White Paper (j): Non-Modeling Methods for Estimating Nutrient Loads from Various Sources

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1.0 Overview

Effective development and implementation of a nutrient TMDL requires that information be obtained on the most significant sources in a watershed so that appropriate implementation measures can be identified and prioritized. Stand-alone computer models such as the Soil and Water Assessment Tool (SWAT), the Hydrologic Simulation Program—Fortran (HSFP), and the Generalized Watershed Loading Functions (GWLF) model are often used to estimate nutrient loads from various sources. In some cases, however, it is desirable to make separate estimates of nutrient source loadings, either to complement a non-modeling approach to TMDL development or because the chosen model does not address a certain source. Non-modeling estimates of nutrient source loads can also be used in a screening-level fashion to help select the most appropriate computer model for a more detailed study.

This paper describes potential methods for evaluating nutrient loadings from various sources and provides some of the literature values needed to do so. Because estimating nutrient loads appropriately is a complex task, the focus of this paper is on straightforward approaches that will result in reliable "ballpark" estimates of annual loads. Even so, many of the recommended techniques are the same as those built into the stand-alone models identified above. The use of models is therefore recommended in situations where time and resources are available to do so because, applied appropriately, they will result in more accurate estimates.

There are many potential nutrient sources within a watershed; however, the following are often the most significant sources and are therefore covered here:

- Wastewater Treatment Plants
- Onsite Wastewater Treatment Systems
- Rural Area Runoff
- Urban Area Runoff
- Livestock
- Animal Feeding Operations
- Fertilizer/Manure Application

(Note that estimating nutrient loading from groundwater sources is covered in a separate white paper).

2.0 Wastewater Treatment Plants

Estimating nutrient loads from wastewater treatment plants (WWTPs) is a relatively straightforward process compared to making estimates from other sources. Facilities are required to report monthly average flow volumes as part of their National Pollutant Discharge Elimination System (NPDES) permit requirements. These flow volumes, typically reported in million gallons per day, are available from EPA's Permit Compliance System (PCS) and can be queried at:

http://www.epa.gov/enviro/html/pcs/pcs_query_java.html

Depending on permit requirements, many facilities also report the nutrient concentrations associated with the discharge and this information can also be queried from PCS. Monthly loads can be calculated by multiplying the reported flow volumes by the reported nutrient concentrations (e.g., mg/L x MGD x 3.7854 = kg/d). However, in many cases, complete nutrient series are not reported. For instance, monitoring requirements may include nitrate/nitrite nitrogen, ammonia nitrogen, and orthophosphate, but not total nitrogen or total phosphorus. Organic phosphorus seems to be the component most frequently omitted.

Where effluent nutrient concentrations are not available, literature values for nitrogen and phosphorus wastewater treatment plant effluent can be used. Because treatment efficiency is affected by weather and other local characteristics that may affect wastewater composition, the best approach is to use surveys of other, similar treatment plants within the region. Typical literature values for WWTPs with secondary treatment are 4-10 mg/L total phosphorus and 15-35 mg/L total nitrogen. A summary of a variety of literature sources is provided in USEPA (1997).

3.0 Onsite Wastewater Treatment Systems

Onsite wastewater treatment systems, such as septic systems, can contribute nutrient loads even when they are designed and installed correctly and are functioning properly. Nitrogen is particularly mobile within groundwater, while phosphorus typically is retained in the soil and is not a concern unless the systems are failing and/or located adjacent to surface waters.

The GWLF User's Manual (Haith et al., 1992) provides a methodology for estimating nutrient loads from onsite wastewater treatment systems. Onsite systems are categorized into four types: normal systems, ponded (or failing) systems, short-circuited systems, and illegal direct discharge systems. Nutrient loads from these systems are calculated by estimating the per capita daily load from each type of system and the number of people in the watershed served by each type. A thorough discussion of the many different types of onsite wastewater treatment systems and issues associated with their design and maintenance is also presented in USEPA's *Onsite Wastewaster Treatment Systems Manual* (2002).

Several factors should be considered when estimating the number of onsite systems within a watershed. The best source of information is the local health department, although often this agency will not have thorough records regarding the number or type of each system. Alternatively, the 1990 U.S. Census provides information on the number of households in each census tract served by sewer or other wastewater disposal methods. This information is not reported in the 2000 Census, so one method is to extrapolate the proportion of onsite systems from 1990 to current population estimates. Another is to overlay sewer service boundaries on Census block group household counts. Seasonal residency and/or visitor issues should be addressed depending on their significance in the watershed.

In the absence of local information on the proportion of failing systems, a rough estimate will need to be made. Factors that should be taken into account include the age of the houses in the watershed, soil conditions, and the number of houses located adjacent to surface waters. Septic system surveys in other areas have shown that 15 percent is a reasonable estimate of failing systems (Nelson et al., 1999 as reported in USEPA, 2002), although the value reported for California is much lower (1 to 4 percent). The discussion below summarizes one method for estimate nutrient loads from failing systems and is based on the approach used in the GWLF model (Haith et al., 1992).

3.1 Normal Systems

Normal systems are those that are properly sited and are functioning according to the normal design standards. No loading of phosphorus is assumed to result from normal septic systems because the phosphorus is adsorbed to the soils. Estimates of nitrogen loads from these types of systems are calculated using per capita daily loading and plant uptake rates. Plants growing over the leach fields are assumed to remove a fraction of the per capita nitrate loads before they enter the waterbody. Typical per capita effluent loading rates are cited as 12.0 g/day for nitrogen and 2.5 g/day for phosphorus (Haith et al., 1992). These loading rates are based on typical wastewater characteristics and an assumed flow generation rate of 170 L/person/d, and should be adjusted to reflect local water use rates. The load from the septic tank to groundwater is reduced by nutrient uptake by plants over the leach field. Per capita plant uptake rates during the growing season are approximately 1.6 g/day for nitrogen and 0.4 g/day for phosphorus, and zero during the rest of the year (Haith et al., 1992). Additional reductions take place during groundwater transport to surface waters. As phosphates have a high affinity for soil particles, a reasonable assumption is that the total phosphorus load to surface water from a properly functioning septic system is minimal. Nitrogen, however, is highly soluble and much of the nitrogen discharged from the leach field may reach streams. Further nitrogen uptake may take place by deep rooted plants, particularly in the riparian zone where good stream buffers are maintained, and the estimated load may need to be reduced accordingly.

3.2 Ponded or Failing Systems

Ponded or failing onsite systems are those that are not operating properly for one reason or another. Failing systems can include systems that are backed up and have surfacing effluent, under-designed systems that are being utilized over capacity, systems that were poorly sited, systems in poor soil types, or systems that have poorly functioning leach fields. Nitrogen loads from failing systems can be estimated the same as for normal systems. However, failing systems located relatively near surface waters can contribute phosphorus loads because there is less time for the surfaced effluent phosphorus to be adsorbed to the soils. Failing systems within approximately 150 meters of a surface water can be expected to deliver all of the phosphorus that is not taken up by plants.

3.3 Short-Circuited Septic Systems

In some situations, a watershed might also contain a percentage of “short-circuited” systems. Short-circuited systems represent those that are sited extremely near (less than 15 meters from) a surface water. In these circumstances, little nutrient removal takes place (even if the system is functioning properly) and the nutrient loadings are the same as for failing systems.

3.4 Direct Discharge Systems

These illegal systems discharge effluent directly into surface waters through agricultural tile or stormwater drains. All nitrogen and phosphorus is delivered to surface waters.

4.0 Rural Area Nonpoint Loads

Rural land uses include agriculture, grazing, rangeland, forest, and barren lands and can contribute both dissolved and particulate forms of nitrogen and phosphorus. The particulate nutrients are generally the more significant component and result from the erosion of soils containing vegetation and organic litter. Soluble nutrients are released during the decomposition of organic materials on the landscape and can enter the waterbody through surface water runoff or shallow subsurface flows.

4.1 Loading Factors

The simplest approach to estimating rural area nonpoint loads is through the use of loading factors, which are simply unit-area average loading rates, usually expressed on an annual basis. While a variety of loading factors have been proposed, most of the research on which they are based derives from the eastern and central U.S., with limited information from the West. Because loading rates from a given land use will vary in accordance with local climate and land management practices, general national numbers are of limited applicability in California. More appropriate loading factors could, however, be obtained by extrapolation of summary results from calibrated nutrient loading simulation models from the region of interest. For instance, when the Lake Tahoe watershed modeling is completed and validated, summary results (average annual unit load per acre of a given land use) could be applied as scoping-level loading factors for other watersheds in the ecoregion.

4.2 Regional Regression Approaches

Several attempts have been made to develop empirical/statistical models of nutrient yield at a national scale. Driver and Tasker (1990) developed one such model using USEPA and USGS data. The regression models for storm load total nitrogen and total phosphorus in region I (areas with less than 20 in/yr average rainfall) include storm rainfall, total rainfall, drainage area, industrial land use, commercial land use, and residential land use as explanatory variables. Mean annual load estimates are obtained by estimating the mean load for a storm and multiplying by the average number of storms per year. Further information on this approach is discussed below in the context of urban loads.

The work of Driver and Tasker as applied to rural areas has generally been superseded by the development of the USGS SPARROW approach, based on analysis of data from 414 stations in the USGS National Stream Quality Accounting Network (Smith et al., 1997). This application attempts to account for both load generation and transport downstream. The final model for total phosphorus incorporates information on point sources, fertilizer application, livestock waste production, nonagricultural land area, soil permeability, stream density, and average stream flow. The model for total nitrogen includes these variables, plus average temperature. Smith et al. (2003) provide a simplified procedure for estimating natural background concentrations based only on flow, basin area, atmospheric deposition, and a regional indicator.

These regional regression approaches generally have large error bounds and their training data sets include little data from California. They also provide little resolution relative to specific land uses and are thus of limited value in taking load estimates beyond a general order of magnitude approximation.

4.3 Estimating Particulate Loads

Particulate nutrient loads for rural runoff can be determined by multiplying an estimate of the annual sediment yield by an average sediment nutrient concentration. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is the most common and best-known method to estimate gross annual soil loss from upland erosion and is the underlying methodology used to estimate erosion in watershed models such as SWAT and GWLF. The USLE is an index method having factors that represent how climate, soil, topography, and land use affect soil erosion caused by raindrop impact and surface runoff. Rather than explicitly representing the fundamental processes of detachment, deposition, and transport by rainfall and runoff, the USLE represents the effects of these processes on soil loss. These influences are described in the USLE with the equation:

$$A = (R)\,(K)\,(LS)\,(C)\,(P)$$

> *where, A is estimated soil loss in tons/acre for a given storm or period; R is a rainfall energy factor; K is a soil erodibility factor; LS is a slope-length, slope steepness factor; C is vegetative cover factor; and P is a conservation practice factor.*

The individual USLE factors for a watershed can be estimated based on available information regarding land cover, soils, topography, and literature values. The use of geographic information system (GIS) data layers for elevation, soils, and land cover help to facilitate the USLE analysis for a large area. Data available for such an analysis include the Natural Resources Conservation Service (NRCS) State Soil Geographic Database (STATSGO), the Gap Analysis Program's land cover data, and the U.S. Geological Survey's 30-meter Digital Elevation Models (DEMs). A description of each of the USLE parameters, and sources for estimating each parameter, are described below.

- Rainfall and Runoff (R) – Estimated are available from the literature (e.g., Haan, Barfield, and Hayes, 1994)
- Soil Erodibility (K) – Calculated from the STATSGO data. Average weighted K-factors can be calculated using the K-factor for the surface layer of each soil, and the soil's percent composition in the larger map unit.
- Slope and Slope Length (S)(L) – Average slopes and slope lengths can be calculated for each land use using the 30-meter DEM data. Slope and slope lengths were input into defined formulas to calculate a slope factor (S) and slope length factor (L).

Equation	Conditions
$S = 10.8\sin\theta + 0.03$	$\sin\theta < 0.09$
$S = 16.8\sin\theta - 0.50$	$\sin\theta \geq 0.09$

Note: θ is the slope angle

$$L = \left[\frac{\lambda}{72.6}\right]^m$$

Where λ = slope length, and m = the slope length exponent derived from literature values, and based on the percent slope and the estimated rill to interrill erosion.

- Cover and Management (C) – Literature values based on the GAP land cover classes (Haan, Barfield, and Hayes, 1994)
- Erosion Control Practice (P) – Estimated from literature values (Haan, Barfield, and Hayes, 1994), (Brady, 1990)

The six USLE soil factors are multiplied together for each unique combination of land cover and soil type in the watershed and then summed for an annual estimate of soil erosion. Vanoni (1975) developed a formula for estimating the sediment delivery ratio (SDR) of the eroded soil that is a function of watershed area. The formula is shown below.

$$SDR = 0.418(Watershed\_Area)^{-0.135} - 0.127$$

Where watershed area is in square kilometers.

Estimates of sediment yield are used to calculate nutrient loads by multiplying the sediment yield by the nutrient concentrations in the soils. National level information on typical soil nutrient concentrations is summarized in the GWLF User's Manual (Haith et al., 1992). This information has proven to be of limited accuracy in evaluating individual watersheds, where the soil nutrient concentrations depend on the soils present as well as agricultural practices. Therefore, locally derived estimates consistent with the soil type are preferred.

5.0 Urban Area Runoff

The nutrient loads originating from areas of residential and commercial land uses are generally assumed to occur as particulate forms of nutrients that are washed into the waterbody during stormwater runoff events, primarily through stormwater drains. Various uses lead to nutrient accumulation on the land surfaces between runoff events. Within residential areas, potential nutrient sources can include lawn care fertilizers, organic debris from gardens, trash, and domestic animal waste. These loads vary according to weather and duration of exposure to sources, and are typically highest during a major storm event that follows an extended dry period. However, some activities, such as landscape irrigation, lawn watering, spraying parking lots and driveways, and washing cars, can contribute nutrient loads during dry periods.

Two methods are described below for making screening-level estimates of nutrient loads from urban area runoff. The Simple Method may be used to estimate pollutant concentration runoff from urban drainage areas and is based on storm event calculations. The USGS Regression Method estimates source loading as a function of land-use, percentage of imperviousness, drainage area, mean annual rainfall, and mean minimal monthly temperature.

5.1 Simple Method

The Simple Method is a lumped parameter empirical model to estimate nonpoint source pollutant loadings under conditions of limited data availability (Schueler, 1987). Runoff is estimated using runoff coefficients for the fraction of rainfall converted to runoff. A correction factor is used to account for those storms that do not produce runoff. Pollutant concentrations in runoff depend on the land use activity and can be obtained from sampling programs such as the National Urban Runoff Program (NURP) or from site-specific monitoring data. Data requirements, consisting of land use, land area, event mean pollutant concentrations, and mean annual rainfall, are usually easily obtainable. In the Simple Method, the amount of rainfall runoff is assumed to be a function of the imperviousness of various land uses. More densely developed areas have more impervious surfaces, such as rooftops and pavement, which cause more stormwater to runoff rather than be absorbed into the soil. The Simple Method equation is given as:

$$\mathbf{L = (P \times P_j \times Rv/12) \times C \times A \times 2.72}$$

where:

- L = urban runoff load (pounds per time interval, typically annually or monthly)
- P = rainfall depth (inches) over desired time period
- Pj = fraction of rainfall events that produce runoff (the default is 0.9, but adjustment may be appropriate for local conditions)
- Rv = runoff coefficient, which expresses the fraction of rainfall which is converted into runoff.
- C = event mean concentration of the pollutant (mg/L or ppm)
- A = area of the watershed (acres)
- 12 = conversion factor (inches/foot)
- 2.72 = conversion factor (pounds/acre-foot-ppm)

Schueler (1987) developed a relationship between watershed imperviousness and the storm runoff coefficient (Rv):

$$\mathbf{Rv = 0.05 + 0.9(I)}$$

where:

I = impervious fraction

The Simple model may be used directly to estimate loads by applying even mean concentration values to the runoff estimates. Implementation of this approach is provided in the PLOAD model (USEPA 2001), distributed with the EPA BASINS system.

The Center for Watershed Protection (Caraco et al., 1998) further refined this approach to develop the spreadsheet SUNOM model. In this approach, runoff is separated into fractions from natural and managed areas (Rn and Rm) through

$$Rn = \frac{0.9\,P\,A_{P1}}{A} \bullet \left[0.05 + 0.9\,I_{P1}\right]$$

$$Rm = \frac{0.9\,P\,A_{P1}}{A} \bullet \left[0.05\left(A_I + A_{P2}\right) + 0.9\left(A_I + I_{P2}\,A_{P2}\right)\right]$$

where *A* is area, *I* is impervious fraction, the subscripts *I* and *P* refer to the impervious and impervious areas, and the subscripts 1 and 2 refer to the managed and natural areas, respectively.

Given the runoff estimates, surface stormwater load may be estimated by multiplying times a typical concentration. The default values recommended by Caraco et al. are shown in **Error! Reference source not found.**. As with all such estimates, revisions to reflect data from local event mean concentration studies are usually needed. The SUNOM model also contains simplified representations of stormwater infiltration load, septic system load, and load reduction from stormwater BMPs.

Table 1. Default Surface Runoff Concentrations for the SUNOM Model (Caraco et al., 1998)

Constituent	Natural Area Concentration (mg/L)	Managed Area Concentration (mg/L)
Nitrogen	0.8	2.0
Phosphorus	0.15	0.25

The effects of dry weather flows can be addressed using the Simple Method by modifying the precipitation estimate for land uses that are watered. For example, typical lawn watering recommendations can be added to monthly rainfall values for land uses likely to be watered. This will result in higher load estimates from these areas to approximate the contribution from dry weather flows.

5.2 USGS Regression Method for Estimating Source Loadings

The USGS Regression Method is used to estimate pollutant concentration from urbanized watersheds and relies upon a statistical approach to estimate annual, seasonal, or storm event mean pollutant loads. The method uses regression equations for estimating mean storm event pollutant loads, and it provides users with a confidence interval to bracket estimates of loading. The method is valid only for areas where regression coefficients are obtainable (i.e., regional transferability is limited). The method applies to smaller watersheds.

The regression approach USGS researchers developed is based on a statistical description of historic records of storm runoff responses on a watershed level (Tasker and Driver, 1988). This method may be used for rough preliminary calculations of annual pollutant loads when data and time are limiting. Simple regression equations were developed using available monitoring data for pollutant discharges at 76 gauging stations in 20 states. Separate equations are given for 10 pollutants, including for dissolved and total nutrients. Input data include drainage area, percentage imperviousness, mean annual rainfall, general land use pattern, and mean minimum monthly temperature. Application of this method provides storm-mean pollutant loads and corresponding confidence intervals. The general form of the regression model follows:

$$W = 10^{\left[a + b\sqrt{DA} + c\,IA + d\,MAR + e\,MJT + f\,X_2\right]} \bullet BCF$$

where:

W	=	mean load, in pounds, associated with a runoff event
DA	=	drainage area in square miles
IA	=	impervious area, in percentage of DA
MAR	=	mean annual rainfall, inches
MJT	=	mean minimum January temperature, in degrees Fahrenheit
X_2	=	land-use indicator variable
BCF	=	bias correction factor

The appropriate regression coefficients for a, b, c, d, e, and f can be obtained from Tasker and Driver (1988). For example, to compute the mean annual load of total nitrogen, in pounds, at a 0.5-mi^2 basin that is 90 percent residential with impervious area of 30 percent and in a region where the mean number of storms per year is 79, first compute the mean load for a storm, W, using the appropriate regression coefficients. Plugging in the values from Tasker and Driver(1988) provides a mean load, in pounds, of 16.9. The mean annual load can be calculated by multiplying this value by 79, the average number of storms per year, to yield a mean annual load of 1,335 pounds of total nitrogen per year.

Table 2. Selected values from Tasker and Driver (1988).

Dependent Variable	Regression Constant a	SQRT (DA) b	IA c	MAR d	MJT e	X2 f	Bias Correction Factor
Total N	– 0.2433	1.6383	0.0061	-	-	– 0.442	1.345
Total NH3+N	– 0.7282	1.6123	0.0064	0.0226	– 0.0210	– 0.4345	1.277
Total P	– 1.3884	2.0825	-	0.0234	– 0.0213	-	1.314
Dissolved P	– 1.3661	1.3955	-	-	-	-	1.469

6.0 Livestock in Surface Waters

Livestock that spend significant periods of time in or near surface waters can contribute significant loads of nitrogen and phosphorus because they use only a portion of the nutrients fed to them and the remaining nutrients are excreted. For example, in a normal finishing diet, a yearling cattle will retain only between 10 percent and 20 percent of the nitrogen and phosphorus it is fed. The rest of the nutrients are excreted as waste, and are thus available for runoff into nearby waterbodies or into the groundwater (Koelsch and Shapiro, 1997).

Table 3 provides nutrient production rates for various types of animals. One can estimate annual nutrient manure loads by multiplying the total number of animals, the average weight for each animal, and the appropriate nutrient production rate. This load will represent the total mass of nutrients produced in manure in the watershed, which of course is larger than the load that reaches surface waters. Estimates of the proportion of the manure that is deposited into surface waters should be based on the percent of time the animals spend in or very near surface waters.

Table 3. Nutrient Production Rates by Type of Animal

Type of Animal	Typical Animal Weight (pounds)	Pounds of N per lb. of animal weight per year	Pounds of P_2O_5 per lb. of animal weight per year
Beef Cow	800	0.12	0.10
Dairy Cow...50 lb./d	1400	0.18	0.09
Dairy Cow...70 lb./d	1400	0.22	0.10
Dairy Cow...100 lb./d	1400	0.27	0.11
Calves	500	0.11	0.03

Sources: NRCS, 1999 except for dry cows. Dairy estimates are from Van Horn, 1991.

6.1 Feedlot Runoff

Feedlot runoff represents another potential source of nutrients and occurs when animal feeding operations are located near surface waters. Table 4 shows an average loss factor by nutrient type for a variety of manure storage systems. These rates were originally developed to estimate the amount of the nutrients still available within the manure, but have been adapted to provide perspective on nutrient loads from different types of systems. An estimate of the amount of nutrients lost from the manure can be calculated by multiplying the total nutrient load of the manure (using Table 3 above) by the loss factor. For example, if a top loaded liquid manure storage facility contains 45,000 pounds of nitrogen approximately 13,500 pounds is assumed to be “lost” to the environment. Some proportion of this loss might reach surface waters depending on the distance to the nearest waterway.

Table 4. Manure Storage Nutrient Loss Rates by Storage System Type.

Manure Storage/Treatment System	Loss Factor for Nitrogen	Loss Factor for Phosphorus
Open Lot or Feedlot	0.50	0.05
Manure pack, under roof	0.30	0
Storage (slurry manure, bottom storage)	0.15	0
Storage (liquid manure, top loaded storage)	0.30	0
Storage (pit beneath slatted floor)	0.25	0
Poultry Manure stored in pit beneath slotted floor	0.15	0
Poultry Manure on shavings or sawdust held in housing	0.50	0
Compost	0.30	0
1-Cell anaerobic treatment lagoon	0.80	0.65
Multi-Cell anaerobic treatment lagoon	0.90	0.65

Source: Adapted from NRCS, 1999.

6.2 Manure or Fertilizer Application

The primary concern with the application of manure or fertilizers on crops or forage areas is that the application might exceed the uptake capability of the crop. If this occurs, the excess nutrients become mobile and can be transported to either nearby surface waters, the groundwater table, or the atmosphere. Many farming operations calculate the nutrient plant requirements and only apply the necessary fertilizer or manure. However, large livestock farms and dairies often have more manure than they do land resources and thus their manure application rates are higher than the crop uptake rates.

To estimate the amount of the load attributed to manure or fertilizer applications, a comparison can be made between the nutrient application rate and the crop removal values, shown in Table 5. This quick check provides a preliminary indication as to whether sufficient land is available for distributing the fertilizer/manure nutrients or if there is an over-application that exceeds the plant/crop uptake.

Table 5. Average Nutrient Removal Rates by Crop Type.

Type of Crop/Forage	Average Nutrient Removal Rates	
	N Content Removal Rate	P_2O_5 Content Removal Rate
Grains	*(lb. of N per bu. of grain)*	*(lb. of P_2O_5 per bu. of grain)*
Corn Grain	0.90	0.39
Grain Sorghum	0.90	0.38
Oats	0.38	0.24
Soybean	3.76	0.82
Wheat	1.36	0.50
Forage	*(lb. of N per bu. of forage)*	*(lb. of P_2O_5 per bu. of forage)*
Alfalfa Hay	57.2	11.8
Alfalfa Haylage	25.0	5.5
Corn Silage	8.6	3.2
Forage Sorghum	7.0	2.7

Source: Koelsch and Shapiro, 1997.

Fields receiving livestock manure require regular soil testing and close monitoring of soil phosphorus levels. Phosphorus levels over 150 to 200 ppm represent a risk to surface water quality due to potential phosphorus loss in surface runoff (Koelsch and Shapiro, 1997). Annual manure applications to the same field will result in increased soil phosphorus levels.

Application of manure usually applies more phosphorus than a crop needs. Most crops have an uptake of nitrogen and phosphorus that is in a ratio of 4.5 to 9 pounds of nitrogen per pound of phosphorus. (Koelsch and Shaprio, 1997). Manure is generally excreted at N to P ratios of 2 - 3 to 1, meaning that there is 2-3 times as much phosphorus in manure than most crops can remove through uptake. In addition, as manure is stored – the nitrogen is more readily lost, resulting in even higher N to P ratios in field applied manure.

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