minshall et al., 1970, Klausner et al., 1976, Converse et al., 1976, Hensler et al., 1970).

ii. Heavy amounts of fertilizer (either manure or commercial grade) applied above the recommended rate will cause increases in nutrient export. The recommended rate is dependent upon the amount and availability of nutrients in the soil (to growing crops).

c. Tillage Practices

i. Conventional tillage methods, in which the ground is left fallow during non-growing periods and crop residues are removed at harvest, are a prime cause of high amounts of nutrient export (lead to high erosion of soils, etc.).

ii. 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 1) nonmoldboard tillage, such as chisel plowing, that does not use a moldboard plow and involves fewer tillage operations than conventional moldboard systems, and 2) "no-till," which involves planting directly into untilled soil (Pollard et al., 1979).

iii. Other techniques, which the above tillage methods may be combined with, can reduce nutrient export further. These methods are 1) contour planting, and 2) terracing (Alberts et al., 1978).

d. Crop Types

i. Row crops (corn, soybeans etc.): Farmland planted with this type of crop is subject to channelization and erosion. Export of nutrients from watersheds consisting of row crops will be much higher than export from non row crop watersheds.

ii. Non row crops (wheat, millet, rye and other small grains): Growth of these crops does not generally lead to channelization. Therefore lower levels of nutrient export may be expected.

3. Agricultural Land Use· Pasture and Grazing Land

Nutrient export from these watersheds depends upon the method of management of the cattle, sheep, etc. and not necessarily on the volume of waste produced.

a. Rotational Grazing: Cattle are grazed on a particular piece of land for a limited time period (e.g., summer only). This allows vegetation to regrow which reduces runoff (including nutrient export).

b. Continuous Grazing: This results in 1) increases in soil compaction, 2) decreases in vegetation, and 3) increases in waste loads (manure). Therefore, nutrient export is usually high (Menzel et al., 1978).

c. Fertilization: Pastured watersheds are often fertilized to increase forage vegetation. This often increases the total amount of nutrient export (Olness et al., 1980).

d. Animal Density: Studies indicate that the greater the number of animals per unit area, the higher the amount of animal waste and the greater the potential for high nutrient export (Chichester et al., 1979).

4. Agricultural Land Use: Feedlot and Manure Storage

a. Percent 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 (Coote and Hore, 1978).

b. Animal Concentration: If the animal density is high, the nutrient export can also be high (McCalla et al., 1972; Clarke et al., 1975).

c. Covered Feedlots: If the feedlot is inclosed 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) (Dornbush and Madden, 1973; Coote and Hore, 1978).

d. Detention Basin: If a detention basin is present, nutrient export will be decreased (Coote and Hore, 1978).

5. Urban Land Use

Most urban runoff is channeled into storm drains, although not all storm drains serve a single watershed. Therefore, the output from a storm drain may consist of material from portions of one or more watersheds. It is important to determine the extent of the drainage system (if storm drains are used) in order to get an accurate estimate of areal nutrient loading.

Urban land uses consist of a number of sub uses, each with different features.

a. Characteristics of residential areas important to nutrient loading include: 1) housing density, 2) grass and vegetation coverage; 3) fertilizer applications, and 4) pet density, type (dogs, cats), etc. These characteristics are important because grass and housing density affect the infiltration/runoff ratio, while fertilizers and pets deposit nutrients in the watershed. Decreases in grass cover and increases in the other three increase nutrient export.

b. Public parks or park-like settings (campuses, research parks, etc.) have more vegetation (lawns, trees, ponds, etc.) than do commercial districts. Therefore, they can produce less runoff and nutrient export than do commercial districts.

c. Commercial/business/industrial areas have considerable street/pedestrian traffic. Thus there is more dust suspension, more contaminants from auto and industrial emissions, and more imprevious surfaces than in residential areas. Therefore, higher nutrient storm runoff often results.

6. Atmosphere

Atmospheric inputs consist of two major components: 1) wind transported material, commonly called dustfall, removed from the air by sedimentation or impaction; and 2) soluble gases or salts which are scavenged by rainfall. It is important when determining the magnitude of atmospheric loads to consider both of these components. Estimates for the dryfall portion alone may be as high as 70 - 90% of the total load (Heany and Sullivan, 1971, Likens and Loucks, 1978; Swank and Henderson, 1976, Miklas et al., 1977). In addition, the size of the dryfall fraction is generally considered to be independent of the amount of wetfall precipitation (Swank and Henderson, 1976; Delumyea and Petel, 1977; Eisenreich et al., 1977).

The sources of air-borne nutrients are not necessarily limited by the actual watershed boundary. That is, a lake's atmospheric input can be a result of cultural practices occurring in neighboring watersheds. However, the impact of atmospheric sources diminishes with distance.

a. In agricultural areas, increases in nutrient loads transported via the atmosphere can be attributed to agrarian activities and associated soil disturbances. These include:

   i. ammonia volatilization from feedlots and fertilizers,

   ii. wind erosion of fertilized soils.

   In addition, peak inputs of nutrients from the atmosphere tend to occur in late spring and early fall, in a pattern that roughly corresponds to fertilization and tilling periods (Andren et al., 1977; Delumyea and Petel, 1977; Eisenreich et al., 1977; Miklas et al., 1977; Hoeft et al., 1972).

b. Urban atmospheric inputs of nutrients can also be higher than those from forests. These increases can be attributed primarily to combustion emissions, since:

   i. Aviation and automotive fuels are known to contain organophosphorus additives to reduce corrosion (Simpson and Hemens, 1979).,

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

   iii. Automotive emissions are believed to be the major source of NO_x, (Robinson and Robins, 1970), and

   iv. 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).

7. Septic Tanks and Soil Adsorption Fields

a. On-site septic tank-tile filed systems are another "non-point" source that must be considered because these systems are not always effective in trapping nutrients and preventing them from entering a waterway via groundwater transport. Three major waste fractions typically compose the septic tank receiving water. These are: 1) garbage disposal wastes; 2) toilet wastes, referred to collectively as black water; and 3) sink, basin and appliance wastewater collectively referred to as gray water (Siegrist et al., 1976, Bennett and Linstedt, 1975, Ligman et al., 1974; Olsson et al., 1968; Wallman and Cohen, 1974; Laak, 1975, Siegrist, 1977). Each waste fraction contributes comparable amounts of nutrients.

i. Phosphorus in septic tank effluent originates from two main sources, human excreta and phosphate detergents.

ii. Major sources of nitrogen (up to 80%) are feces and urine, with the predominant forms occurring as NH_4 and organic-N.

b. The mass loading of each nutrient to the septic system may depend on a number of considerations, and per capita-year loading coefficients presented in Table 14 should be chosen accordingly. These considerations include:

i. Fraction of the year that the system is in use and the number of people using this form of waste disposal (i.e., summer cottage or year-round dwelling).

ii. Amount of detergent used and the detergent phosphorus content. Phosphorus detergent bans will substantially reduce the total load since gray water phosphorus loads are high. Sawyer (1965) estimated that detergent - based phosphorus accounts for approximately 50 - 75% of the total phosphorus in domestic wastewater.

iii. Use of waste flow reduction methods. Siegrist (1977) estimates that several devices and systems such as low volume flush toilets, no-water toilets, wastewater recycle for toilet flushing, and suds-saver clotheswashers should produce waste flow reductions of up to 35%. This could significantly lower the concentration and/or pollutant mass in the household wastewater stream.

c. The estimated nutrient loading from septic systems to lakes will depend upon the location of the system with respect to the surface water body. The hypothesized "impacting zone" should include those systems within the watershed that contribute nutrients directly to a lake. For example, Rodiek (1979) developed a phosphorus budget for Lobdell Lake in Michigan and chose to use a 100 meter wide impact zone around the lake. Tributaries to the lake should also be included if certain conditions exist. These conditions include population distribution and other factors related to soil retention such as:

i. Phosphorus adsorption capacity: Relative phosphorus adsorption categories have been proposed by Schneider and Erickson (1972) and are outlined below:

Rate classes	Kilograms of phosphorus per hectare in top .9 meters
Very low	Less than 1120 Kg per hectare
Low	1120 to 1460 Kg per hectare
Medium	1460 to 1800 Kg per hectare
High	1800 to 2240 Kg per hectare
Very high	Over 2240 Kg per hectare

The percentage of phosphorus adsorbed is highly dependent on soil type and pH. Tofflemire and Chen (1977) proposed a procedure for the evaluation of soil retention of phosphorus. They examined several New York soils and found that, as a rule, for phosphorus removal, acid soils are better than calcareous, tills are better than outwashes, and clay soils are better than sandy soils.

ii. Soil drainage: Natural soil drainage is generally related to the depth of the water table. For septic system suitability, it is essential that a zone of aeration exist between the septic tile field and the water table at all times of the year. This zone functions as a chemical and physical filter for phosphorus (Ellis and Childs, 1973). For nutrient retention, well-drained to moderately well-drained soils are preferable because these conditions tend to lower the risk of nutrient contamination of groundwater. In other words, the greater the distance between the septic-tile field and the water table, the greater the likelihood that phosphorus will be immobilized and not transported to a surface water body via groundwater.

iii. Soil permeability: Permeability is the rate at which water is transmitted through saturated soil. This transmission rate is generally a function of soil texture and structure (i.e., the proportion of sand, silt and clay). High rates of water transmission are usually indicative of sandy soils, while low rates are usually associated with clay soils, soils possessing a clay lens, or an impervious layer at or near the ground surface. Relative classes of soil permeability can be used to describe conditions of water transmission. Schneider and Erickson (1972) propose the following classes of soil permeability.

Rate classes	Permeability rate in centimeters per hour
Very slow	< .50
Slow	.50 - 2.00
Moderate	2.00 - 6.40
Rapid	6.40 - 25.40
Very rapid	> 25.40

Soils having a moderate rate of permeability are optimal in terms of septic system operation since these rates are slow enough for phosphorus adsorption reactions to occur, yet fast enough to avoid system "back-up" that results in standing effluent.

iv. Groundwater movement: In addition to the above three factors, both direction and flow rate for groundwater must be considered. The presence of clay lenses or bedrock can substantially reduce groundwater flows to a lake, and in some situations flow can be redirected from the lake altogether (to subterranean reservoirs or to another watershed).

v. Slope: Steep slopes and low permeability rates may cause erosion problems and perhaps convert the septic tank effluent to overland runoff. In soils of good drainage and high permeability, gravitational forces hasten groundwater flow (and nutrient transport to surface water bodies).

vi. System age: Soils have only a finite capacity for phosphorus adsorption. Old systems may provide less soil retention of phosphorus than do new systems.

vii. Plant uptake: The presence of a "green strip" of vegetation consisting of shrubs, bushes, trees, etc., between the septic tank-tile field and the waterbody can effectively reduce the amount of phosphorus entering a lake. This will depend, in part, on vegetation type and density.

viii. Season: High rainfall seasons, such as spring or late summer, keep the soil saturated, thereby decreasing soil phosphorus adsorption capacity.

ix. Other: Factors such as frequency of cleaning (of both septic tank and drainfield) and the effluent-soil redox potential should also be considered.

8. Sewage Treatment Plants

Wastewater treatment plants are another phosphorus source that have been studied to some degree. As a result, data do exist for the estimation of phosphorus loads and variability. Among the issues that should be considered by the analyst attempting to use these loading coefficients (Table 15) are:

a. Type of plant: Plant type, or more appropriately, the type of treatment the plant is using, will determine to a great extent how much phosphorus will be contined in the effluent. Different treatment types provide different levels of phosphorus reduction in the waste stream. Obviously, those plants using phosphorus removal will have lower per capita phosphorus outputs than those that do not.

b. Separate or combined sewerage systems: Wastewater treatment facilities have a finite capacity to treat sewage inputs. Under normal circumstances, treatment capacity is closely related to the extent of the sewerage system. If the system is composed of both storm and sewage drains, treatment capacity if overtaxed during high rainfall events, and a portion of the combined inputs are short circuited through to the outfall. Final mass loads of phosphorus can be appreciably higher when this occurs.

c. Phosphate detergent ban: If phosphorus inputs are reduced, (i.e., through a ban on phosphate detergent additives), the final per capita mass load will also be lower. From a study of 702 wastewater treatment plants with a variety of treatments processes employed, Allum et al., (1977), estimated a median phosphorus loading of 1.0 ± 0.04 kg/capita/yr. However, for Indiana, with a full-year phosphate detergent ban, this median figure was found to be 0.5 ± 0.11 kg/capita/yr (25 plants). New York, with about a one-half year phosphate detergent ban, fell between the two with a median phosphorus discharge of 0.7 ± 0.11 kg/capita/yr (42 plants).

In concluding this section on guidelines for export coefficient selection, some comments on watershed size, proximity to the application lake, and bioavailability are in order. It should be noted that small watersheds, such as microplots (<0.5 hectares), provide less opportunity for redeposition of suspended sediment (and nutrients) than do large watersheds. Even though the "100-year" storm will scour considerable amounts of deposited nutrients from streambeds--thus 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. Studies by Meyer and Likens (1979) at Bear Brook (an undisturbed headwater stream in the Hubbard Brook Experimental Forest, New Hampshire) indicate that there was a net conversion of dissolved phosphorus and course particulate phosphorus (leaves, organic fragments, etc.) to the fine particulate fraction, which was the predominant form (62% of the total) exported downstream.

Therefore, small plots (from which many of the export coefficients presented in Chapter 3 and in the Appendix are based) are likely to yield high export values for certain situations. These values will consist of both high solution fractions and high sediment fractions. These fractions will tend to be higher than those reported for larger watersheds (several hectares in size). Thus, small watershed export coefficients are most applicable to application lake watershed sections adjacent to a surface water body (tributary streams or the lake). This means, of course, that watershed size is an important watershed matching criterion.

For large basins consisting of mixed agricultural activities, export coefficients from the tables entitled "Mixed Agriculture" should be used. Individual assignment of export coefficient according to each use may result in an overly high total loading estimate due to the small watershed bias mentioned above.

Bioavilability is another concern. In general, the more solution phosphorus converted to sediment phosphorus, the lower the bioavilable fraction. However, since the models are based on total phosphorus, bioavailability cannot be incorporated into the Chapter 2 methodology. If it is thought that an unusually large fraction of the phosphorus loading to a lake is not biologically available, then the analyst should note this and be aware of possible model prediction bias.

3.4 The Phosphorus and Nitrogen Export Coefficients

1. Summary Tables - Text To facilitate the analyst's ability to use the model and quantitative approach presented in this manual, nutrient loading coefficients from overland runoff were identified in an extensive literature search (Beaulac, 1980). While the emphasis of this report is on phosphorus management and modeling, for comparison purposes, export coefficients are also given for nitrogen. Those studies which conform to the sampling criteria discussed in earlier sections of this chapter have been aggregated by land use and are presented in tabular fashion in Tables 6 through 12. The major land uses examined are undisturbed forests, agriculture and urban.

   As previously discussed, the range of nutrient export from forest land use is relatively narrow. Climate (i.e., precipitation and runoff) and productivity appear to be the major criteria determining nutrient export variability. The analyst is therefore urged to extrapolate only those coefficients originating from climatic conditions and regions similar to the application watershed. For comparison, vegetation type, soil type, location, precipitation and runoff amount have been tabulated along with the export coefficient and reference in Table 6.

Agricultural land uses consist of a number of different perturbations, and sufficient studies exist in the literature to describe these activities. Therefore, this land use was further subdivided into row crops, non-row crops, pasture/grazing land, and manure storage/animal feedlot. The loading coefficients are presented in Tables 7 through 10 respectively. For comparison purposes, and to allow for estimation of nutrient export from highly mixed agricultural watersheds, export coefficients were compiled for general (mixed) agricultural activities in Table 11. In addition to the descriptive conditions listed in the forest export tables, fertilization rate and crop type(s) have also been included.

The coefficients describing urban land uses also exhibit a high degree of variability depending primarily on the type of urban activity (i.e., low density residential, heavy industrial) and the associated percentage of impervious surface area. Unfortunately, sufficient data do not currently exist in the literature to adequately compile summary tables for each of these activities. Therefore, the analyst is urged to pay particular attention to the accompanying descriptive criteria listed in Table 12.

2. Summary Tables - Appendix To provide the reader with a more complete record of the variability and magnitude of the chemical fractions composing both phosphorus and nitrogen (i.e., sediment phosphorus, NO_3-N), a breakdown of these chemical fractions is included in the Appendix. The tables in the Appendix include all "approved" 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 have been eliminated if the particular study was adequately described in the text tables.

3. <u>Histograms</u> 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. Accordingly, histograms describing nutrient export from the above land uses have been developed and are presented in Figures 4 through 10

From the histograms it is apparent that the cross-sectional data are highly skewed. Consequently, robust statistics such as the median and interquartile range are generally less biased as summary statistics than are the mean and standard deviation. These statistics accompany the histograms for each land use.

The histograms allow the analyst to note the cross-sectional variability resulting from different characteristics among watersheds that determine nutrient export. As an example the reader is referred to Figure 7a, representing phosphorus export from pastured and grazed watersheds. 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.

Cross-sectional variability among watersheds must be distinguished from longitudinal variability. Longitudinal, or time series, variability represents the variation in nutrient export in a single watershed over time. To illustrate longitudinal variability, phosphorus exports 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 11. Since variation in precipitation runoff is the probable key cause of longitudinal variablity, a histogram of water runoff rates was also developed and presented in Figure 12 Note the high degree of similarity between the two distributions.

4. Box Plots A 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 2).

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 include the following (Reckhow, 1980):

1. the interquartile range;
2. the sample range;
3. an indication of skew (from a comparison of the symmetry above and below the median), and
4. the size of the data set.

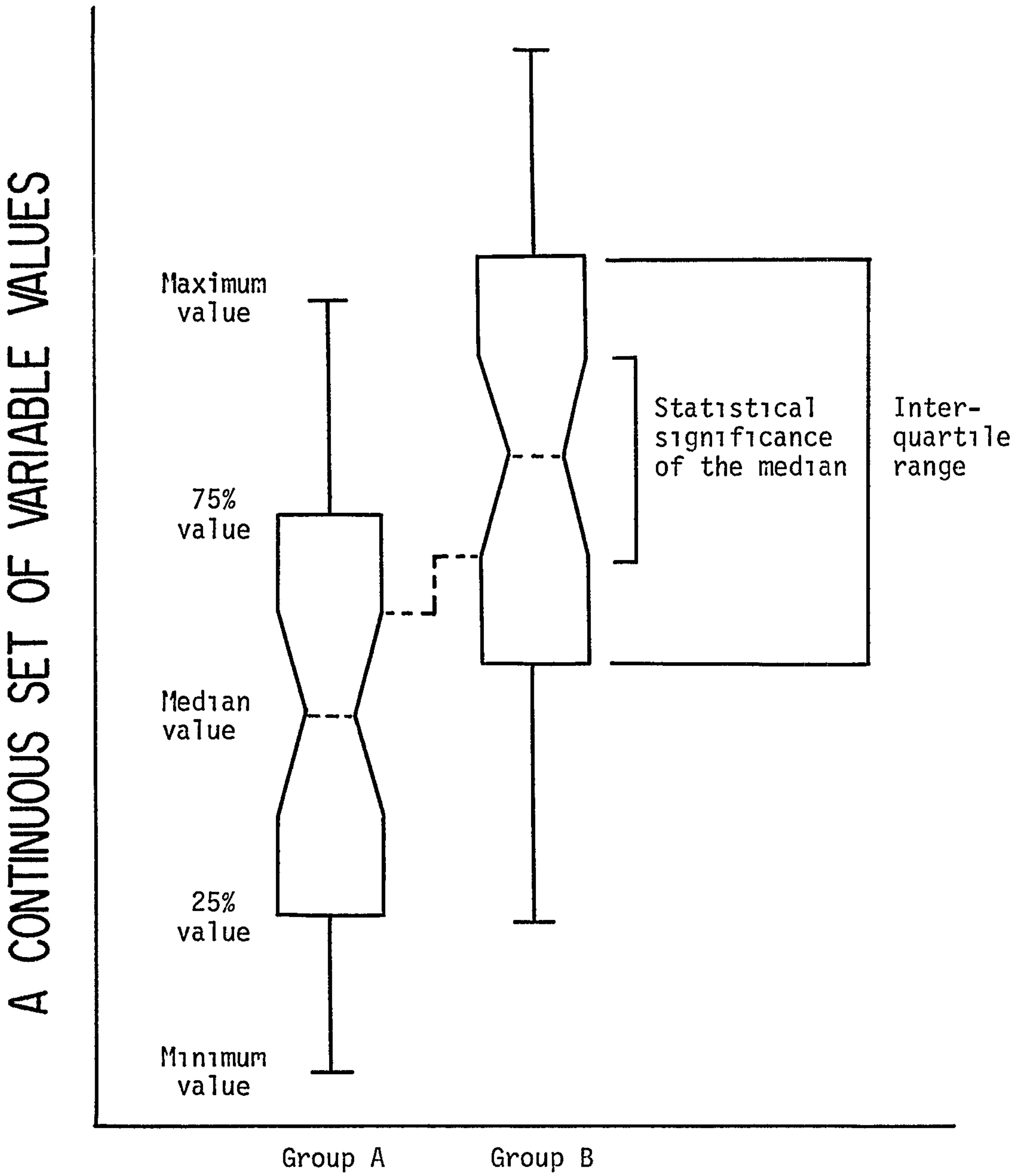


Figure 2: The Basic Configuration of a Box Plot and Comparison of Two Plots Possessing Significantly Different Medians

Note that the box plot medians for forested phosphorus and nitrogen export (Figure 3) are significantly different from those of agriculture and urban land runoff (with the exception of pasture land).

5. Other Tables In addition to the thorough examinaton of the literature on nutrient runoff from forest, agriculture, and urban land use activities, other non-point and point nutrient loading information was compiled in tabular form for this document.

   a. Atmospheric Inputs: Uttormark et al., 1974, listed at least 40 factors influencing atmospheric nutrient contributions. The bulk of these factors are related to local conditions. Therefore, a literature review was conducted to collect data relating bulk nutrient precipitation inputs to specific land uses. A major requirement for data acceptability was that the nutrient inputs be collected from one of three land uses: 1) undisturbed-forest; 2) agricultural-rural; and 3) urban-industrial. Studies dealing with regional or cross-sectional watersheds were thereby disregarded. In this respect, precipitation chemistry may more closely reflect endemic situations. These nutrient coefficients are presented in Table 13.

   b. Septic Tank Inputs: Information was collected to define a range of values for the nutrient load in household wastewater discharged into septic tanks. Since the values expressed in Table 14 are not quantified according to the number of sources contributing to the total load (i.e., percent contributed by gray water vs. black water), it is recommended that the reader examine the section dealing with septic tanks in order to justify the selection of the export coefficient.

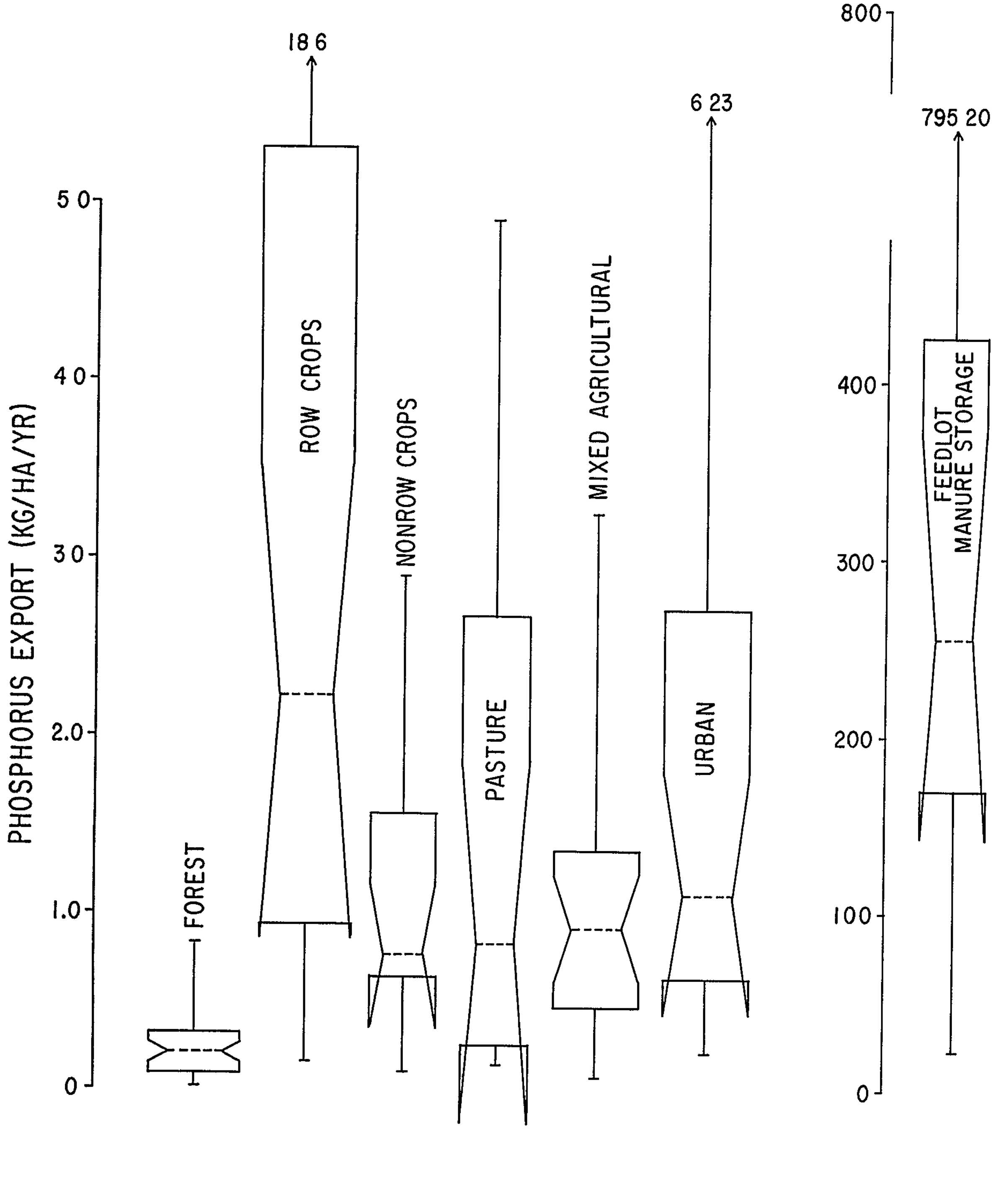


Figure 3a: Box Plots of Phosphorus Export Coeffıcıents from Varıous Land Uses.

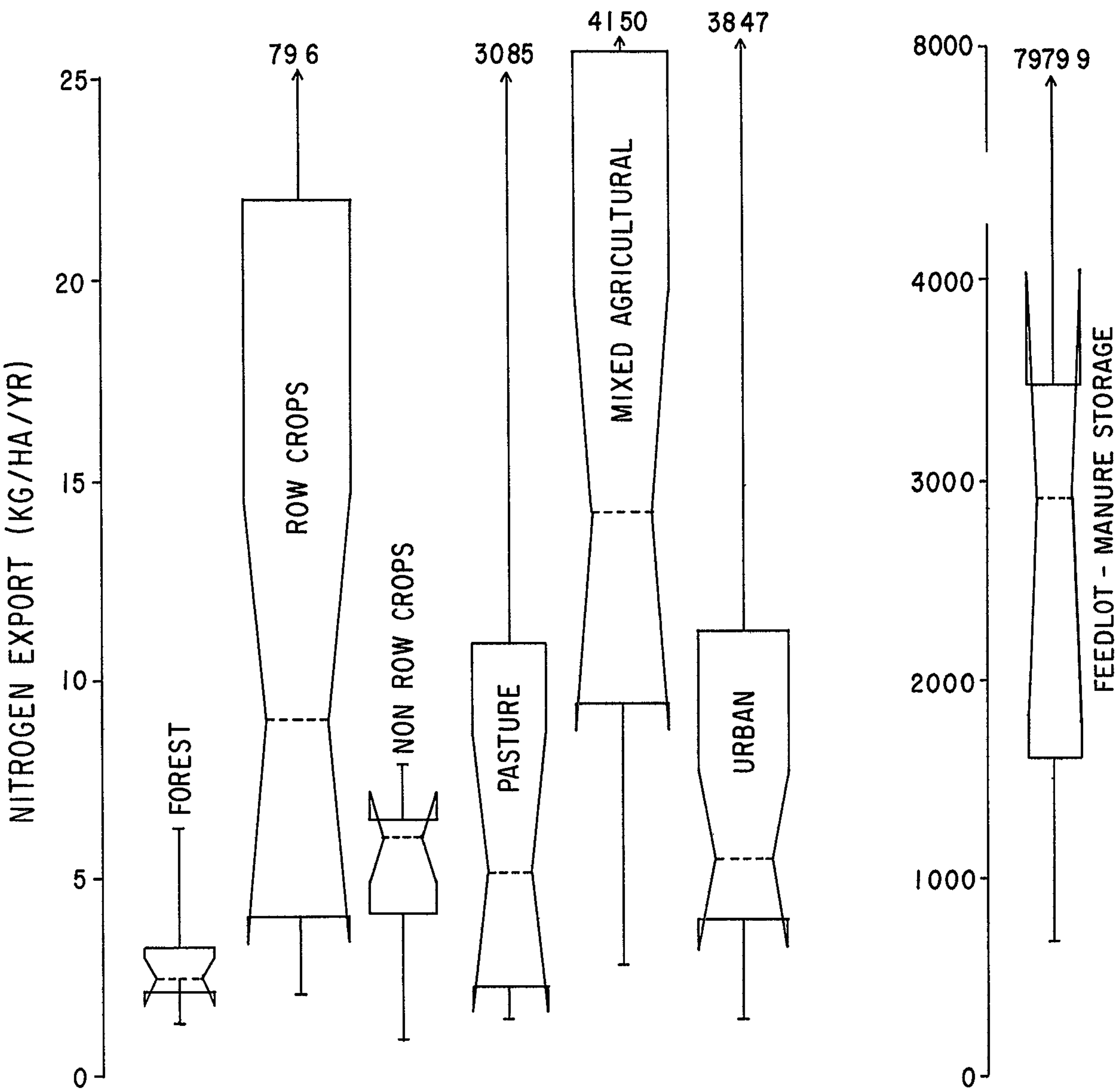


Figure 3b   Box Plots of Nitrogen Export Coefficients from Various Land Uses.

c. Sewage Treatment Plant Inputs: The data set compiled by the EPA-NES (1974) listing statewide sewage treatment plant phosphorus loads was summarized according to treatment type in Table 15. As previously discussed in earlier sections, a number of factors can increase or reduce the coefficients presented. This may be verified from an examination of the ranges given for each treatment type. It is further stressed that the analyst examine the actual conditions within the study watershed before the selection of these coefficients is made.

Table 6: 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 6: (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		136[g]	70 70[g]	3 1[g]		Henderson and Harris, 1973
Oak-hickory forest (97 5 ha)	Walker Branch Watershed, Oak Ridge, Tennessee		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 6: (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

Table 7: 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 7· (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 7: (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

Table 8. Nutrient Export from Non Row Corps

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 laom	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 8: (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

Table 9: 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, blue-grass cover (1.88 ha)	37	16	8	Waynevilte, 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, blue-grass 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 rota-tional, 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 85	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 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
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 (1' 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

Table 10: 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 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
Solid manure storage agea (05 ha)	Elmira, Ontario, Canada	2/3 paves 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	539 9	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

Table 11 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 11: (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 11 (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 11: (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

Table 12. 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 12: (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 12· (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	249 0	48 3		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

TABLE 13a: Forest Atmospheric Inputs

LOCATION	PHOSPHORUS (kg/ha/yr) Dissolved-P	Total-P	NITROGEN (kg/ha/yr) NO_3-N	NH_3-N	Organic-N	Total-N	REFERENCE
Rawson Lake, Ontario, Canada		327				6 27	Schindler et al., 1976
Clear Lake, Ontario, Canada		26	——7 153——				Schindler et al , 1970
White Mountains, New Hampshire			6 0	2 8			Martin, 1979
Hubbard Brook Exp Forest New Hampshire	035		4 3	2 24			Likens et al , 1977
Walker Branch Watershed Tennessee		54	3 9	2 0		8 7	Henderson, 1977
Coweeta Experimental Watershed, N Carolina		19	2 88	52			Swank & Henderson, 1976
North Carolina		21	——5 54——				Wells & Jorgensen, 1975
Duke Forest, N Carolina		28	1 46	74	1 33	3 53	Wells et al , 1972
N East, Minnesota		14					Wright, 1976
H J Andrews Exp Forest, Western, Oregon		27	135	85		99	Fredriksen, 1972
N Central, Minnesota		48	2 25	2 74	2 32	7 32	Verry & Timmons, 1977
Mississippi		3				11 3	Switzer & Nelson, 1972
Northern Mississippi		07	3 12	5 73			Schreiber et al , 1976
Northern Mississippi		41					Duffy et al, 1978
New Mexico			2 64	1 74	2 39	6 77	Gosz, 1978
Sapelo Is , Georgia			1 255	95	633	2 84*	Haines et al , 1976
Watersmeet, Michigan		19					Eisenreich et al , 1977
Beaver Island, Mich	036	216					Eisenreich et al , 1977
Beaver Island, Mich	032						Murphy & Doskey, 1976
Rock Island St Pk , Wis	039						Murphy & Doskey, 1976
Finger Lakes Area, NY		181	5.37	3 37			Likens, 1972

*wetfall only

TABLE 13b· Agricultural-Rural Atmospheric Inputs

LOCATION	PHOSPHORUS (kg/ha/yr)		NITROGEN (kg/ha/yr)				REFERENCE
	Dissolved-P	Total-P	NO_3-N	NH_3-N	Organic-N	Total-N	
Treynor, Iowa			——7 26——				Schuman & Burwell, 1974
Rhode River Watershed Edgewater, Maryland		82	4 71		5 66	10 49	Miklas et al , 1977
Coshocton, Ohio		.20	——8 8——				Chichester et al , 1979
Morris, Minnesota		125	2 45	5 09			Burwell et al , 1975
Southern Ontario, Canada		97				38 0	Sanderson, 1977
Pellston, Michigan	.20	25	4 85	3 09			Richardson & Merva, 1976
Houghton Lake, Michigan	29	31	3 21	2.09			Richardson & Merva, 1976
Silver Lake St Pk , Michigan	086						Murphy et al , 1976
Wisconsin			3 51	12 22	14 43	30 16	Hoeft et al , 1972
Wisconsin			2 73	2 86	6 54	13 13	Hoeft et al , 1972
Great Britain		74				13 1	Frissel 1978
Eatonton, Georgia		192					Krebs & Golley, 1977

TABLE 13c: Urban-Industrial Atmospheric Inputs

LOCATION	PHOSPHORUS (kg/ha/yr)		NITROGEN (kg/ha/yr)				REFERENCE
	Dissolved-P	Total-P	NO_3-N	NH_3-N	Organic-N	Total-N	
Washington, D C		2 58**				9.09**	Randall et al , 1978
Knoxville, Tennessee	2 17	3 67	4.4	3.4	24 8	24.8	Betson et al , 1978
San Francisco, Cal.		26	23	76			McDoll et al , 1978
Wisconsin			3 73	3.61	6 19	13 53	Hoeft et al , 1972
Madison, Wisconsin		99				24 0	Likens & Loucks, 1978
Madison, Wisconsin		1 02				23 0	Kluesener, 1972
Milwaukee, Wisc		.372					Eisenreich et al , 1977
Grand Haven, Mich		415					Eisenreich et al , 1977
Saginaw Bay, Mich	1 12	1 21	4 73				Richardson et al , 1976
Chicago, Illinois	327						Murphy et al , 1976
Chicago, Illinois	084	558					Eisenreich et al , 1977
Halifax, Nova Scotia		.56	1 21				Hart & Ogden, 1977
Durban, South Africa	27	.52	3 95	4 22	14 74	22 91	Simpson & Hemens, 1979
Munich, Germany		80	8 26	3 6			Goettle, 1978
Hamburg, Germany		2 0	3 3	20.2		23 5	Frissel, 1978
Stockholm, Sweden		1 6	8	2 1		7 4	Frissel, 1978
London, England		2 1	2 5	17 3		19 8	Frissel, 1978
Paris, France		1 6	2 3	14 8		17 1	Frissel, 1978

**dustfall only

Table 14: Nutrient Loads for Household Wastewater Discharged into Septic Tanks. (kg/capita/yr).

Total P	Total N	Reference
1.49	6.45	Ligman et al, 1974
1.43	5.99	Laak, 1975
	2.65	Bennet and Linstedt, 1975
.74	4.61	Chan et al, 1978
1.59		Ellis and Childs, 1973
1.49	2.15	Siegrist et al, 1976
3.00		Bernhard, 1975
.80		Otis et al, 1975
	8.20	Walker et al, 1973
1.28	3.20	EPA-NES, 1974

Table 15: Magnitude and Variability for Phosphorus Loading from Waste Water Treatment Plant Effluent*

Treatment Type	Median Loading (kg/capita/yr)	Range (kg/capita/yr)	Sample Size
Activated Sludge	.89	.32 - 4.99	183
Trickling Filter	1.10	.39 - 5.44	158
Phosphorus Removal	.57	.23 - 1.81	16
Primary Settling and Digestion	.82	.27 - 3.18	53
Oxidation Pond	1.07	.36 - 3.63	52
Sand Filter	2.86	.77 - 6.11	11

*Ten to fourteen samples taken per year. Adapted from EPA-NES Working Paper Number 22 (U.S.E.P.A., 1974)

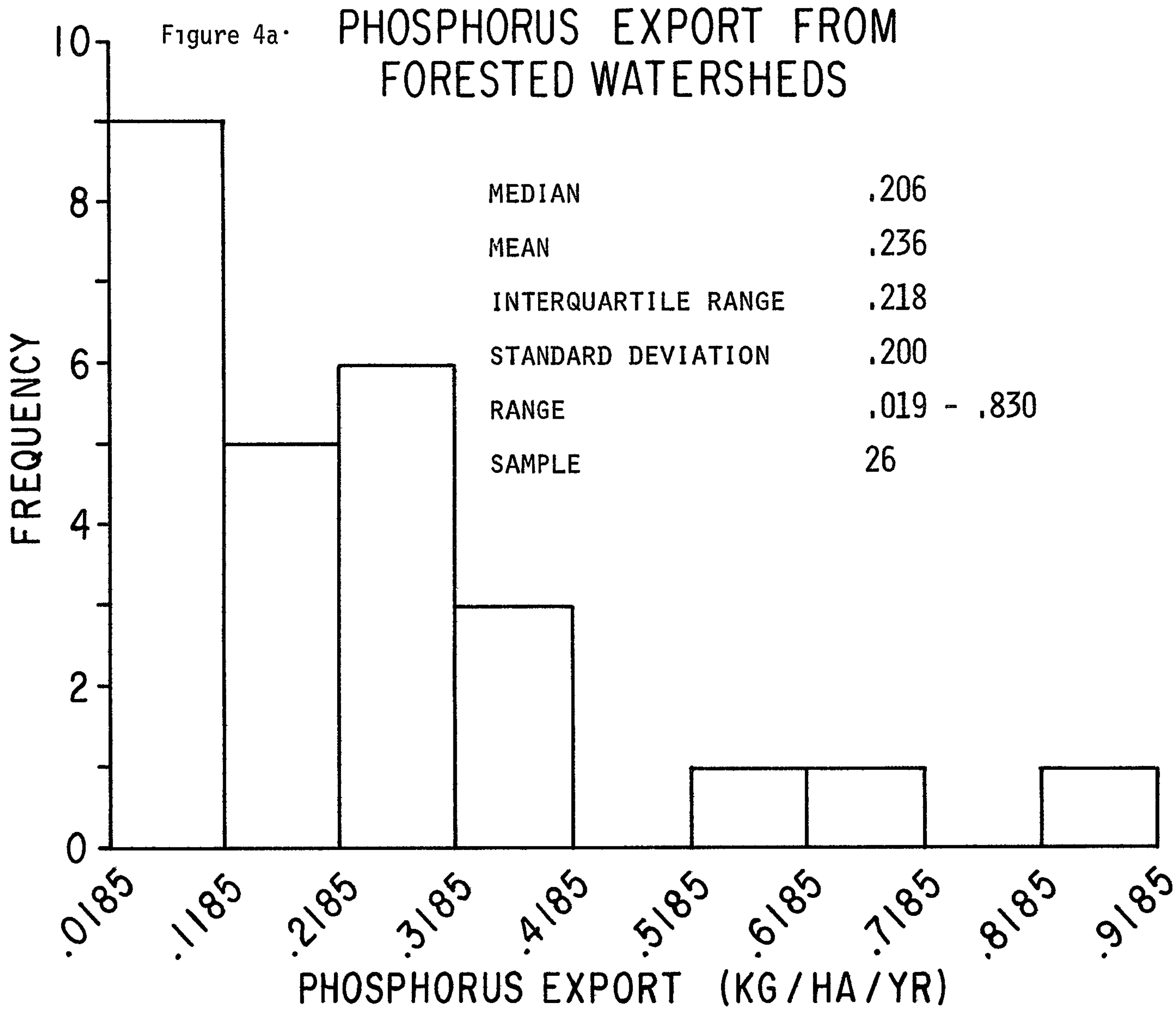


Figure 4a: PHOSPHORUS EXPORT FROM FORESTED WATERSHEDS

Figure 4b: NITROGEN EXPORT FROM FORESTED LAND USE

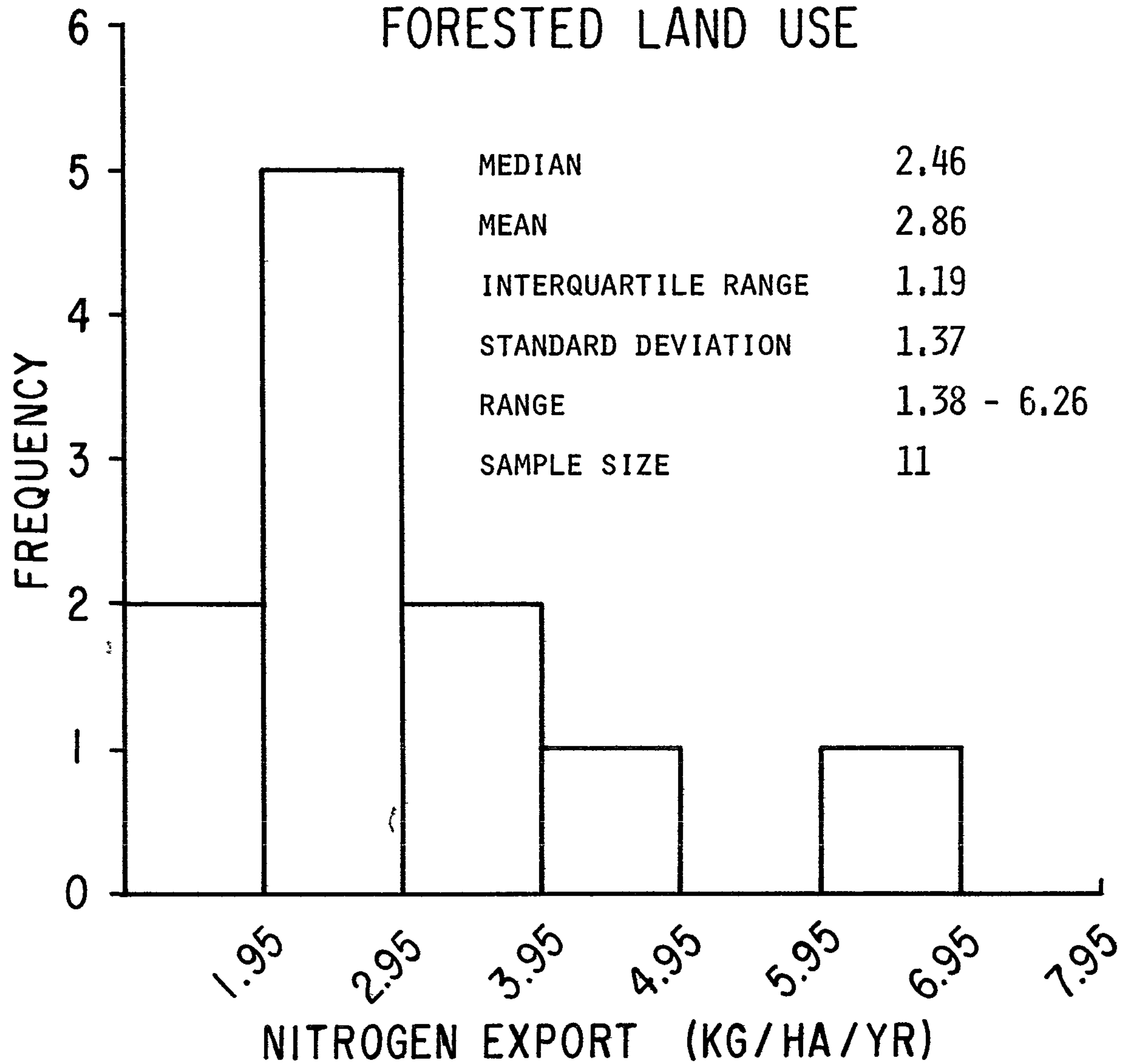


Figure 5a: PHOSPHORUS EXPORT FROM ROW CROPS

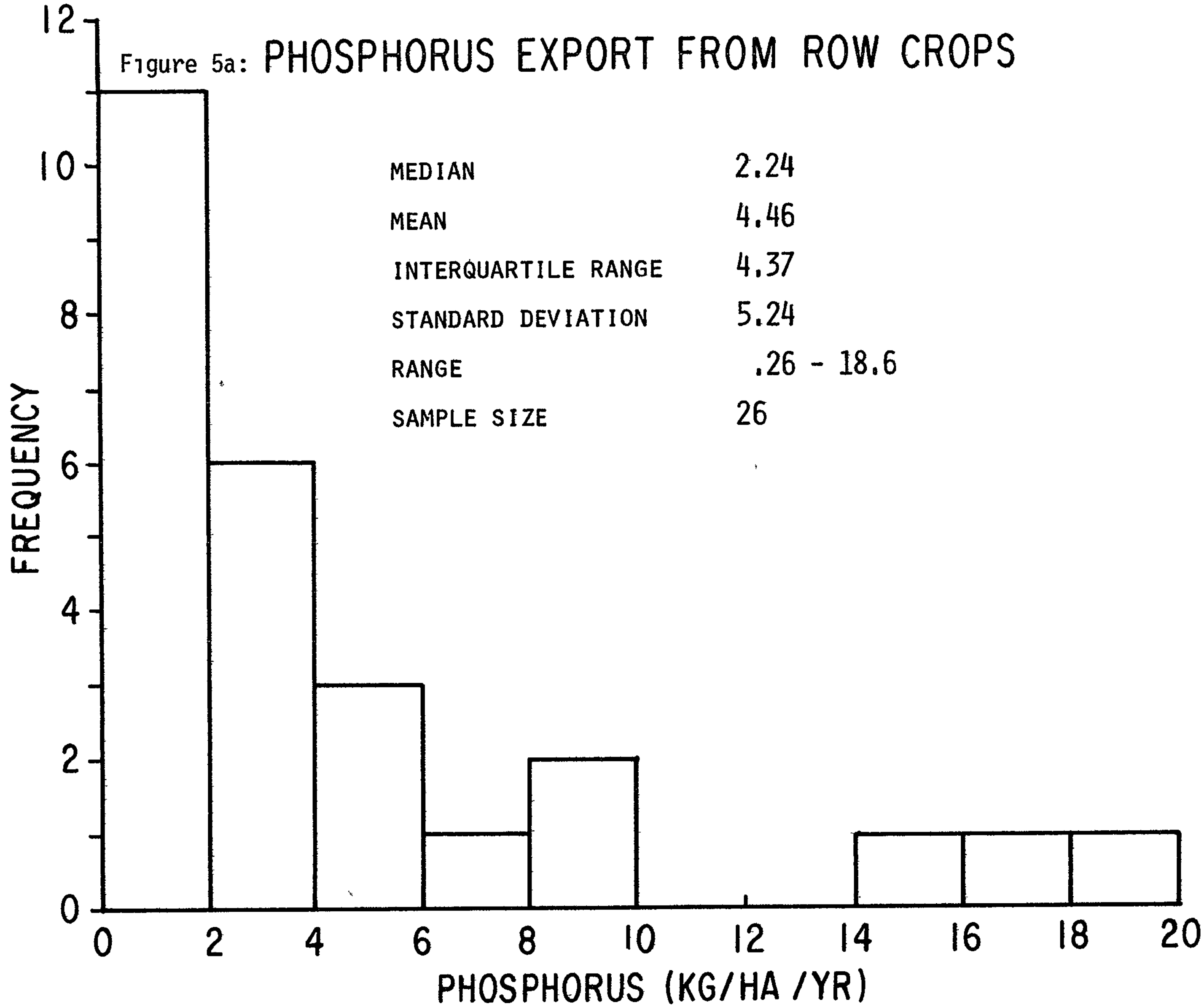


Figure 5b: NITROGEN EXPORT FROM ROW CROPS

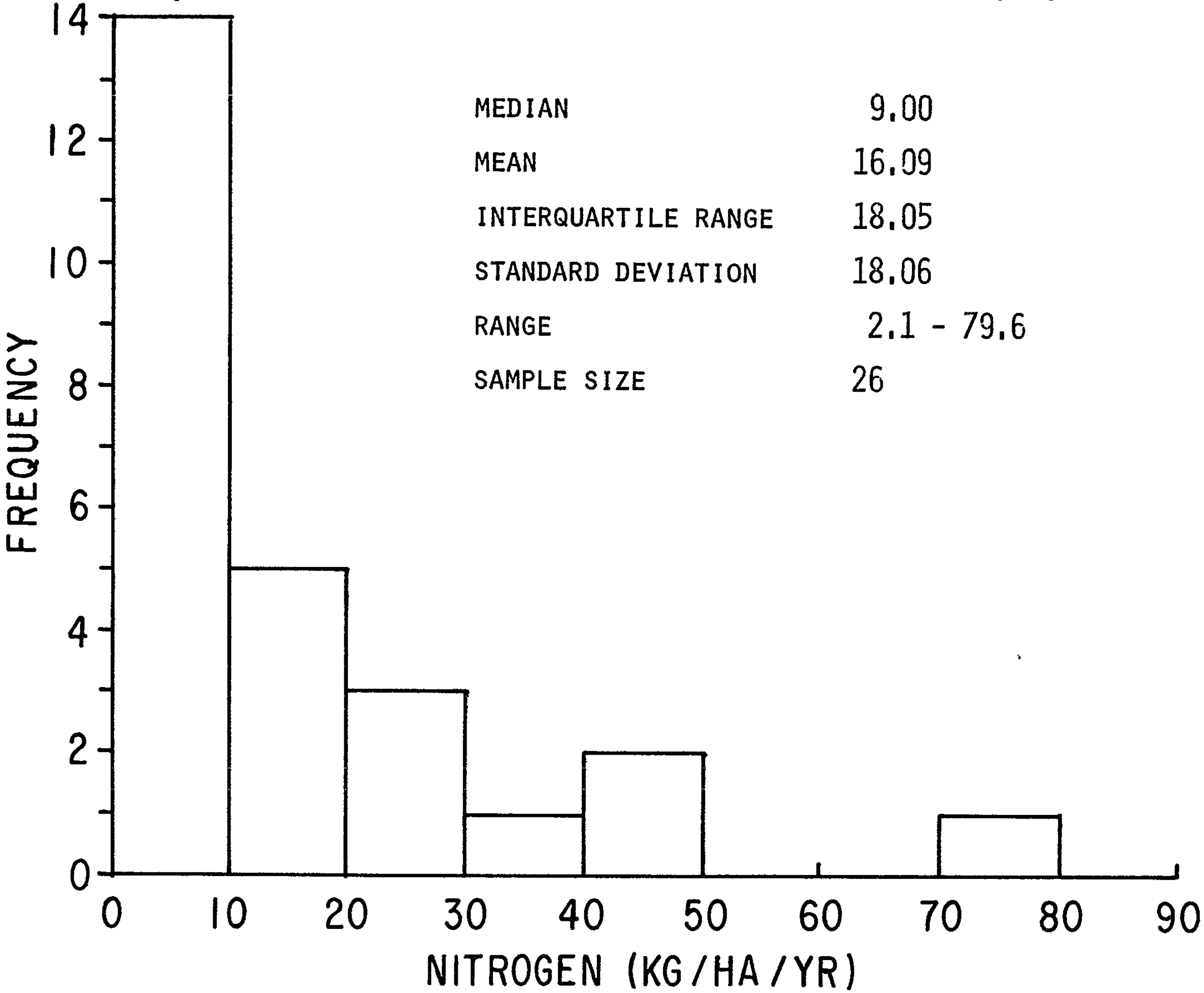


Figure 6a: PHOSPHORUS EXPORT FROM NONROW CROPS

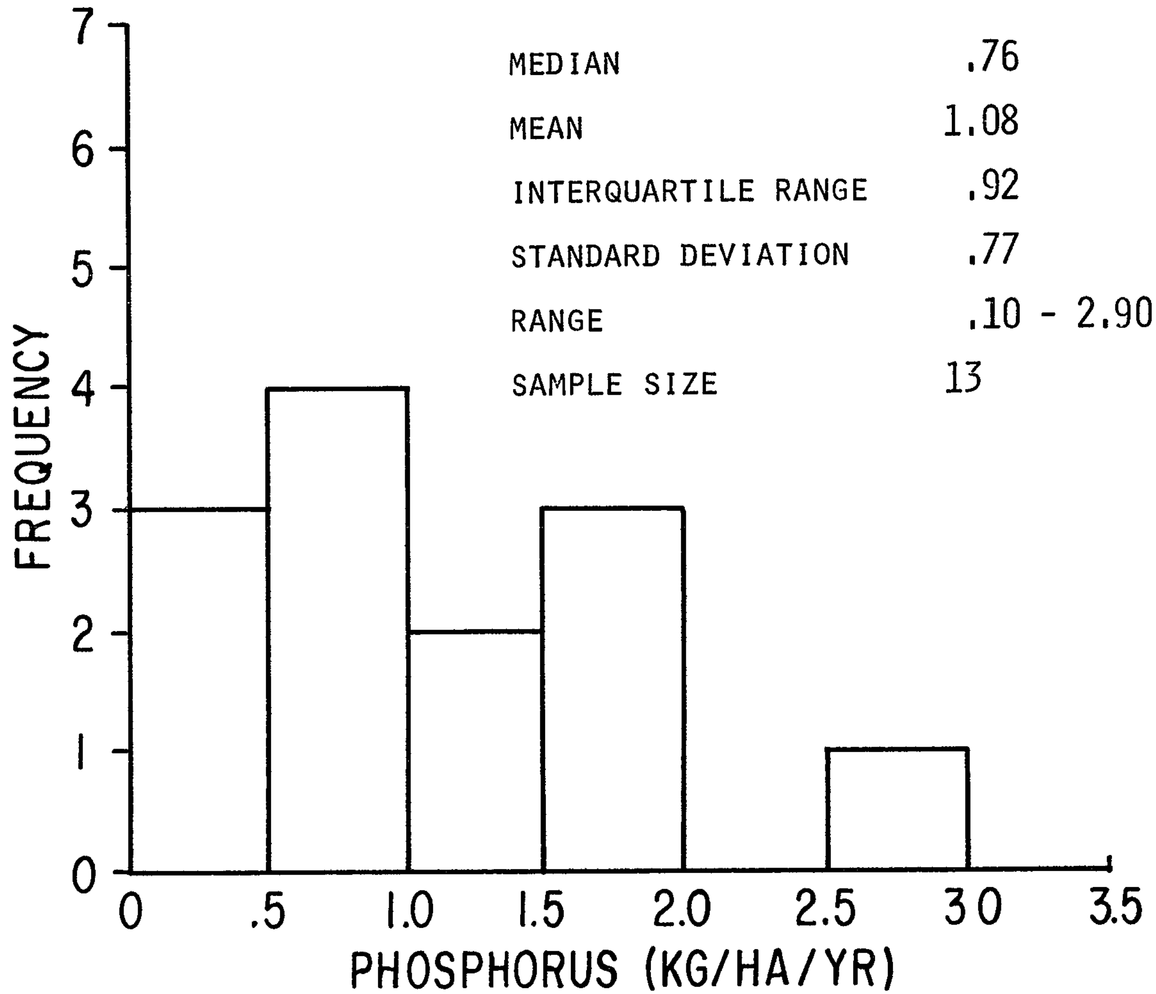
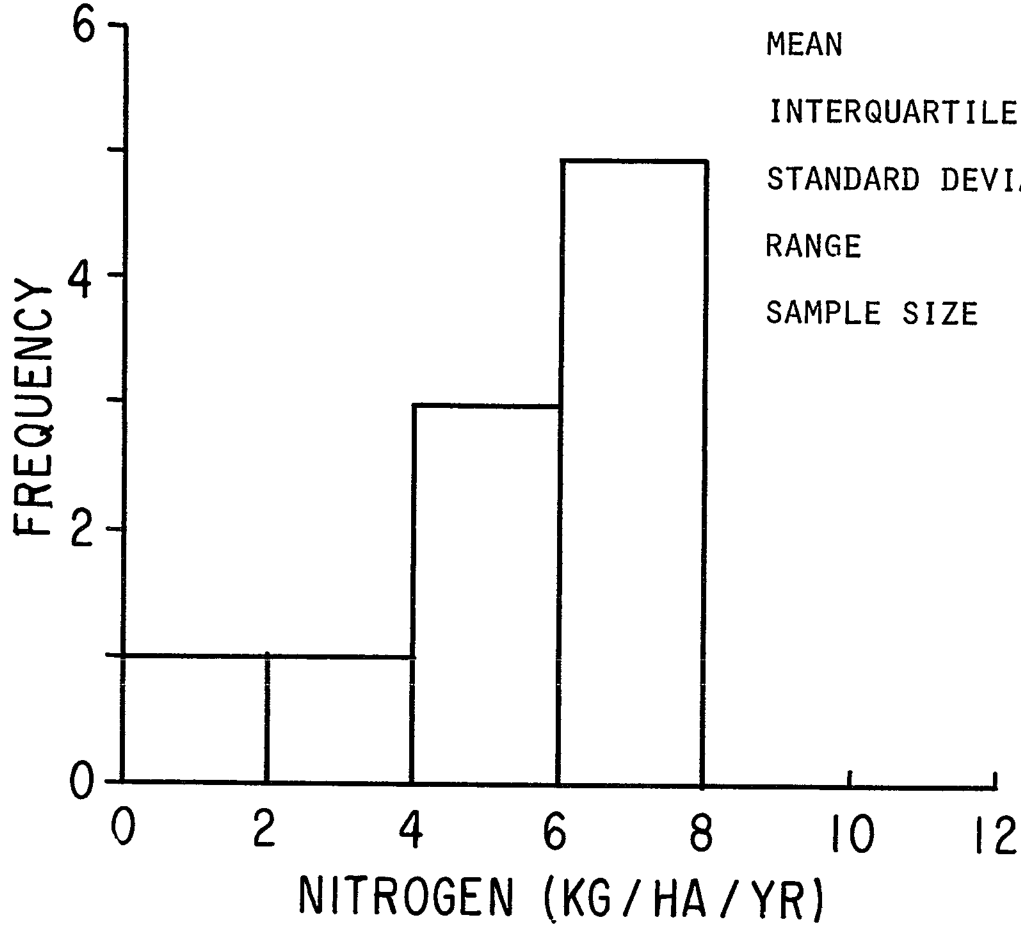


Figure 6b: NITROGEN EXPORT FROM NONROW CROPS



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

Figure 7a. PHOSPHORUS EXPORT FROM GRAZED AND PASTURED WATERSHEDS

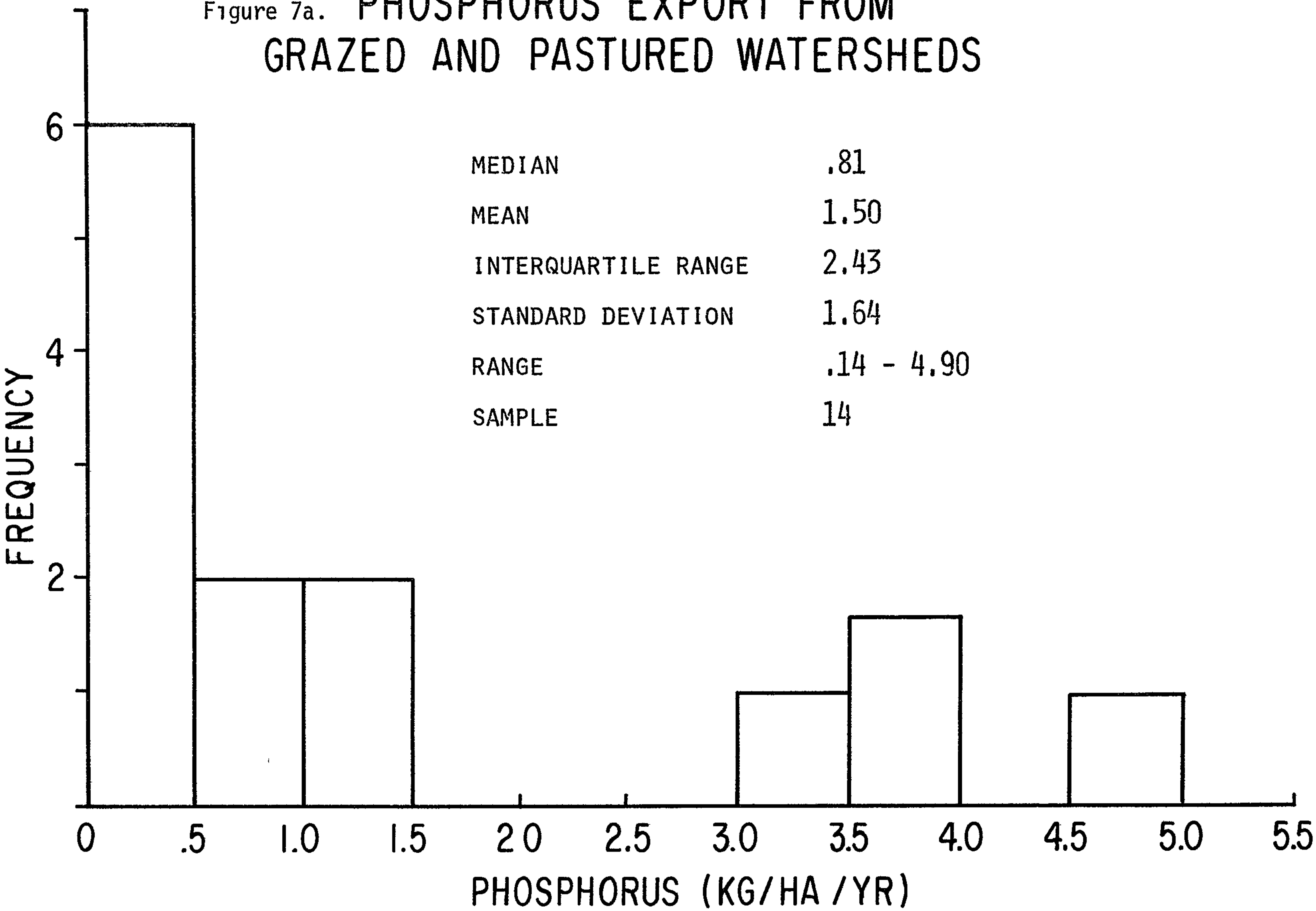


Figure 7b: NITROGEN EXPORT FROM GRAZED AND PASTURED WATERSHEDS

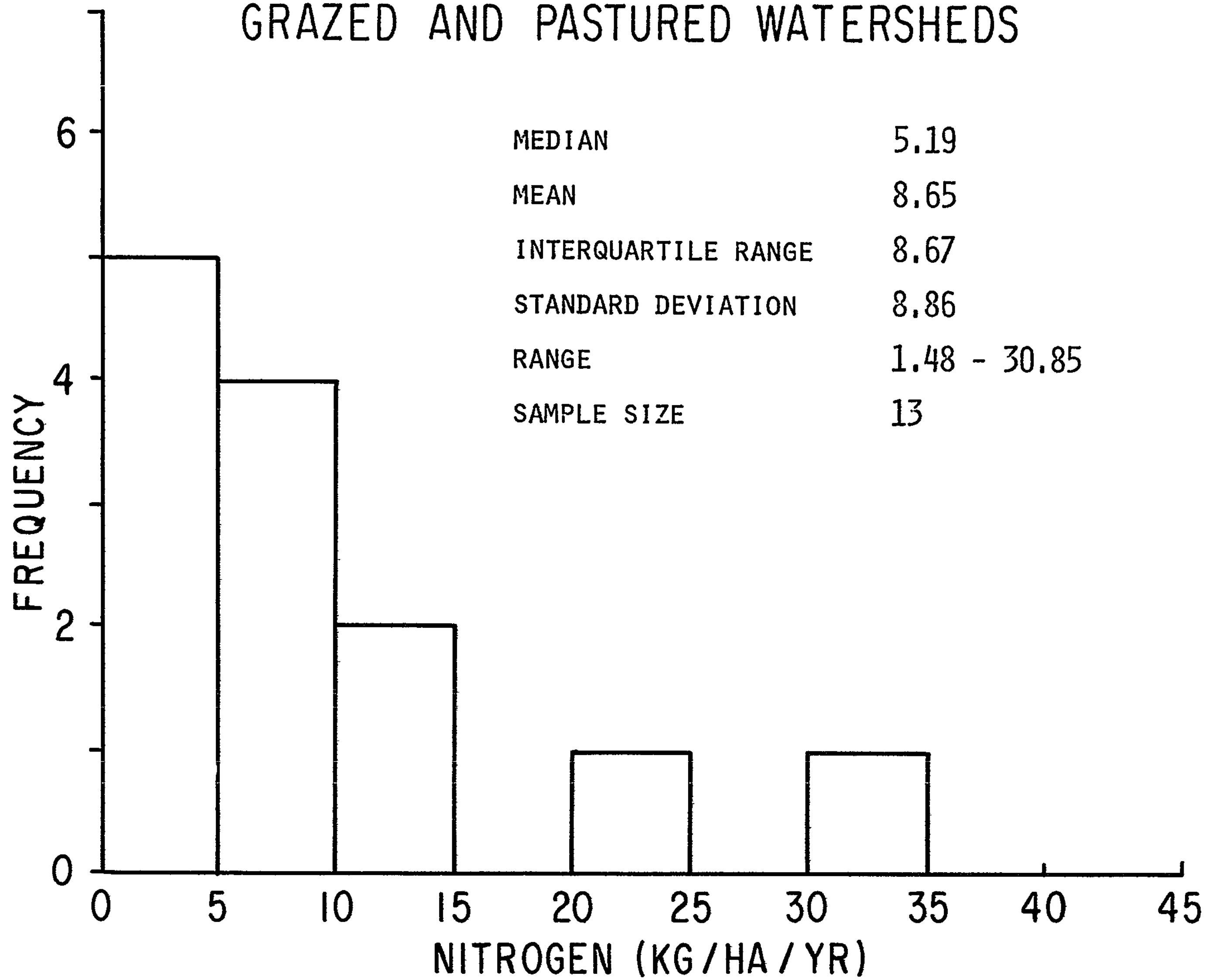


Figure 8a: PHOSPHORUS EXPORT FROM ANIMAL FEEDLOT AND MANURE STORAGE

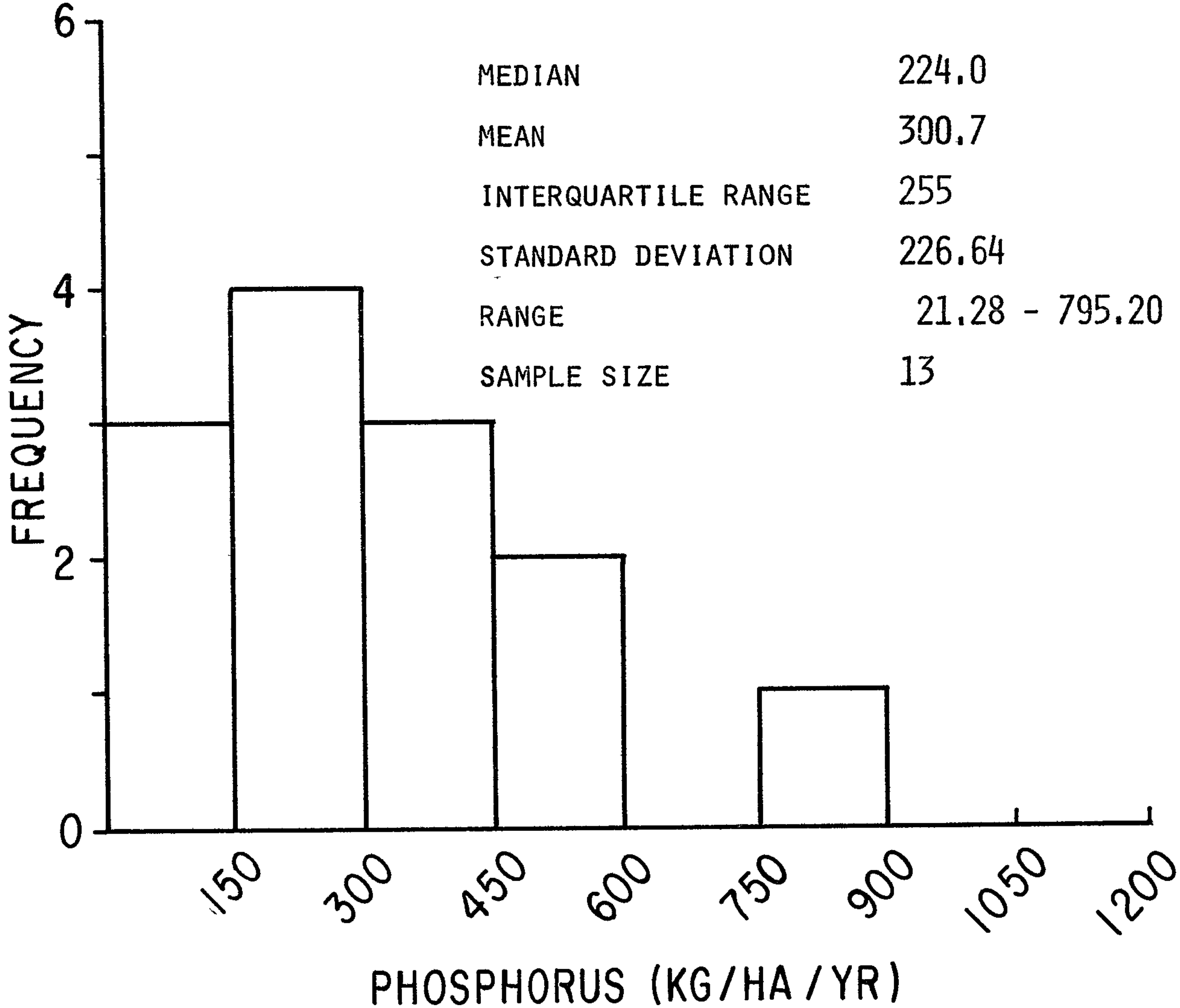


Figure 8b: NITROGEN EXPORT FROM ANIMAL FEEDLOT AND MANURE STORAGE

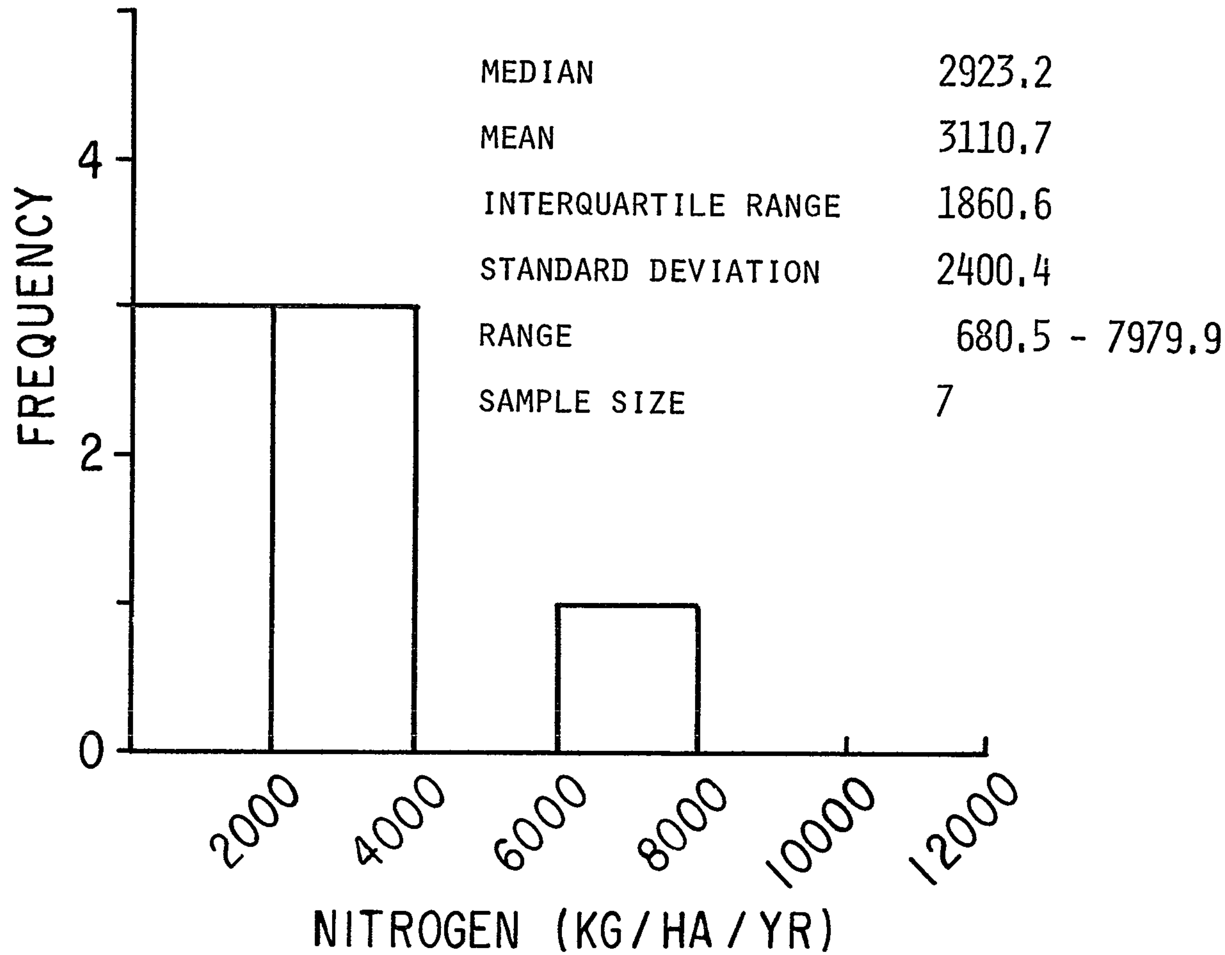


Figure 9a: PHOSPHORUS EXPORT FROM MIXED AGRICULTURAL WATERSHEDS

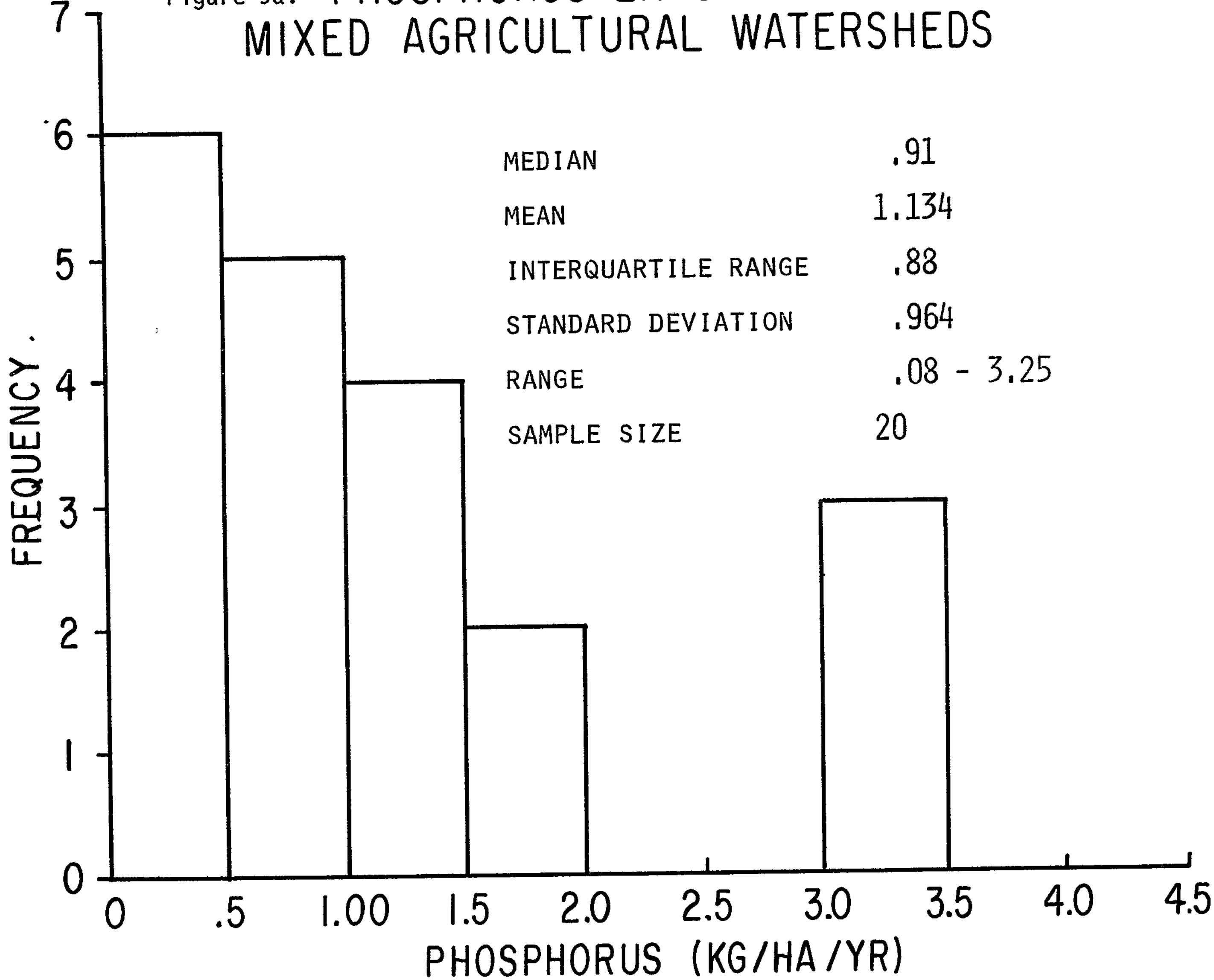


Figure 9b: NITROGEN EXPORT FROM MIXED AGRICULTURAL WATERSHEDS

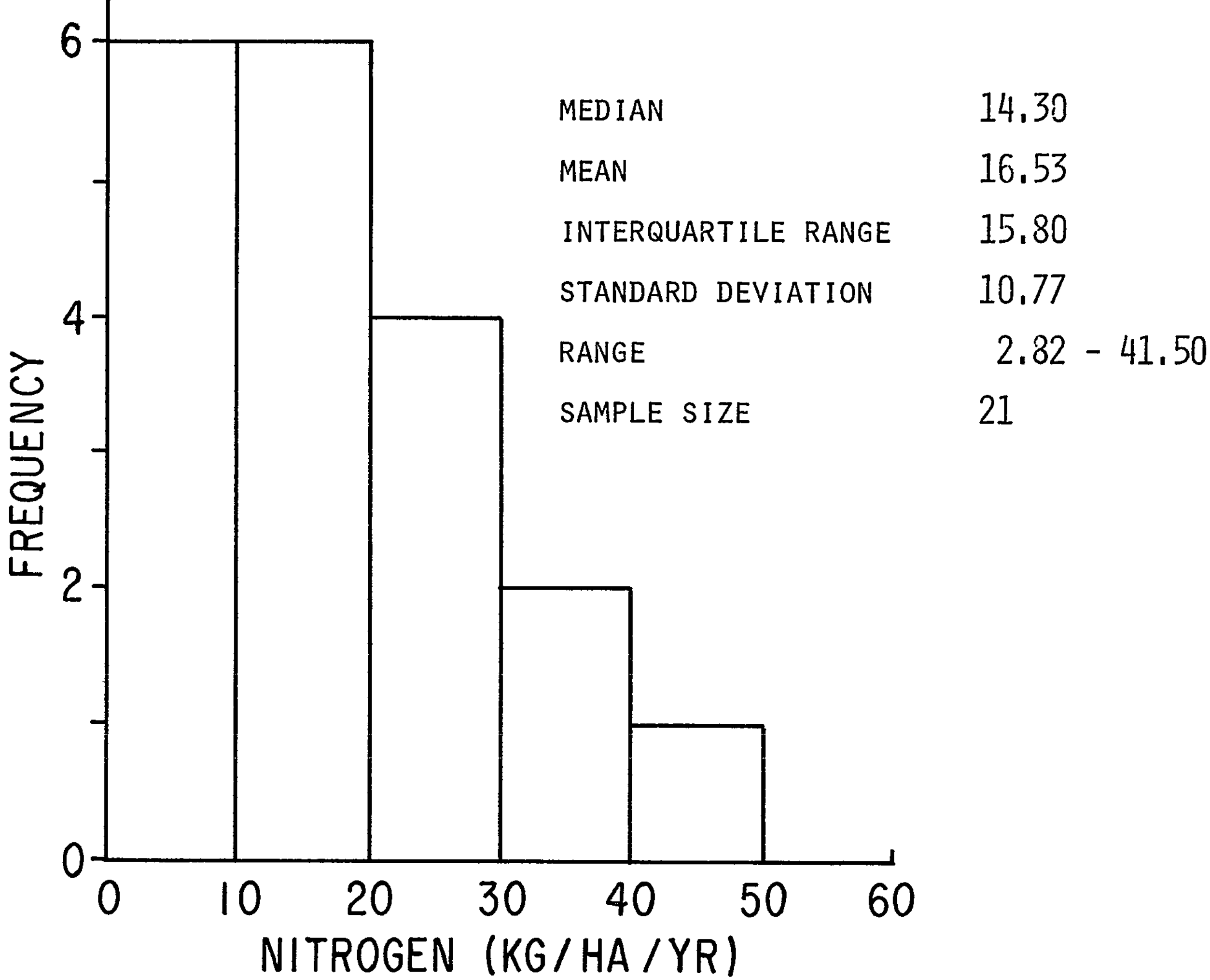
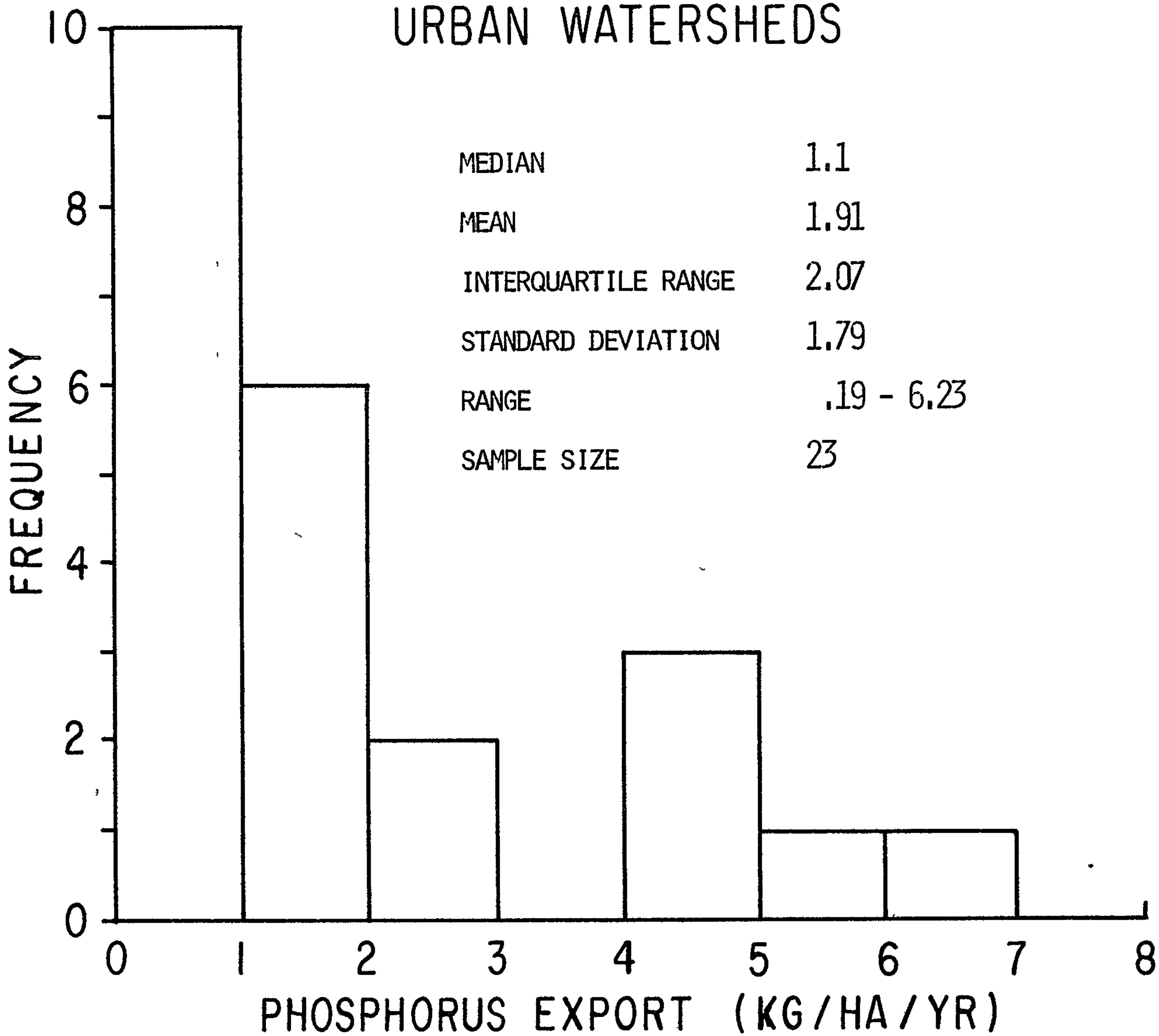


Figure 10a· PHOSPHORUS EXPORT FROM URBAN WATERSHEDS



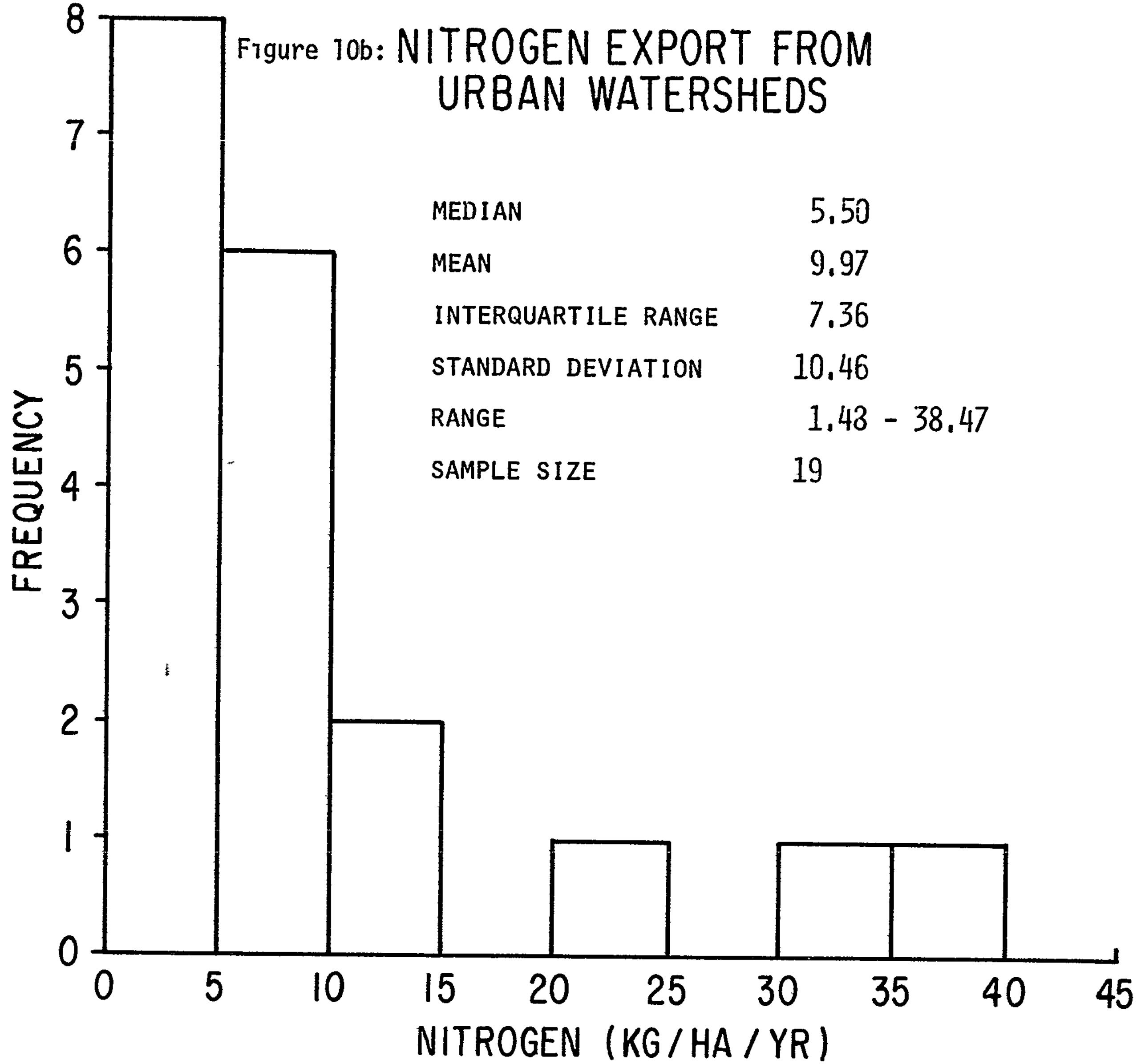


Figure 10b: NITROGEN EXPORT FROM URBAN WATERSHEDS

Figure 11· TOTAL PHOSPHORUS EXPORT FROM TWO CORN CROPPED WATERSHEDS ILLUSTRATING VARIABILITY OVER TIME

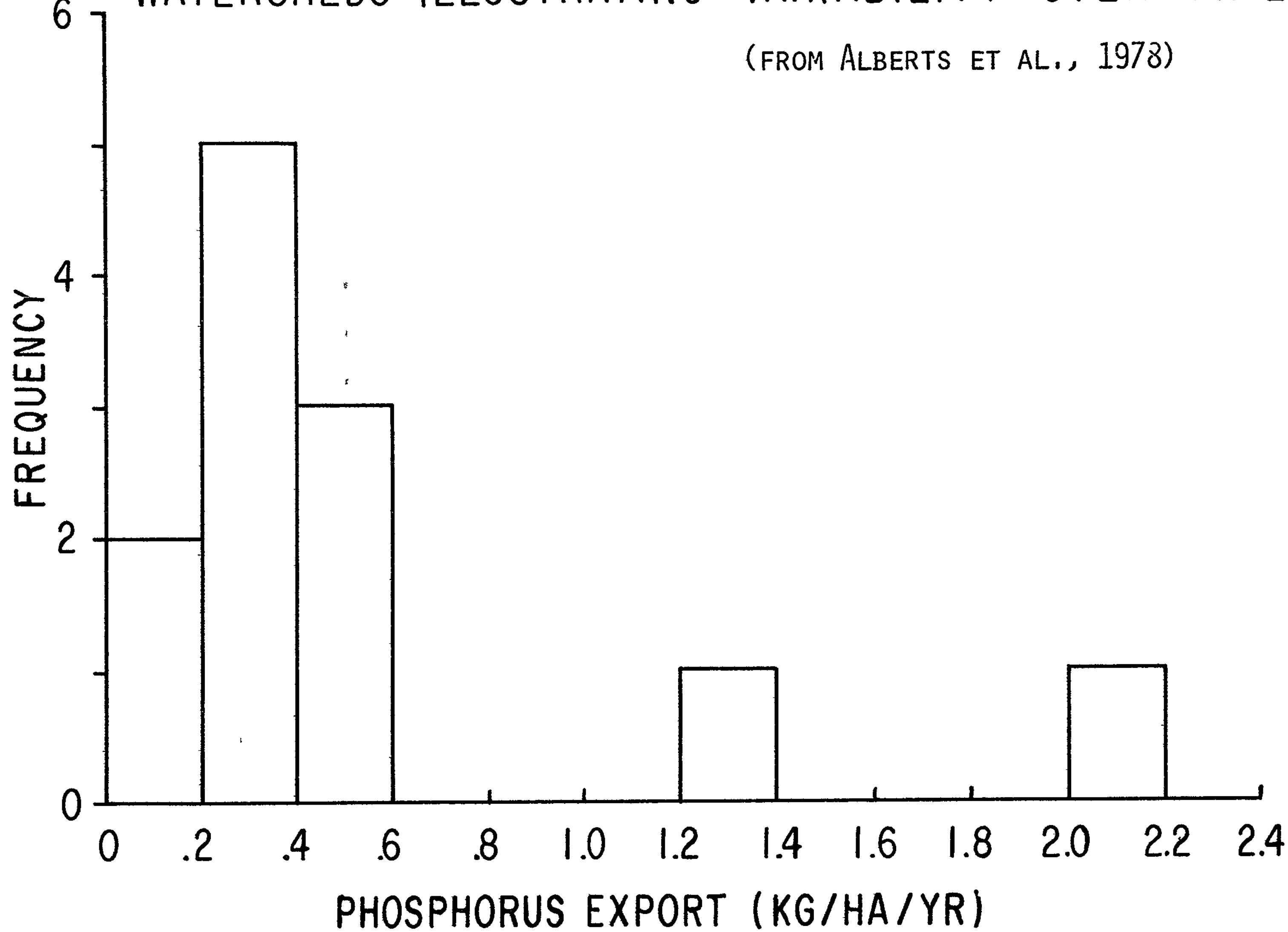
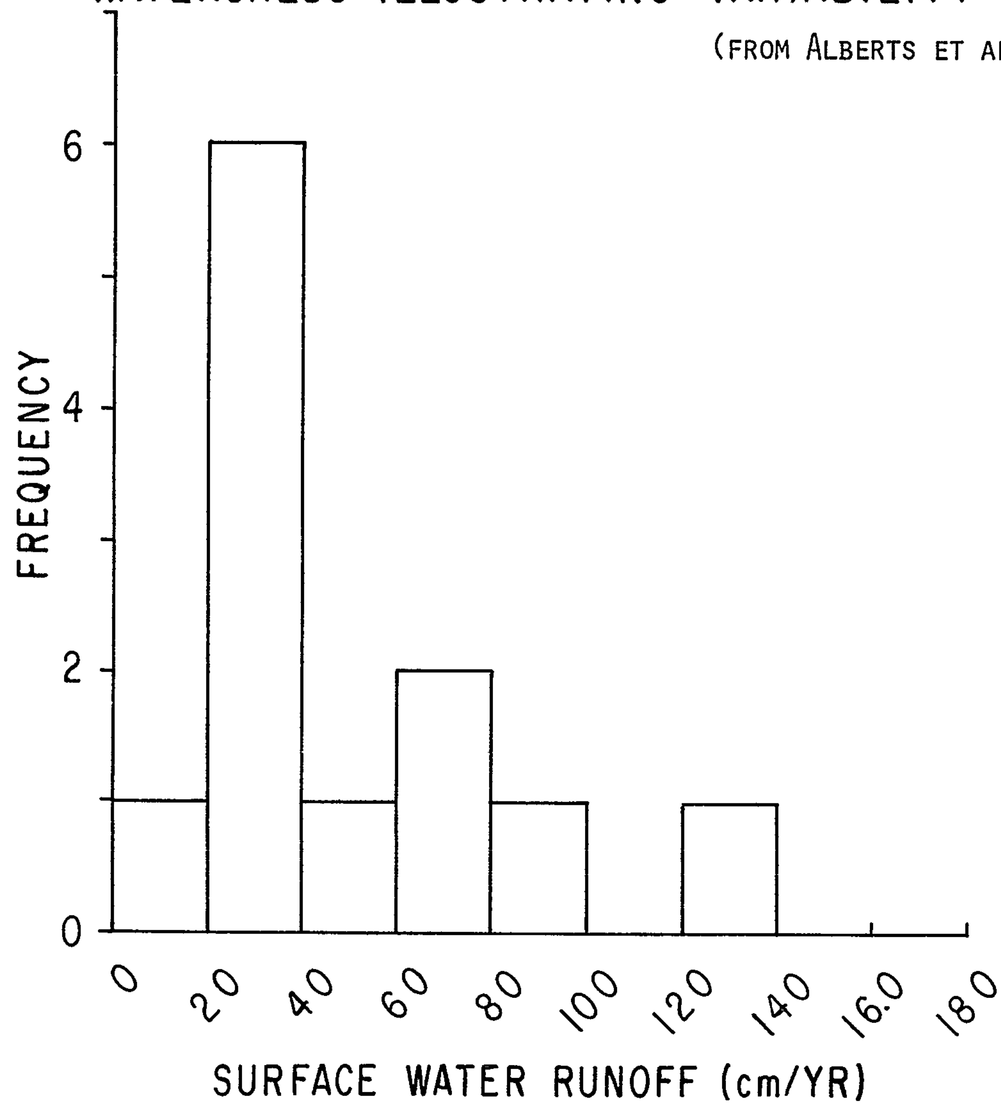


Figure 12: SURFACE WATER RUNOFF FROM TWO CORN CROPPED WATERSHEDS ILLUSTRATING VARIABILITY OVER TIME



Chapter 4

CONCLUDING COMMENTS

The procedure described in Chapter 2 should be useful for lake trophic management planning because of the inclusion of uncertainty analysis and the carefully screened tables of export coefficients Its value will be enhanced, however, if the analyst is mindful of the limitations of the methodology. Listed below are several items reflecting these limitations as well as guidelines for the interpretation and communication of the modeling/uncertainty analysis results

1. The prediction of quantitative water quality impacts associated with changes in land use necessitates the use of a mathematical model Projected or anticipated land use changes cannot be measured so information must be extrapolated from other points in space and/or time Both the application of the mathematical model and the extrapolation of information imply prediction error. This error is therefore unavoidable, but when quantified, prediction uncertainty can be extremely useful in the planning process.
2. Prediction uncertainty is a measure of the information value contained in a prediction. If the uncertainty is small, the prediction is precise, and the predictive information is valuable Alternatively, if the uncertainty is large, the prediction is imprecise, and the predictive information is less valuable. Prediction uncertainty is caused by natural

process variability, and bias and error in sampling, measurement, and modeling. Prediction uncertainty can be useful to the planner as long as it is reliably estimated. However, it is possible that unquantified supplemental uncertainty (Mosteller and Tukey, 1977) exists. This uncertainty term generally results from errors that are unknown to the analyst. For example, supplemental error may be introduced, but unquantified, because of poor choice of export coefficients. This hidden error may increase planning risks because the error is not included in the error analysis. Therefore the analyst must exercise care in the selection of the export coefficients and in the conduct of the modeling process.

3. The notion of supplemental uncertainty and hidden planning risks underscores the importance of selecting representative nutrient export coefficients. The watershed matching process described in Chapter 3 is central to this concern. The analyst must be aware of those watershed characteristics that are the major determinants of nutrient export. Then the appropriate export coefficients are selected according to a match between application lake watershed and export coefficient watershed, on the basis of these causal characteristics. This match leads to representative and reliable coefficients and diminishes supplemental uncertainty.

4. The discussion in Chapter 2 identifies the major limitations on the modeling/uncertainty analysis methodology In fundamental terms, the limitations are generally associated with the fact that the model development data set for any particular model represents a subpopulation of lakes. Application

lakes that differ substantially from the model development subpopulation may not be modeled well (i.e , results may be biased). Any limnologic characteristic that is a causal determinant of lake phosphorus concentration is a candidate as a limiting, or constraint, variable. These include constraints on the model variables (e.g., all model development data set lakes have P < .135 mg/l), constraints on hydrology (e.g , there are no closed lakes in the model development data set), or constraints on climate (e.g., the model development data set contains only north temperate lakes).

5. The methodology described in Chapter 2 can be used to quantify the relationship between watershed land use and lake phosphorus concentration. Yet phosphorus by itself is not an objectionable water quality characteristic. The real quality variable of concern (i.e , the characteristic(s) that lend(s) value or human benefit to the water body, abbreviated "qvc") may be algal biomass, water clarity, dissolved oxygen levels, or fish populations (see Figure 1). Therefore the modeling methodology and the error analysis do not include all of the calculations necessary to link control variables (land use) with the qvc. This means that the relevant prediction error (on the qvc) is underestimated by the phosphorus model prediction error, and planning and management risks are inadequately specified. More useful methodologies are needed that quantitatively link control variables with the qvc for a particular application.

6. The error analysis procedure presented in Chapter 2 should provide a reasonable estimate of prediction uncertainty.

However, there are still problems in interpretation and application. For instance, the model error component was estimated from a least squares analysis on a multi-lake (cross-sectional) data set. This error is then applied to a single lake in a longitudinal sense. Thus, much of the model error term actually results from multi-lake variability, whereas when the model is applied to a single lake, the model error term should consist primarily of lack-of-fit bias and single lake variability. On the basis of present knowledge, it is not clear how a multi-lake-derived error relates to a single lake analysis.

7. A second issue associated with the error analysis concerns the subjective determinations of phosphorus loading and hence, loading estimation error. Statisticians and modelers generally prefer objective measures of uncertainty, such as calculated variability in a set of data However both limited available data and the obviously unmeasurable nature of future impacts favor (or necessitate) subjective estimates Given this subjectivity, and the inexperience of most planners and analysts with phosphorus loading estimation, there may be uncertainty in the uncertainty estimates. This is exacerbated by the potential for loading error "double counting" (see Reckhow, 1979d), although the procedure described in Chapter 2 is designed to reduce error double counting. It is likely that as analysts gain experience in loading and error estimation, this problem will be of less concern.

8. A third uncertainty analysis issue concerns the precise description of error terms presented in Chapter 2 to minimize

error double counting. It was noted in Chapter 2 that some variable error is already incorporated into the model standard error. The error analysis procedure proposed is designed to require additional application lake error only for those factors not already included in the model error. Therefore the analyst is urged to closely follow the guidelines in Chapter 2 for export coefficient selection and error estimation The alternative may be a well-intentioned but inaccurate estimate of prediction uncertainty.

9. The simplicity of this technique necessarily limits its adaptability to certain situations that may occur within a watershed. This procedure may be flexible enough to accommodate some of these situations, but others may require more intensive study (than the procedure provides for). Therefore, it must be left to the judgment of the analyst as to whether or not this method is appropriate. Examples of events or characteristics that would alter the effectiveness of this procedure are:

    a) the input of phorphorus from sources not considered in the method presented. These sources might include a large number of resident water fowl in and around the lake or fertilizers applied to shoreline lawns,

    b) the trapping of phosphorus by mechanisms not considered These phosphorus traps might include aquatic plants or an upstream lake within the watershed,

    c) the occurrence of an unnatural phenomenon that alters the lake ecosystem. These phenomena might include dredging, filling, and chemical treatment,

d) lake types not modeled well with this black box nutrient model. These types include closed lakes (lakes without well-defined outlets) and lakes with strong internal concentration gradients (i e , lakes with significant local quality variations)

10. Water quality management planning and modeling incur a cost that is presumably justified in terms of the value of the information provided. The actual achievement of a water quality level often requires management and pollutant abatement costs but also carries with it various benefits. The analyst must be cognizant of the fundamental economic nature of environmental management, planning, and decision making The acquisition of additional data or the conduct of additional modeling and planning studies should be justified in terms of information return for improved decision making

11. Finally, the planner or analyst conducting a lake modeling study has as his/her primary goal the effective communication of the work carried out. This does not simply mean documentation of the calculations and presentation of the prediction and prediction uncertainty. Rather, effective communication requires consideration of the knowledge and concerns of the likely audience. The analyst must then describe his/her study so that the audience can comprehend the results, can understand the study's limitations, and can act (if necessary) in an informed manner As a rule, this means that the analyst should complecely describe procedural limitations and assumptions made in conducting the study

Beyond that, the analyst should explain how the limitations and assumptions affect the interpretation of the results for planning. As a related issue, the analyst should justify his/her choice of export coefficients. A comprehensive discussion of the application of the modeling/uncertainty analysis methodology that meets the needs of the intended audience facilitates good water quality management planning.

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APPENDIX

A. 1 Research Methodology for the Assessment of Nutrient Runoff in Field Studies

During his literature survey of nutrient export coefficients, Beaulac (1980) found considerable variability in the methods employed by researchers for experimental design, sampling design, mass flux estimation, and result reporting. Unfortunately the lack of a standard methodology resulted in the rejection of some reported values for this manual. Since it is likely that some readers of this manual will at some time be involved in studies designed to directly measure nutrient mass transport to surface water bodies, research and reporting methods are discussed below This is particularly important since a premise supporting this manual is that export coefficients are transferable among selected watersheds. Researchers are urged to adopt certain standard procedures so that their results may be added to the literature on nutrient export coefficients.

A. 1. 1 Watershed Designs

Of the criteria necessary for a nonpoint 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 accommodate 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 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 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 on 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 design is 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. 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 flow, 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 forested systems nutrient export from agricultural areas demonstrates wide variability. Practices are highly diversified and an agricultural basin can consist of a mosaic of different uses such as pasture, feedlots, row and nonrow 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 hydrologic 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 20 individual plots. At the base of each plot is the flow/sampling device often consisting of a collecting tank which relies heavily on the "batch" collection methods.

Because of the low area and labor requirements, this particular design has increased in use by university agricultural experiment stations and other research agencies. Small size permits close proximity to research facilities and personnel, which has allowed for both close monitoring and manipulation of environmental conditions such as soil, slope, fertilizer, tillage methods and crops.

urban land uses

Sampling site selection for urban runoff monitoring potentially poses the greatest difficulty of the three land uses. 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 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) indicated that aside from these problems, the following factors also influence site selection for urban runoff studies.

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

A. 1. 2 Sampling Design and Flux Estimation

The estimation of phosphorus export from watersheds requires good experimental and sampling design. Design considerations include the methods of acquisition of the concentration samples and flow values, the extent of temporal sampling, and the method of combination of concentration and flow data for flux estimation. Use of an inadequate methodology for any of the tasks mentioned can bias the resultant export coefficients. The discussion presented below on these issues is probably most appropriate for watersheds of moderate to large size, although the concepts discussed are generally applicable to all watersheds.

Systematic temporal sampling (not including storm sampling) throughout the year has been examined in the literature for stream quality assessments. Allum et al. (1977) reported on intensive sampling of tributary phosphorus discussed in three papers (Treunert et al., 1974; Unger, 1970; Hetling et al., 1976). In all three studies, the sampling was quite frequent (twice weekly or daily); samples taken from the data set at a reduced frequency, on a systematic basis, could then indicate the effectiveness of less frequent sampling. In general, these three studies found that, 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.

In addition, Walker (1977) evaluated the effect of serial correlation of the phosphorus concentration measurements on the equivalent sample size. Treating the time sequence of samples as a first-order autoregressive (Markov) process, and assuming a phosphorus concentration serial correlation coefficient of 0.75 to 0.90 (one day lag), the effective number of samples and the actual number of samples are essentially equivalent at sampling intervals of 14 to 28 days (or longer). At more frequent sampling, the effective number/actual number ratio drops below one, indicating that less information is being acquired per sample.

Therefore, a sampling interval of about 14 to 28 days may be a general guideline for phosphorus concentration. This must be considered in light of the following comments, however.

1. More frequent sampling will still reduce uncertainty 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 (see data presented in Hetling et al., 1976).
3. Sampling should not be systematic with respect to time (e.g., every two weeks). A better approach is to establish sampling as systematic with respect to flow, with a random start. This means that the year should be divided into n equal flow periods, for the purpose of taking n concentration samples per year.

Sampling should also occur during storm events, as storms may be the major transporter of phosphorus from the land to surface water bodies in certain situations. During storms, the method of acquisition of the concentration samples is important, because of significant concentration variability. Concentration sampling should preferably be a composite on a flow-weighted or mass-flow-weighted basis, not on an equal time basis (Marsalek, 1975). Alternatively, grab samples could be collected, at perhaps five to ten minute intervals during a storm, but this would lead to a higher sample processing cost. One way grab sampling may be acceptable is through stratification of the sampling with respect to time, assuming a model of first flush followed by an exponential decay with time. This can be thwarted, however, by storms that, due to fluctuating intensity, produce several runoff peaks. Remote automatic sampling units may be necessary because human response may be too late for the important first flush.

Flow estimation can basically be undertaken in three ways. Continuous flow measurement is clearly preferable, but it is costly and often not feasible. An acceptable alternative is an annual flow regression equation developed by the USGS. These should be available for each state (e.g., Bent, 1971), and they provide an estimate of the annual flow and the standard error of the flow estimate. A third alternative, which must be considered unacceptable here because it does not yield an estimate of precision, is to simply measure instantaneous flow at the time of concentration sampling.

Finally, flux estimation can follow several approaches, each of which can be most 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.

The following comments outline the approaches taken. Walker (1977) looked at several flux estimation approaches and concluded that flow-weighted concentration times average flow is the best (determined by bias, variance, and calculation effort) estimator when concentration does not vary greatly with flow. The EPA-NES (1975) developed a concentration versus flow regression from data taken at 250 sampling sites. Their equation indicates that a 1% change in flow results in a -0.11% change in phosphorus concentration and a -0.06% change in nitrogen concentration. The magnitude and direction of these changes must be considered with the fact that the EPA-NES data included watersheds containing major point sources. Bouldin et al. (1975) developed a regression equation for phosphorus concentration as a function of flow and the rate of change of flow. Smith and Stewart (1977) looked at eight different approaches for the estimation of annual nutrient flux. Included among these approaches were flow-weighted concentration times mean flow and concentration/flow polynomials. They selected a regression of log flux on log flow because of both good results and mathematical simplicity. Finally, Verhoff et al. (1980) found that a flow interval method relating phosphorus flux to streamflow provides the best fit to Lake Erie tributary data.

In conclusion, 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
3. simplicity of the mathematics.

A. 1. 3 Standardization of Results Reported in the Literature

In addition to the need for statistical considerations in sampling designs, there is also a necessity for uniformity in the presentation of results. Nutrient contributions from overland drainage have been and continue to be reported in a variety of forms - usually expressed as either concentration (mass/volume) or loading (mass/unit area-time). Because of difficulties in interpretation, however, these results must sometimes be analyzed and compared carefully. Cross-sectional comparisions of concentrations are particularly risky.

Streamwater concentrations alone can suffice for total output comparison provided several important assumptions are satisfied. If the watersheds to be compared have similar values for precipitation, precipitation chemistry, evapotranspiration and chemical response characteristics (or if the differences in these properties among watersheds can be measured), then streamwater chemistry is a sufficiently accurate measure of total elemental losses (Vitousek, 1977; Vitousek and Reiners, 1975).

However, a better unit for comparison is an area yield rate such as loading. This is the product of flow volume and concentration over time divided by watershed area. This unit incorporates runoff duration and catchment area directly, as well as rainfall intensity and catchment character indirectly (Betson, 1978; Griffin et al., 1978). Not only are comparisions between watersheds and land uses possible, but relationships between certain inputs (i.e., precipitation) and outputs are more definitive. Therefore, investigators conducting studies of nutrient runoff from land use activities are urged to report unit areal loading or export in addition to concentration.

A. 2 Issues Important in the Determination of Phosphorus Loading to Lakes

A. 2. 1 Phosphorus Fractions and Availability

The transport of contaminants, especially those emanating from diffuse sources, is intimately connected with the hydrologic cycle. Nutrient flux to streams and lakes is generally positively correlated with rainfall, runoff, and sediment inputs. While linked with one common transport vector, the forms of these contaminants are source-dependent Groundwater inputs are primarily in the dissolved phase, while precipitation, stormwater runoff and point source effluents consist of both dissolved and particulate species.

The form of particular nutrients has become increasingly important in terms of biological availability. Until recently, eutrophication control programs have been based largely on the regulation of any fraction of phosphorus that was amenable to management, irrespective of whether the phosphorus was in an available fraction which could support algal growth. 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 included 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, 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:

$$\text{available P} = \text{SRP} + .2\ \text{PP}_T \tag{A-1}$$

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:

$$\text{available P} = \text{SP}_0 + 0.2\ \text{PP}_T \tag{A-2}$$

where:

SP_0 = 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 was estimated to be in a biologically available form. Overall, probably 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).

The issue of phosphorus availability has also been directed towards other inputs such as precipitation and point sources. For precipitation, Dillon and Reid (1980) estimated that up to 28% of the total bulk loads and 40% of the total P in wet-only precipitation was available. Studies by Murphy and Doskey (1975) speculated that 50% of the total phosphorus in bulk loads was ultimately available.

The availability of point source phosphorus is variables, depending upon whether phosphorus removal is practiced (i e., iron, aluminum, or calcium hydroxide precipitation), or depending upon factors such as limitations on phosphorus detergents. It is generally believed, however, that the major fraction of wastewater phosphorus is available (Lee et al., 1979). Studies by Young et al. (1980) indicate that up to 72% of total phosphorus, 55% of the total particulate phosphorus and 82% of total soluble phosphorus are available

It should be stressed that availability usually applies to the phosphorus fraction that is utilized within one growing season. Depending on conditions, there is, however, a potential for at least some (if not all) of the remaining fraction of particulate phosphorus to be utilized at a later date (due to sudden equilibrium changes). Regardless of what percent of the total is initially utilized, or what fraction of the remainder has future potential availability, it is imperative that sampling be undertaken for both soluble and particulate forms. This is especially important since particulate phosphorus can be an order of magnitude greater in quantity than the reported dissolved fraction.

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. The cumulative effect of many storm events is not only considerable enough to degrade water quality but often sufficient to negate the positive aspects of local point source pollution abatement programs. Many studies have demonstrated that just a few storms during a given year were responsible for the bulk of the total annual nutrient load (Alberts et al., 1978; Kissel et al., 1976; Schuman et al., 1973).

Both dissolved and particulate fractions respond to storm events differently. Although variation exists, their response relative to the storm hydrograph can be discussed in somewhat general terms (see Figure A-1).

The initial 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, resulting 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 baseflow conditions.

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

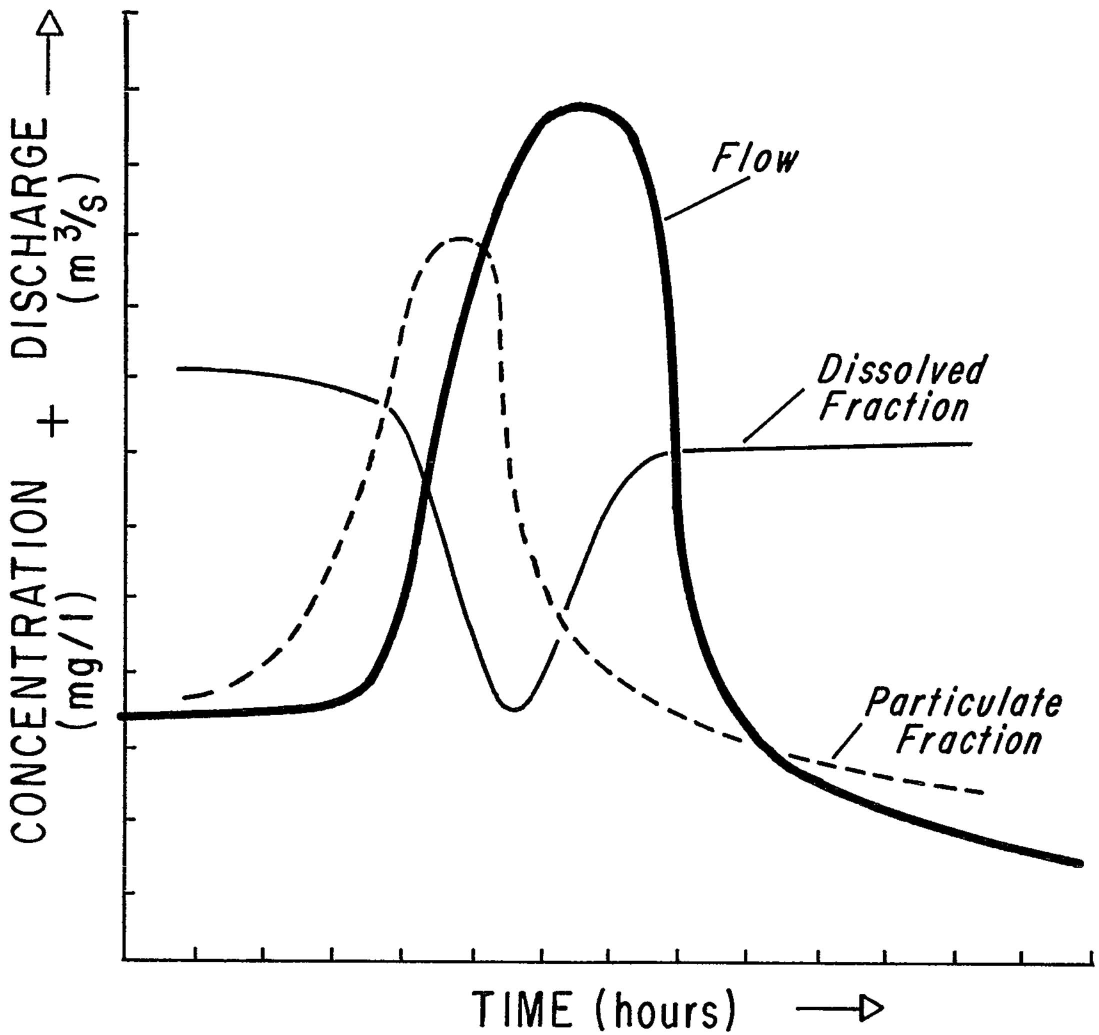

Figure A-1 Dissolved and Particulate Nutrient Response to the Storm Hydrograph.

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.

A. 2. 2 Variability, Precision, and Accuracy

Variation in nutrient flux through time has been intimately linked to changes in flow. 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 (i.e., rural to urban) the effect on drainage basin hydrology is to:

1. increase the storm peak discharge,
2. increase the storm runoff volume while reducing baseflow,
3. decrease response time,
4. increase annual runoff and reduce groundwater recharge, and
5. increase the number of days of no (baseflow) discharge.

(Turner et al., 1977, Ikuse et al., 1975, Okuda, 1975, Yoshino, 1975; Hollis, 1975; Gregory and Walling, 1973; Lindh, 1972; Moore and Morgan, 1969; Holland, 1969; Leopold, 1968).

The result of the first three of these effects is visually interpreted in Figure A-2

Since peak discharge and flow volume are higher in urban areas, urban nutrient storm loads are often substantial. In a comparison between urban and rural watersheds, Burton et al. (1977) reported that up to 98% of the total phosphorus load was exported in storm flow on an urban watershed while storm events accounted for slightly more than half this amount on the rural basin. Conversely, overland runoff from forested basins is a rare event with an extended response time resulting from slow discharge after precipitation. Hence, sampling frequency need not be as rigorous as in "flashy" urban watersheds.

To sufficiently describe the nutrient export from differing land uses, Sherwani and Moreau (1975) describe the desired frequency of measurement as a function of the following considerations:

1. the response time of the system,
2. expected variability of the parameters,
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. the magnitude of response, and
8. variability of the inputs.

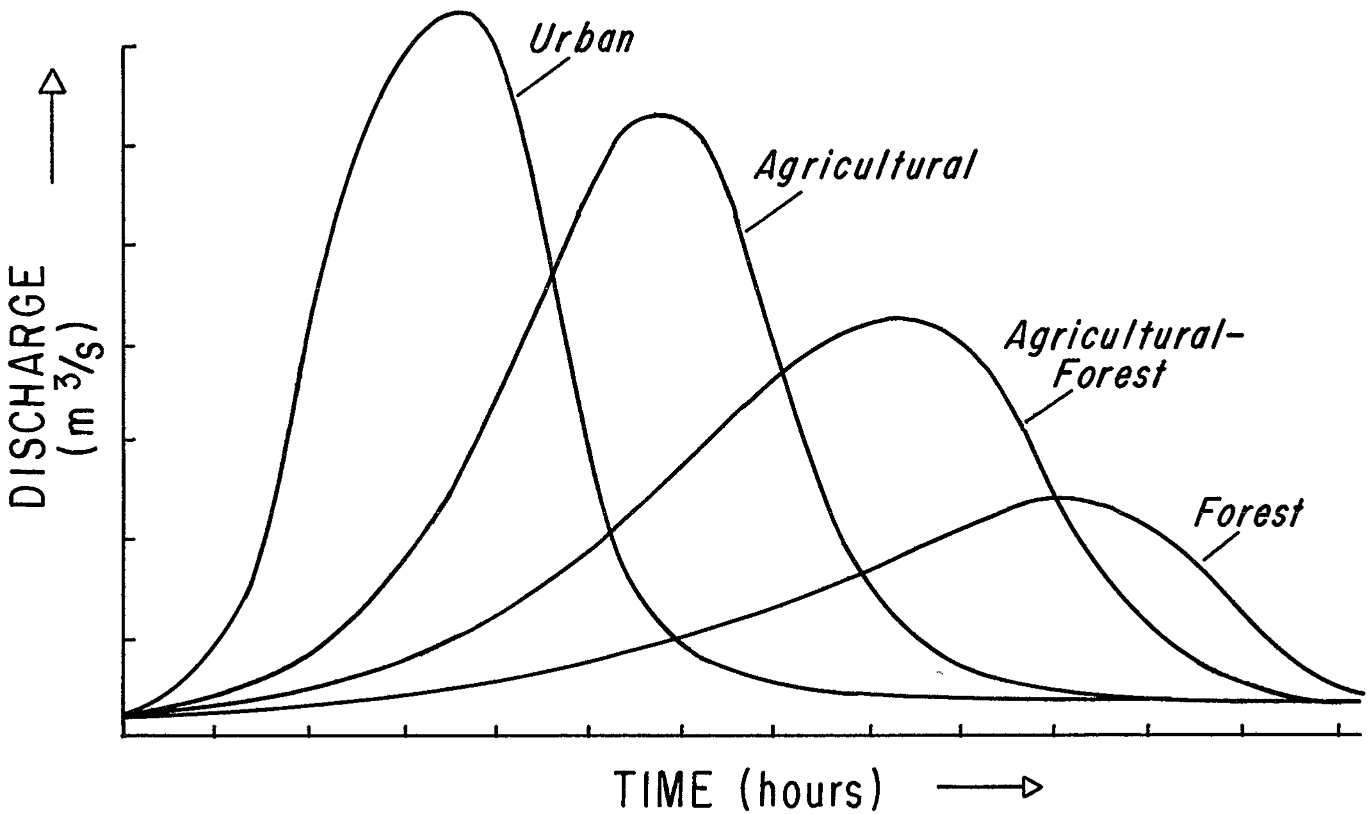

Figure A-2 Hydrographic Response of Varying Land Uses to a Storm Event.

Simply stated, there is no single best sampling frequency for all conditions.

To reduce loading uncertainty, a greater degree of accuracy and precision may be gained by maintaining complete flow records while obtaining enough concentration samples to adequately characterize the flow variability. While accumulation of flow records is fairly straight forward (using USGS stream gauging stations, for example), the concentration sample collection process can often be made reasonably efficient if stratified random sampling is employed (Reckhow, 1979b). 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.

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.

The studies selected for inclusion in the export coefficient tables employed a wide variety of sampling techniques, but nearly all were based upon complete flow records. 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 nutrient load for a particular land use.

A. 2. 3 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/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 undisturbed forests is in sharp contrast to the highly variable flows eminating 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 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 reader 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)

A. 3. Prediction Uncertainty Estimation for Areal Water Loading (q_s) Error

The methodology presented in Chapter 2 is based on the assumption that model variable error is contributed only by uncertainty in phosphorus loading (L). Under some conditions and in some lakes, uncertainty in areal water loading (q_s) may also be significant. For example, since uncertainty includes natural variability, lakes with highly variable flushing rates may be candidates for q_s-error analysis. In addition, since measurement error is also a part of total uncertainty, lakes for which flushing rates are poorly characterized might also be analyzed for q_s-uncertainty.

The procedure presented below is designed to interface with the steps in the Chapter 2 methodology. It is assumed that the uncertainty may originally be estimated in terms of Q (the annual volumetric water flow through a lake), but that for analysis purposes it is re-expressed as $q_s = Q/A_o$ (where A_o = the lake surface area (a constant)).

The contribution to total prediction uncertainty from uncertainty in q_s is calculated using the error propagation equation (Benjamin and Cornell, 1970).

$$s(P) \approx \sum_{i=1}^{n}\left[\left(\frac{\partial P}{\partial x_i}\right)^2 s^2\,(x_i) + \sum_{j=i+1}^{n} 2\,\frac{\partial P}{\partial x_i}\,\frac{\partial P}{\partial x_j}\, s(x_i)s(x_j)\rho(x_i,x_j) \right]^{1/2} \qquad \text{(A-3)}$$

where:

$s(P)$ = contribution to total uncertainty in the model (P), due to uncertainty in variables x_i and x_j,

x_i, x_j = model parameters or independent variables,

$s(x_i)$ = uncertainty (standard error) in x_i, and

$\rho(x_i,x_j)$ = correlation between x_i and x_j.

The phosphorus lake model is

$$P = \frac{L}{11.6 + 1.2q_s} \qquad \text{(A-4)}$$

Therefore, using the error propagation equation, the additional prediction uncertainty in total phosphorus concentration due to uncertainty in q_s is

$$s_{q_s} = \left[\frac{1.44\ L^2}{(11.6 + 1.2q_s)^4}\ s^2(q_s) - \frac{2.4\ L}{(11\ 6 + 1\ 2q_s)^3}\ s(q_s)s(L)\rho(L,q_s) \right]^{1/2} \tag{A-5}$$

The confusing array of symbols necessitates interpretation. In conjunction with their interplay with the steps in Chapter 2, the symbols are

1. $\rho(L,\ q_s)$ is the correlation between L and q_s. Since both are primarily determined by Q, this correlation should be positive, which diminishes the importance of the q_s-uncertainty contribution. Ideally this correlation should reflect a time series of data for an application lake In the absence of this site-specific information, cross-sectional studies suggest a correlation coefficient between L and q_s of + 5 to +.8.
2. $s(q_s)$ is the estimate of uncertainty in q_s determined by the analyst. It is different from s_{q_s} which is defined below.
3. $s(L)$ is the estimate of uncertainty in L It has positive and negative components. In Step 2G, the high, most likely, and low phosphorus loading terms are calculated The resultant uncertainties in loading are

$$s(L)^+ = \frac{L_{(high)} - L_{(ml)}}{2} \tag{A-6}$$

$$s(L)^- = \frac{L_{(ml)} - L_{(low)}}{2} \tag{A-7}$$

4. s_{q_s} is the contribution to the total phosphorus concentration prediction uncertainty due to uncertainty in q_s. It, too, has positive and negative components (resulting from the positive and negative components in $s(L)$). Thus

   a. $s_{q_s}+$ is found using $\rho(L, q_s)$, $s(q_s)$ and $s(L)^+$ in Equation A-5.

   b. $s_{q_s}-$ is found using $\rho(L, q_s)$, $s(q_s)$ and $s(L)^-$ in Equation A-5.

Then:

a. $s_{q_s}+$ is squared and added to the right side of Equation 12 in Step 4F.

b. $s_{q_s}-$ is squared and added to the right side of Equation 14 in Step 4G

This modification results in positive and negative error intervals reflecting all known uncertainties (including uncertainty in q_s)

Table A1a: 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	96 7	29.7				329	Schindler et al , 1976
jack pine -	80 3	35 4				435	
black spruce	70 1	22.3				289	
(34 ha)	74 3	23 4				220	
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		17 7				124	Verry, 1979
30% black spruce		19 2				179	
and alder		15 5				157	
(10 ha)							
Aspen - birch	82 1	21 47	05			19	Timmons et al , 1977
(6 48 ha)	79 48	15 56	20			38	
	75 51	13 73	16			28	
Maple, birch, beech (15 6 ha)	132 2	83 3		007	012	019	Likens et al , 1977

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	
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	129 0	84 3				090	Singer and Rust, 1975
forest (01 ha)							

Table A1a: (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
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 hydro-logic 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 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
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 A1a: (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
Douglas fir and western hemlock		76 0	47			680	Fredriksen, 1979

Table A1b· Nitrogen Export from Forested 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
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											6 45 7 32 6 07 5 69	Schindler et al , 1976
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 30% black spruce and alder (10 ha)		17 7 19 2 15 5	20 05 33	23 10 37		1 83 2 21 1 34							2 26 2 37 1 74	Verry, 1979
Aspen-birch (6 48 ha)	82 1 79 48 75 51	21 47 15 56 13 73	17 19 09	16 47 19		2 13 2 63 1 64							2 46 3 29 1 32	Timmons et al , 1977
Sugar maple, yellow birch, beech, red spruce, balsam fir and paper birch New Hampshire (607 ha)			6 6	04										Martin, 1978

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
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 88 9 92 8	25 3 35 6 32 0	80 1 60 70										1 37 3 16 2 82	Taylor et al , 1971
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 5 174 7	114 8 116 1	1 2	3 2	2 1 1 5		2.2 1 7						2 2 1 7	Henderson et al , 1977
Oak, maple, yellow poplar, black cherry, beech (34 ha)			45 60 86	1 52 84 86										Aubertin and Patric, 1974
Mixed mature hardwoods, Coweeta hydrologic lab , North Carolina (12 1 - 61 1 ha)			03 06 05 35 05 05 15	03 05 05 10 07 06 07										Swank and Douglas 1977
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														Schreiber et al , 1976
(2 81 ha)	189 08	39 48	33	4 40										
(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 A1b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/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
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

Nitrogen Export (kg/ha/yr)

Table Alb: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/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
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											

Nitrogen Export (kg/ha/yr)

Table A2a: Phosphorus Export from Row Crops

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
Corn	77 6	10 7				1 22	Minshall et al ,
continuous plant-	77 0	8 51				1 49	1970
ing (004 ha)	65 76	21 95				1 22	
Corn	77 6	12 26				5 77	Minshall et al ,
continuous plant-	77 0	5 97				1 03	1970
ing	65 76	19 41				2 00	
fresh manure							
winter applied							
(004 ha)							
Corn	77 6	11 51				96	Minshall et al ,
continuous plant-	77 0	5 59				75	1970
ing	65 76	15 32				68	
fermented manure							
spring applied							
(004 ha)							
Corn	77 6	12 45				1 18	Minshall et al ,
continuous plant-	77 0	5 61				95	1970
ing, liquid manure	65 76	15 60				76	
spring applied							
(004 ha)							
Corn		8 71				1 00	Hensler et al ,
continuous plant-		14 33				1 60	1970
ing, no manure							
(004 ha)							

Table A2a· (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
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) Dissolved Phosphorus				Reference
			PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	
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 (contınued)

Land Use	Precıp-ıtatıon cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Total P	Partıculate/Sedıment Phosphorus	Total Phosphorus	Reference
Corn	52 8	70		081	009	09	Alberts et al , 1978
contınuous	73 12	35		009	015	024	
terraced	76 41	1 75		059	228	287	
(60 - ha)	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 plant-ıng (1 29 ha)	107 7	13 0	25	54	1 67	2 21	Smıth et al , 1978
Corn 6 replıcatıons (001 ha)	87 39					40	Bradford, 1974
Soybeans	118 0	28 3		025			McDowell et al , 1978
two crops/yr conventıonal tıll (01 ha)	169 2	83 2		25	17 5	17 75	
Soybeans	118 3	13 0		1 2			McDowell et al , 1978
two crops/yr no tıll (01 ha)	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) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
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) Dissolved Phosphorus PO_4-P	Dissolved Phosphorus Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
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	77 6	10 7											5 53	Minshall, et al ,
planting (004 ha)	77 0	8 51											3 61	1970
	65 76	21 95											3.96	
Corn, continuous	77 6	12 26											26 88	Minshall et al ,
planting, fresh	77 0	5 95											3 05	1970
manure, winter	65 76	19 41											7 97	
applied (004 ha)														
Corn, continuous	77 6	11 51											5 32	Minshall et al ,
planting, fermented	77 0	5 59											3 35	1970
manure, spring	65 76	15 32											3 38	
applied (004 ha)														
Corn, continuous	77 6	12 45											2 81	Minshall et al ,
planting, liquid	77 0	5 61											2 88	1970
manure, spring	65 76	15 60											5 07	
applied (004 ha)														
Corn, continuous		8 71											4 08	Hensler et al ,
planting, no		14 33											4 58	1970
manure (004 ha)														
Corn, continuous		7 11											26 06	Hensler et al ,
planting, fresh		11 53											4 44	1970
manure, winter														
applied (004 ha)														

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	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
			Nitrogen Export (kg/ha/yr)											
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· (contınued)

Land Use	Precipitatıon 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 Nıtrogen	Reference
Corn, contınuous plantıng (1 29 ha)	107 7	13 0	86	1 48	5 90				85	5 66			12 42	Smıth et al , 1978
Corn, 6 replıca-tıons (001 ha)	87 39		078	55									3 29	Bradford, 1974
Soybeans, two crops/yr , conventıonal tıll (01 ha)	118 0 169 2	28 3 83 2	70 1 0	1 5 2 8								42 7	46 5	McDowell et al , 1978
Soybeans, two crops/yr , no tıll (01 ha)	118 3 169 2	13 0 42 8	1 2 0 6	2 1 1 6								2 3	4 5	McDowell et al , 1978
Cotton, contınuous plantıng (17 9 ha)	97 3 72 7 88 1 74 4	24 1 8 6 12 6 13 6											11 49 4 99 9 79 8 82	Menzel et al , 1978
Cotton, contınuous plantıng (12 1 ha)	96 3 73 1 88 2 72 9	24 8 8 0 11 9 13 5											14 84 5 18 10 03 12 19	Menzel et al , 1978
Soybeans - corn two crops/yr , no tıll (01 ha)	118 3 169 2	21 5 88 2	3 0 3 0	2 2 3 8								17 0	23 8	McDowell et al 1978

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 fertiliza- tion (004 ha)	105 4 107 8 108 8	8 2 14 2 18 5				75 76 2 40	Converse et al , 1976
Alfalfa fall applied manure (004 ha)	105 4 107 8 108 8	5 2 7 8 9 0				1 24 1 20 8 09	Converse et al , 1976
Alfalfa winter applied manure (004 ha)	105 4 107 8 108 8	8 2 10 3 12 8				64 58 6 09	Converse et al , 1976
Alfalfa spring applied manure (004 ha)	105 4 107 8 108 8	6 7 10 1 15 0				2 39 55 1 81	Converse et al , 1976
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 72 9 87 7 73 1	20 8 7 0 10 5 5 5		61 19 36 13	2 73 51 60 2 19	3 34 80 96 2 32	Menzel et al , 1978

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	96 6	23 0		.52	3 77	4 29	Menzel et al , 1978
continuous	73.1	5.5		09	.50	59	
planting	87 9	9 3		.26	.53	79	
(5 3 ha)	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 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
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 bromegrass two plots (3 55 - 4 10 ha)	57 91	2 69											10	Harms et al , 1974
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 planting (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)											Reference
			Dissolved Nitrogen					Particulate/Sediment Nitrogen					Total Nitrogen	
			NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N		
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	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			
Moderate dairy grazing, blue-grass cover (1 88 ha)	106 8 104.3 105 5 119.8	20 2 22 5 12 3 24 6				.15 16 13 12	Kilmer et al , 1974
Heavy dairy grazing, blue-grass cover (1 88 ha)	106 8 104.3 105 5 119 8	26.0 26 9 19.9 31 8				70 18 11 12	Kilmer et al., 1974
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 73 30 75 40	4 39 94 3 86		193 064 386	058 017 126	251 081 512	Schuman et al , 1973
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	105 0	28 4		14	3 72	3 86	Menzel et al , 1978
little bluestem	77 8	12 6		07	99	1 06	
cover, active	98 7	17 6		03	1 83	1 86	
gullies (11 1 ha)	50 7	2 02		01	26	26	
Rotation grazing	109 1	17 8		10	1 34	1 44	Menzel et al , 1978
little bluestem	77 3	4 2		02	22	24	
cover, good	99 4	7 7		02	25	27	
cover (11 0 ha)	52 4	35		00	02	02	
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	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
Moderate dairy grazing, gluegrass cover (1 88 ha)	106 8	20 2	2 97	47									3 44	Kilmer et al , 1974
	104 3	22 5	2 63	44		77							3 83	
	105 5	12 3	1 68	18		55							2 41	
	119 8	24 6	2 14	21		1 15							3 47	
Heavy dairy grazing, bluegrass cover (1 88 ha)	106 8	26 0	16 10	1 95									18 05	Kilmer et al , 19/4
	104 3	26 9	10 79	61		1 32							12 71	
	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 (42 9 ha)	77 83	4 39	1 14	66						52			2 32	Schuman et al , 1973
	73 30	94	17	09						21			47	
	75 40	3 86	96	43						2 89			4 28	
Continuous grazing, little bluestem cover, active gullies (11 1 ha)	105 0	28 4											6 84	Menzel et al , 1978
	77 8	12 6											5 43	
	98 7	17 6											9 23	
	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 feedloc (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)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
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

			Nitrogen Export (kg/ha/yr)											
			Dissolved Nitrogen					Particulate/Sediment Nitrogen						
Land Use	Precipitation cm/yr	Water Runoff cm/yr	NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Beef livestock feedlot (4 76 ha)	61 06	28 52								1332 8[a]				Dornbush and Madden, 1973
	60 71	8 92								577 9[a]				
	53 19	21 87								1196 2[a]				
Lamb feedlot (21 32 ha)	59 0	1 96								32 48[a]				Dornbush and Madden, 1973
	49 96	2 18								53 76[a]				
Lamb feedlot (12 63 ha)	49 96	3 10								64 96[a]				Dornbush and Madden, 1973
Dairy confinement, 45 head of cattle (13 ha)	62 53	15 16								705 6[a]				Dornbush and Madden, 1973
	58 01	82 65								1561 28[a]				
	48 16	27 18								1154 70[a]				
Beef and sheep feedlot (603 ha)	62 53	15 24								973 3[a]				Dornbush and Madden, 1973
	58 01	30 35								433 4[a]				
	48 16	14 40								287 84[a]				
Beef feeding (1 6 ha)	63 73	3 99								99 68[a]				Dornbush and Madden, 1973
	55 83	8 71								975 40[a]				
Beef cattle feedlot, 9 29 m^2/cow (0019 ha)		17 07											3830 4	McCalla et al , 1972
		14 68											2016 0	

Table A5b: (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
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	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
58% row crops 31% small grain and pasture 6% woods 5% urban (4950 ha)	112 0 70 0	27 5 11 2				5 2 1 1	Lake and Morrison, 1977
63% row crops 26% small grain and pasture 8% woods 3% urban (942 ha)	112 0 70 0	29 1 12 4	14 06	24 09	5 20 98	5 4 1 1	Lake and Morrison, 1977
35% row crops 48% small grain and pasture 5% woods 12% urban (714 ha)	112 0 70 0	26 0 10 1	34 18	46 22	4 5 73	5 0 1 0	Lake and Morrison, 1977
50% pasture 25% rotation cropland 25% hardwood forest (123 ha)	77 7 88 6 88 9 92 7	26 9 34 4 33 9 32 8		031 080 067 077			Taylor et al , 1971
39% corn 46% legumes and grass, 9% small grain, 2 6% idle 4% roads (594 ha)	99 0 93 5 92 7					0 10 0 80 0 60	Patni and Hore, 1978

Table A6a· (contınued)

Land Use	Precıp-ıtatıon cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Total P	Partıculate/Sedıment Phosphorus	Total Phosphorus	Reference
60% row crops 40% hay and pasture two lıvestock 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
Intensıve agrıcultural crops and ımproved pasture (202 ha)	105 0 88 0	21 3 12 1	1 21 63			1 34 86	Campbell, 1978
Actıve croppıng and pasture						409	Grızzard et al , 1977
At least 80% of watershed devoted to agrıcultural actıvıtıes				233		1 29	Avadhanula, 1979

Table A6a: (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
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) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
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

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					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		
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	Dissolved NH_4-N	Dissolved TKN-N	Dissolved ORG-N	Dissolved Total-N	Particulate/Sediment Nitrogen NO_3-N	Particulate/Sediment NH_4-N	Particulate/Sediment TKN-N	Particulate/Sediment ORG-N	Particulate/Sediment 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	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
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) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
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) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
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	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
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)	249 0	48 3	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 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
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)	/6 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 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% 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)	249 0	48 3	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

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