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:

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

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:

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

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

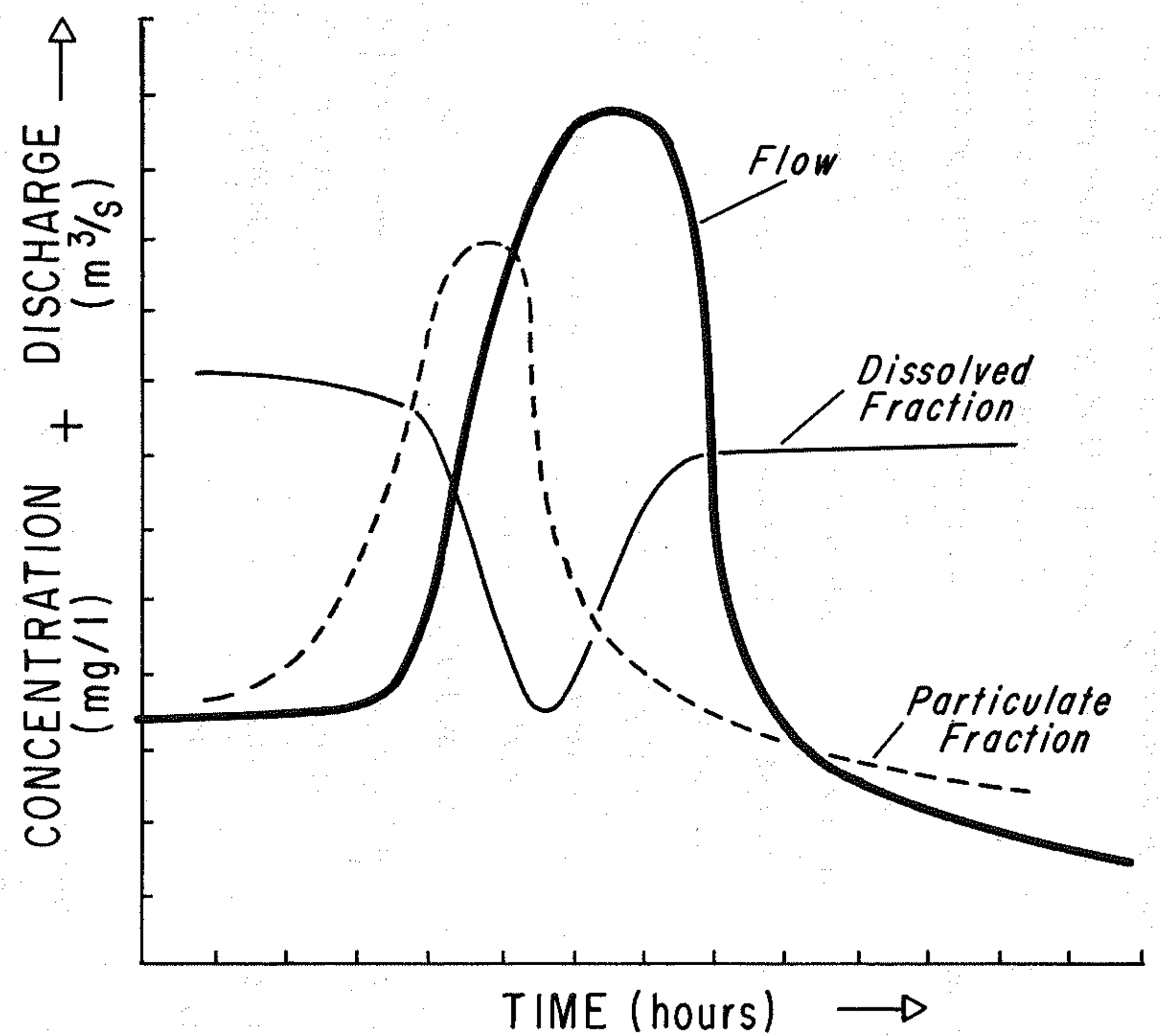

Figure A-1: Dissolved and Particulate Nutrient Response to the Storm Hydrograph.

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.

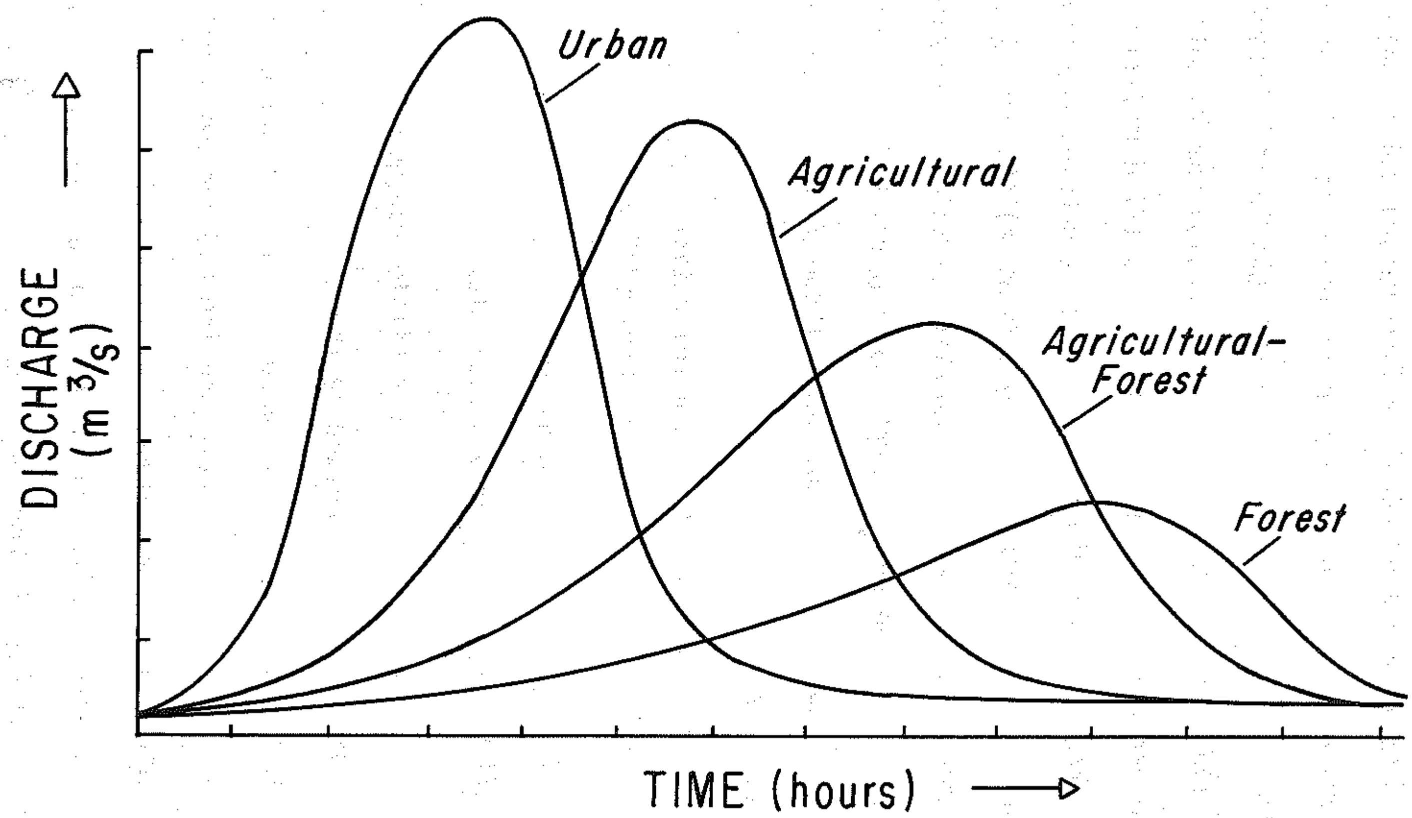

Figure A-2: Hydrographic Response of Varying Land Uses to a Storm Event.

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).

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

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

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

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

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

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:

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

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

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

Table A1a: (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
Deciduous hardwood and pine (17.6 ha)	85.4	25.3	.035			.035	Taylor et al., 1971
	88.9	35.6	.072			.072	
	92.8	32.0	.035			.035	
Mixed deciduous forests, sandy soils - igneous formation						.070	Dillon and Kirchner, 1975
						.047	
						.067	
						.075	
						.046	
						.050	
						.037	
						.025	
						.060	
						.072	
						.030	
						.052	
						.025	
						.035	
						.037	
						.077	
						.048	
						.038	
						.027	
						.041	
Mixed deciduous forests, loam soils, sedimentary formation						.145	Dillon and Kirchner, 1975
						.092	
						.122	
						.067	
Mixed deciduous forest (.01 ha)	129.0	84.3				.090	Singer and Rust, 1975

Table Ala: (continued)

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

Table A1a: (continued)

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

Table Ala: (continued)

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

Table Alb: Nitrogen Export from Forested Watersheds

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr): Dissolved Nitrogen					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		
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 1.92	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	25.3	.80										1.37	Taylor et al., 1971
	88.9	35.6	1.60										3.16	
	92.8	32.0	.70										2.82	
Oak-hickory forest (97.5 ha)	136.0	70.7	.40	1.10		1.60	3.10						3.10	Henderson and Harris, 1973
Oak hickory forest (97.5 ha)	189.5	114.8	.1	.3	2.1		2.2						2.2	Henderson et al., 1977
	174.7	116.1	.2	.2	1.5		1.7						1.7	
Oak, maple, yellow poplar, black cherry, beech (34 ha)			.45	1.52										Aubertin and Patric, 1974
			.60	.84										
			.86	.86										
Mixed mature hardwoods, Coweeta hydrologic lab., North Carolina (12.1 - 61.1 ha)			.03	.03										Swank and Douglas 1977
			.06	.05										
			.05	.05										
			.35	.10										
			.05	.07										
			.05	.06										
			.15	.07										
Mixed pine and hardwood													1.50	Correll et al., 1977

Table A1b: (continued)

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

Table Alb: (continued)

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

Table A2a: Phosphorus Export from Row Crops

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

Table A2a: (continued)

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

Table A2a: (continued)

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

Table A2a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Dissolved Phosphorus 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	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 planting (.004 ha)	77.6 77.0 65.76	10.7 8.51 21.95											5.53 3.61 3.96	Minshall, et al., 1970
Corn, continuous planting, fresh manure, winter applied (.004 ha)	77.6 77.0 65.76	12.26 5.95 19.41											26.88 3.05 7.97	Minshall et al., 1970
Corn, continuous planting, fermented manure, spring applied (.004 ha)	77.6 77.0 65.76	11.51 5.59 15.32											5.32 3.35 3.38	Minshall et al., 1970
Corn, continuous planting, liquid manure, spring applied (.004 ha)	77.6 77.0 65.76	12.45 5.61 15.60											2.81 2.88 5.07	Minshall et al., 1970
Corn, continuous planting, no manure (.004 ha)		8.71 14.33											4.08 4.58	Hensler et al., 1970
Corn, continuous planting, fresh manure, winter applied (.004 ha)		7.11 11.53											26.06 4.44	Hensler et al., 1970

Table A2b: (continued)

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

Table A2b: (continued)

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

Table A2b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
Corn, continuous planting (1.29 ha)	107.7	13.0	.86	1.48	5.90				.85	5.66			12.42	Smith et al., 1978
Corn, 6 replications (.001 ha)	87.39		.078	.55									3.29	Bradford, 1974
Soybeans, two crops/yr., conventional till (.01 ha)	118.0 169.2	28.3 83.2	.70 1.0	1.5 2.8								42.7	46.5	McDowell et al., 1978
Soybeans, two crops/yr., no till (.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, continuous planting (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, continuous planting (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 till (.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)											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		
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	Precipitation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Alfalfa no fertilization (.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	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
Wheat continuous planting (5.3 ha)	96.6 73.1 87.9 72.9	23.0 5.5 9.3 5.4		.52 .09 .26 .11	3.77 .50 .53 2.21	4.29 .59 .79 2.32	Menzel et al., 1978
Spring wheat and summer stubble two year rotation (4 - 5 ha)		62.5 7.0	0.3 0.1			0.6 0.1	Nicholaichuk and Read, 1978
Spring wheat and summer fallow two year rotation (4 - 5 ha)		98.0 19.0	0.9 0.1			2.3 0.4	Nicholaichuk and Read, 1978
Spring wheat and fall fertilized summer fallow (4 - 5 ha)		49.0 7.0	2.3 0.2			5.6 0.2	Nicholaichuk and Read, 1978
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				Reference
			PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	
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 no fertilization (.004 ha)	105.4 107.8 108.8	8.2 14.2 18.5	1.36 1.14 2.02	1.27 .98 3.86									6.28 5.66 14.67	Converse et al., 1976
Alfalfa fall applied manure (.004 ha)	105.4 107.8 108.8	5.2 7.8 9.0	1.24 .78 1.50	2.63 3.41 8.92									6.10 6.63 23.09	Converse et al., 1976
Alfalfa winter applied manure (.004 ha)	105.4 107.8 108.8	8.2 10.3 12.8	1.51 .79 1.88	1.71 1.17 13.12									7.82 5.88 38.22	Converse et al., 1976
Alfalfa spring applied manure (.004 ha)	105.4 107.8 108.8	6.7 10.1 15.0	2.69 .98 1.73	3.58 .85 2.75									6.43 4.07 11.42	Converse et al., 1976
Alfalfa and bromegrass two plots (3.55 - 4.10 ha)	57.91	2.69											.10	Harms et al., 1974
Wheat continuous plant- ing (5.2 ha)	96.5 72.9 87.7 73.1	20.8 7.0 10.5 5.5											6.12 3.77 5.63 7.12	Menzel et al., 1978

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

Table A4a: Phosphorus Export from Pastured and Grazed Watersheds

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

Table A4a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus PO_4-P	Total P	Particulate/Sediment Phosphorus	Total Phosphorus	Reference
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					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		
Moderate dairy	106.8	20.2	2.97	.47									3.44	Kilmer et al.,
grazing,	104.3	22.5	2.63	.44		.77							3.83	1974
gluegrass cover	105.5	12.3	1.68	.18		.55							2.41	
(1.88 ha)	119.8	24.6	2.14	.21		1.15							3.47	
Heavy dairy grazing,	106.8	26.0	16.10	1.95									18.05	Kilmer et al.,
bluegrass cover	104.3	26.9	10.79	.61		1.32							12.71	1974
(1.88 ha)	105.5	19.9	7.20	.19		.99							8.31	
	119.8	31.8	7.28	.32		1.46							9.26	
Pasture (6.28 ha)	58.4	4.44	.40		1.12								1.52	Harms et al., 1974
Winter grazed and summer rotational (1 ha)	108.0	12.94	5.75			7.8						8.25	30.85	Chichester et al., 1979
Summer grazed (1 ha)	108.0	2.92	0.5			0.6						0	21.85	Chichester et al., 1979
Rotation grazing	77.83	4.39	1.14	.66						.52			2.32	Schuman et al.,
(42.9 ha)	73.30	.94	.17	.09						.21			.47	1973
	75.40	3.86	.96	.43						2.89			4.28	
Continuous grazing,	105.0	28.4											6.84	Menzel et al.,
little bluestem cover,	77.8	12.6											5.43	1978
active gullies	98.7	17.6											9.23	
(11.1 ha)	50.7	2.02											1.33	

Table A4b: (continued)

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

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

Table A5a: Phosphorus Export from Animal Feedlot and Manure Storage

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

Table A5a: (continued)

Land Use	Precip-itation cm/yr	Water Runoff cm/yr	Phosphorus Export (kg/ha/yr) Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	Reference
			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, 3.70 cows/ha, Ohio (.17 ha)		31.9 27.9		14.11 19.98			Edwards et al., 1972

Table A5b: Nitrogen Export from Animal Feedlot and Manure Storage

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

Table A5b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr): Dissolved Nitrogen NO_3-N	Dissolved Nitrogen NH_4-N	Dissolved Nitrogen TKN-N	Dissolved Nitrogen ORG-N	Dissolved Nitrogen Total-N	Particulate/Sediment Nitrogen NO_3-N	Particulate/Sediment Nitrogen NH_4-N	Particulate/Sediment Nitrogen TKN-N	Particulate/Sediment Nitrogen ORG-N	Particulate/Sediment Nitrogen Total-N	Total Nitrogen	Reference
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)				Reference
			Dissolved Phosphorus		Particulate/Sediment Phosphorus	Total Phosphorus	
			PO_4-P	Total P			
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: (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
60% row crops 40% hay and pasture two livestock feedlots (157.5 ha)	67.79	10.74		.319	.329	.648	Burwell et al., 1974
Three years pasture and two years corn (42.9 ha)	84.71	17.65		.19	.08	.27	Burwell et al., 1977
Intensive agricultural crops and improved pasture (202 ha)	105.0 88.0	21.3 12.1	1.21 .63			1.34 .86	Campbell, 1978
Active cropping and pasture						.409	Grizzard et al., 1977
At least 80% of watershed devoted to agricultural activities				.233		1.29	Avadhanula, 1979

Table A6a: (continued)

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

Table A6a: (continued)

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

Table A6b: Nitrogen Export from Mixed Agricultural Watersheds

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)											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		
60% row crops 40% hay and pasture two livestock feedlots (157.5 ha)	67.79	10.74	1.19	1.37					7.08				9.64	Burwell et al., 1974
Three years pasture and two years corn (42.9 ha)	84.71	17.65	11.68	.40								2.03	14.11	Burwell et al., 1977
Intensive agriculture crops and improved pasture (208 ha)	105.0 88.0	21.3 12.1	.37 .09	.68 .09		5.3 1.92							6.36 2.10	Campbell, 1978
Active cropping and pasture													2.83	Grizzard et al., 1977
At least 80% of watershed devoted to agricultural activities			8.86										14.3	Avadhanula, 1979
37.4% soybean and whitebean 27.1% cereal 23% corn (5080 ha)	72.9							10.7		5.3			16.1	Coote et al., 1978

Table A6b: (continued)

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

Table A6b: (continued)

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

Table A6b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen NO$_3$-N	NH$_4$-N	TKN-N	ORG-N	Total-N	Particulate/Sediment Nitrogen NO$_3$-N	NH$_4$-N	TKN-N	ORG-N	Total-N	Total Nitrogen	Reference
27.8% vegetables 22.8% corn 10.0% woodland 8.9% cereal 7.9% soybean and whitebean (1990 ha)	77.0							21.0		4.2			25.2	Coote et al., 1978
66.6% pasture and hay 12.1% cereal 9.5% corn 9.4% woodland (4504 ha)	92.4							5.4		4.1			9.4	Coote et al., 1978

Table A7a: Phosphorus Export from Urban Watersheds

Land Use	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
Residential (50 ha)	69.93	10.49	.64			1.10	Kluesener and Lee, 1974
78% industrial 22% commercial		7.88 40.18				1.06 4.28	Konrad et al., 1978
Commercial (15.8 ha)	76.5		.64			.88	Much and Kemp, 1978
Central business district (9.3 ha)	76.5		3.58			4.08	Much and Kemp, 1978
Industrial (8.1 ha)	76.5		.62			.75	Much and Kemp, 1978
Residential (41.7 ha)	76.5		.27			.35	Much and Kemp, 1978
Low density residential (46.82 ha)	77.19					0.19	Landon, 1977
Low density residential (33.73 ha)	77.19					2.7	Landon, 1977

Table A7a: (continued)

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

Table A7a: (continued)

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

Table A7b: (continued)

Land Use	Precipitation cm/yr	Water Runoff cm/yr	Nitrogen Export (kg/ha/yr) Dissolved Nitrogen					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		
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					Particulate/Sediment Nitrogen NO_3-N					Total Nitrogen	Reference
			NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N	NO_3-N	NH_4-N	TKN-N	ORG-N	Total-N		
60% residential 19% commercial and industrial 12% institutional 10% unused (432.54 ha)		24.64								6.83				Colston, 1974
20% urbanized large scale residential (47900 ha)													33.76	Grizzard et al., 1978
Single family residential (19.2 ha)	125.6	9.42											1.48	Mattraw and Sherwood, 1977
67% residential 13% commercial 12% woodland 8% agricultural (792 ha)	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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