PAPER NO. 80-2015

NONPOINT SOURCE LOADING RATES FROM SELECTED LAND USES

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For presentation at the 1980 Summer Meeting
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

San Antonio Convention Center
San Antonio, TX
June 15-18, 1980

SUMMARY:

Selected land uses were evaluated with respect to areal loadings. Land uses examined were construction sites, barnyards and agricultural dairying. While sediment yields were highest from the construction site, runoff from the barnyard area was considered to have the highest potential for adverse water quality impacts.

American Society of Agricultural Engineers

St. Joseph, Michigan 49085

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[1/] This work was supported by the Soil Science Department, College of Agricultural and Life Sciences, University of Wisconsin-Madison, and the U.S. Environmental Protection Agency, Region V, Chicago, Illinois (Grant No. G005139-01).

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ABSTRACT

Loading rates derived from monitoring natural runoff from selected land uses are compared. Land uses selected for evaluation are construction sites, barnyards, and agriculture (dairying). Runoff volumes, sediment, and nutrient fractions were monitored and expressed as areal loadings for comparison purposes.

Sediment yield and total phosphorus (total P) loss was directly proportional to runoff (m^3/ha). In decreasing order, the loadings for sediment and total P were as follows: construction site > barnyard > general dairying. Runoff from the barnyard area was approximately 10 times higher in soluble phosphorus and ammonium nitrogen than the other land uses under investigation. Areal loss for nitrate nitrogen was highest from the construction site and was attributed to the higher volume of runoff per unit area.

Results show that barnyards in a dairying watershed are potentially a major source of sediment and nutrients, especially those dissolved fractions which have the potential for immediate water quality impacts. Relative to general agricultural land, urban construction sites also appear to be a major source of sediment and nutrients. As with barnyard sites, however, the effect of such sites on water quality likely depends on proximity to surface water bodies and other watershed characteristics affecting delivery ratios of contaminants.

INTRODUCTION

A major objective of Public Law 92-500 is the development of control strategies for limiting contaminant loads arising from agricultural nonpoint sources. To address this issue investigations were started whereby the existing data base was examined to compare loading rates from different land uses and to develop monitoring programs to examine specific land uses posing potential problems. As experience was gained in the process it became clear that regional conditions would dictate the major nonpoint problems and the results were not necessarily transferable.

Within the Great Lakes Region, sediment from cropland and barnyards located in close proximity to streams has been identified as major sources of nonpoint pollution. The most dominant type of agricultural land use in the Great Lakes Region is dairying (Great Lakes Basin Commission, 1974). Unfortunately, sediment yield data arising from this type of activity are currently unavailable. However, in related watershed studies, Olness et al. (1975) determined sediment yields in Oklahoma of 9 and 18 metric tons/ha/yr for dry land and irrigated cotton, respectively. For mixed farmland in Nebraska, Dragoon and Miller (1966) showed that areas under sound management produced 8.9 metric tons/ha/yr as compared to 13/6 metric tons/ha/yr for areas lacking in conservation practices. Burwell et al. (1975) and Schuman et al.(1973) found that sediment yields can exceed 25 metric tons/ha/yr on highly erodible, poorly managed soils. Murphee et al. (1976) found similar losses from intensively tilled soils of the Lower Mississippi Valley.

Similarly, data have been lacking on the annual loading rates from animal concentration areas (barnyards) typical of the dairying enterprise. The pollution strength of the runoff waters from such areas has been well documented from a concentration standpoint (Miner et al., 1966; Robbins et al., 1972; Cramer et al., 1976). However, annual loads developed as a result of natural rainfall is lacking.

This publication adds to the evolving data base on nonpoint pollution and compares, where possible, loading rates from specific land uses such that priority problems can be identified. The data are from an ongoing water quality monitoring program loacted in southeastern Wisconsin (Washington County). The research and demonstration aspects of the project were directed toward developing two years of base line data on the extent of the nonpoint pollution problem in a dairying watershed. After obtaining reliable base line data, the effect of various best management practices on water quality were to be examined.

MATERIALS AND METHODS

Three agricultural subwatersheds having land use typical of dairy-based agriculture in the Great Lakes Region were selected for monitoring from within the Kewaskum Creek Watershed near the town of Kewaskum, Wisconsin (Fig. 1). The majority of soils in the upland areas of these watersheds are of the Hochheim-Theresa association. They are well-drained soils formed in loess overlying sandy loam and loam-glacial till with a clay loam subsoil. In the main drainageways, soils consist of very poorly drained organic soils of the Houghton-Palms-Adrian association (alluvium).

Topography, land use and the location of monitoring sites are illustrated in Figure 1. The K1 monitoring site is located in the main drainage way of the 167-ha watershed. The K2 site monitors a 27-ha subwatershed of the K1 watershed, and the K4 site monitors a separate 9.4-ha watershed. The majority of cropland in each watershed is corn, oats and hay. For the 1977 cropping year, crops in the K1 watershed consisted of 19% corn, 33% oats and 32% hay;

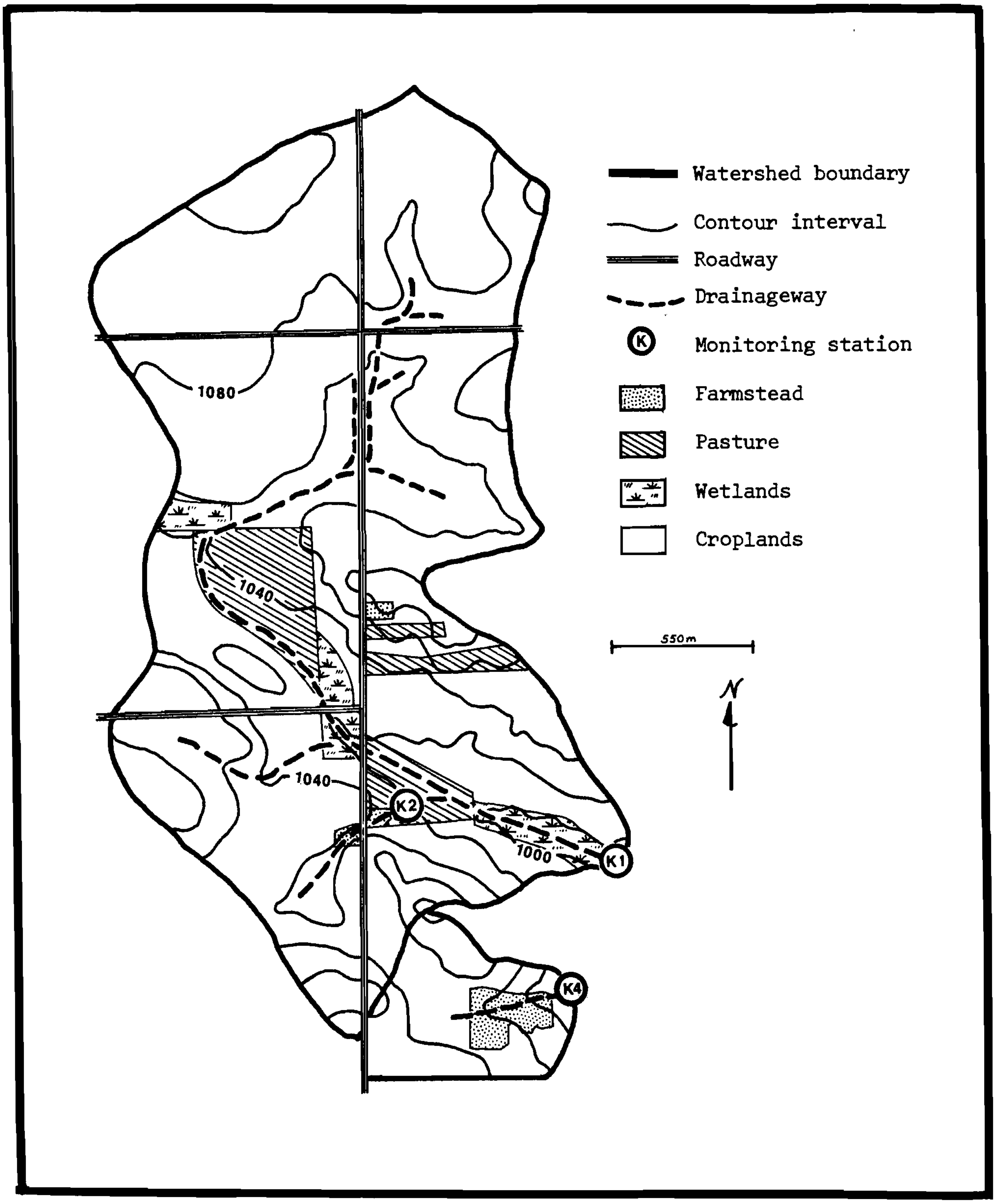

Figure 1. Land use map of the Kewaskum Watershed, indicating cropping pattern (1977), topography, monitoring stations and subwatershed boundaries.

the K2 watershed 11% corn, 53% oats and 34% hay; and the K4 watershed 32% corn, 0% oats and 62% hay. Approximately 28, 42 and 72% of the cropland within the K1, K2 and K4 watersheds, respectively, were stripcropped or contour-stripcropped. In most cases the remainder was tilled perpendicular to the direction of the major slope. Conventional tillage methods were used in all cases.

Although the K4 monitoring site does contain cropland, the primary factor in location was its proximity immediately downslope of a typical dairy barnyard having potential water quality problems. Approximately 0.6 ha served as an exercise and feedlot area for approximately 85 head of dairy cattle. The steep areas (4-6%) received excessive cattle traffic and little vegetation remained. Additionally, such conditions hampered manure removal and as a result manure accumulated, especially during winter months. Above K2 approximately 35 head of dairy cows were pastured in a much less extensively used area. Vegetative cover was maintained and the manure was removed daily from the barnyard area. Topographic and management conditions indicated that the results would be more representative of cropland runoff rather than adverse barnyard conditions. About 35 additional cattle were similarly pastured near the center of the K1 watershed, but removed from any major drainageways. An additional 70 head of cattle were located in various other areas of the K1 watershed but in concentrations less than the above.

The flow-control structures utilized at sites K1 and K2 were 1.07 and 0.61 m broad-crested weirs (5 to 1), respectively. At site K4, a 1.22 m HL flume was used. Sites were instrumented with automated equipment capable of providing a continuous record of discharge volume and of collecting samples of water discharged as a function of flow volume. Further details of site instrumentation are given in Daniel et al. (1978). Precipitation data were collected at site K2 with a recording rain gauge (25 cm single traverse, Universal, Belfort INst. Co., Baltimore, MD). The kinetic energy (E) and maximum 30-min intensity (I) were determined from precipitation data for each rainfall event using methods described by Wischmeier and Smith (1958) and Holtan et al. (1962). The rainfall factor (R) was calculated by summing the product of E and I for each event.

Runoff samples were frozen shortly after collection; they were thawed (25°C) and a portion of each was filtered through a 0.45 μm filter (Millipore Corp. Bedford, MA) before analysis. The filtrate was analyzed for nitrate plus nitrite nitrogen $(NO_3 + NO_2)$-N, ammonium nitrogen (NH_4-N) and dissolved molybdate reactive phosphorus (DMRP). Aliquots of unfiltered samples were analyzed for suspended solids (SS) and total phosphorus (total P). Event loads were calculated by summing the product of the parameter concentration and volume increment for each sample collected during the event. Annual loads of the various parameters for each watershed were calculated by summing each event load. To compare between watersheds the results were normalized and expressed as kg/ha/yr.

RESULTS AND DISCUSSION

Water quality monitoring stations were implemented during the fall of 1975. However, 1976 was one of the driest years on record, therefore, no runoff occurred (Daniel, et al., 1979). Rainfall and runoff during 1977 were near normal and the remedial measures were implemented during 1978. Therefore, only one year of base data was obtained and is reported as 1977 results.

Precipitation

Total rainfall at site K2 for 1977 was 72.6 cm. This is similar to the 30 year average of 77.2 cm recorded at a nearby U.S. Weather Bureau Station in West Bend, Wisconsin. The rainfall factor (R) in the USLE was determined to be 261. Additional U.S. Weather Bureau data shows average annual R values to range from about 40 to 230 over the past 30 years. Thus, the 261 value for 1977 is higher than the average 112 reported for this area by Wischmeier and Smith (1965). A major reason for this high R value for 1977 was an intense storm which occurred June 11 and accounted for approximately 44% of the total R value for 1977.

For comparison purposes, a portion of the information collected during 1977 from an area undergoing residential construction 25 km from the agricultural watersheds is presented with the data. Data from this site will be denoted as G2 results. Total rainfall at the urban site averages approximately 75.6 cm and had an average R value of 197. Unlike that for the agricultural watersheds, the R value is not dominated by a single rainfall event but is reasonably well distributed among several major events. Further details regarding the urbanizing watershed are presented in a separate paper (Daniel et al., 1979).

Runoff Volume

The amount of rainfall-induced runoff per ha in decreasing order is as follows: Construction site (G2) > barnyard (K4) > dairying (K2) > dairying (K1). Among the agricultural sites, greatest amounts of runoff occurred at K4 (Fig. 2). This is due in part to the higher proportion of land used for barnyard purposes in the K4 watershed. The compaction caused by animals can greatly reduce infiltration rates and increase runoff. The pastured area immediately upslope of the K2 site may similarly have caused greater runoff volumes than those observed at K1. However, because of less intensive land use the compaction problem was not as extensive as at the K4 site. During the

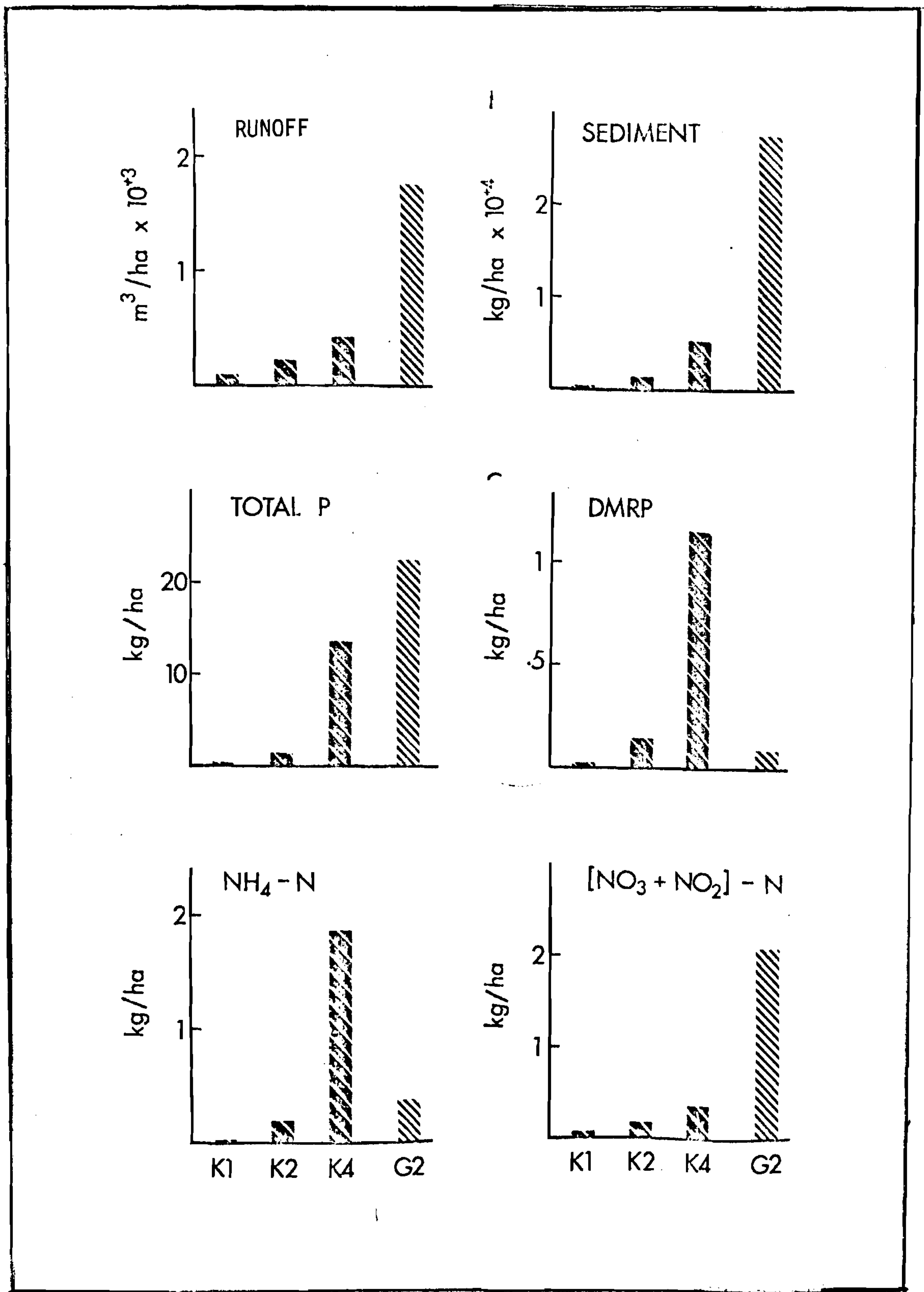

Figure 2. Influence of land use on loading rates from nonpoint sources.

same year, runoff volumes occurring at the construction site (G2) were 4 to 10 times greater than those at the agricultural sites.

Sediment Yield

Relative differences and the order of sediment yield paralleled those of runoff volumes (Fig. 2). This is in agreement with results of Williams and Berndt (1977) who demonstrated a direct relationship between sediment yield and runoff volume. For the agricultural watershed, K4 produced approximately 5.5 MT/ha/yr with the K1 site producing <0.5 MT/ha/yr. Somewhat higher results were received from K4 than expected and was attributed to adverse site conditions. Sediment yields from K1 were lower (<0.5 MT/ha) than previous literature would indicate for cropland. This was attributed to the high percentage (65%) of the upland area devoted to cover crops. However, this aspect is inherently part of the dairying enterprise and as such sediment yields would be expected to be lower than a watershed devoted to row crops. An additional factor which may have influenced the low sediment yield from K1 is the presence of an upstream marsh area. Some runoff velocity reduction and settling out of suspended solids (SS) did occur, however, the extent of deposition is difficult to estimate because the stream followed a defined channel through the marsh area. As with runoff volumes, sediment yields were much higher from the construction site (27 MT/ha/yr) than from the agricultural watersheds (<1 MT/ha/yr).

Nitrogen and Phosphorus Losses

As shown by Burwell et al. (1975) total P loads were primarily associated with sediment (Fig. 2). Thus, the order and relative differences in total P loads between sites were similar to those for sediment yield (Fig. 2). Among agricultural sites, greatest nutrient losses occurred below the barnyard area (K4). Particularly for total P, yields at K4 reached 14 kg/ha/yr and appear disproportionately high relative to differences in sediment yield suggesting a more nutrient-rich sediment from the barnyard site. Further indications of the presence of a high animal concentration are chemical oxygen demand (COD) (Taras et al., 1971) values found in K4 runoff, i.e., values of 5,000 ppm were common with maximums as high as 15,000 ppm.

Among the dissolved parameters measured on filtered runoff samples, relative differences in DMRP and NH_4-N between sites were markedly similar (Fig. 2). For both, much greater losses (>1 kg/ha/yr) occurred at site K4 than at any of the other sites monitored. This was undoubtedly due to the relatively large contribution of nutrients from animal manure at this site. Although DMRP and NH_4-N losses were somewhat higher below the pastured area at K2 than at K1, areal losses for both sites were much less than those at site K4. For both DMRP and NH_4-N, the flow-weighted average concentrations in runoff were less at urban sites than agricultural sites. For NH_4-N, the concentrations were 0.20 ppm for G2 and 1.0 ppm for K2. DMRP values for G2 were 0.1 ppm with K2 approaching 0.60 ppm. However, due to higher runoff volumes at the urban site, total load was similar to that at K2 and greater than that at K1.

Relative differences in dissolved $(NO_3 + NO_2)$-N runoff for all land uses studied range from 0.6-1.25 ppm. Loehr (1974) has reported NO_3-N concentrations in rainwater to be relatively constant at about 1 ppm. This suggests that for the land uses studied, precipitation was the major contributor and the amount of runoff was the major determining factor for $(NO_3 + NO_2)$-N losses. This is not surprising as sediment should act neither as a source nor a sink for NO_3 or NO_2 unless rapid nitrification is occurring during the runoff event. Thus, due to greater runoff volumes, $(NO_3 + NO_2)$-N losses were greater at urban sites.

DISCUSSION

The data reported here were from only one year. While several years of data would provide more credence to derived loading rates, it has been our experience that these systems are so inherently variable that only wide ranges in loading rates can be developed for any of the contaminants. The issue that appears to be more important is the relative differences between land uses. From this standpoint the single year's data is meaningful. While local conditions will vary from year to year and will greatly affect the loading rates, the relative differences in loading rates between the land use should not change and thus will be of value in establishing priorities.

For the results reported here, it is clear that the highest areal loadings of sediment and nutrients in a typical dairying watershed arises from barnyard areas. Although the 5.5 MT/ha/yr sediment yield from the barnyards was considerably less than from construction site areas, runoff from barnyards contain contaminants which have more potential for affecting water quality adversely. The total P load from the barnyard area is approximately 10 times higher than from the other agricultural land uses. Additionally the dissolved fraction of the runoff is high in DMRP and NH_4-N, each having the potential for immediate effects on water quality, such as rapid algae blooms and aquatic weed growth.

It is also interesting to note that sediment yield from dairying activity is low when compared to the other land uses. Clearly this reflects the high amount of land area protected by cover crops. Runoff and sediment yield was consistently highest from the construction site, but the dissolved fraction of DMRP and NH_4-N were low. Nitrate loading was highest from the construction site and attributed to the greater amount of runoff.

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