Application of soil survey to assess phosphorus loss by runoff from agricultural watersheds

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Abstract
The loss of nutrients in runoff from agricultural land is a major cause of poor surface water quality in the United State. Scientists (NRCS) developed a technique to estimate the impact of agricultural watersheds on natural water resources. The objectives of this study were to apply this technique on the Wagon Train (WT) watershed (Lancaster County, Nebraska) to predict: loss of phosphorus (P) from soils by runoff, and P loading for WT reservoir. The predicted annual P loss by runoff was 844 kg and could be considered as the annual loading for WT reservoir. The predicted P concentration in the runoff water at field sites was 196 µg/L. The average P concentration in water samples taken from different locations in the reservoir was 140 µg/L . The average P concentration observed in the main stream samples for the entire rainy season (March through October), ranged between 157 and 346 µg/L with an average of 267 µg/L (SD = 65 µg/L). Application of P fertilizers (April/May) for summer crops might explain the increase in P concentration. When factors affecting P concentration in streams are considered, the technique could provide a reasonable estimation of P concentration in stream water.

Key Words
Runoff phosphorus, runoff water, agricultural watershed.

Introduction
Managing nonpoint sources of contamination from agricultural land is technically complex. Contamination sources often are located over a large geographic area and are difficult to identify. Identifying hot spots within a watershed enables more efficient use of funds to alleviate potential problems and protect water resources. The NRCS developed an exploratory technique (Elrashidi *et al.* 2003; 2005; 2008) to estimate P loss by runoff for agricultural watersheds. The NRCS technique applies the USDA runoff curve number (USDA/SCS 1991) to estimate loss of runoff from soils by rainfall. The technique assumes that dissolved P is lost from a specific depth of surface soil that interacts with runoff and leaching water. Geographical Information Systems, GIS (ESRI 2006) are used to present data spatially in watershed maps. The objective was to apply the NRCS technique on Wagon Train (WT) watershed in southeast Nebraska to estimate P loss from soils by runoff and loading in WT reservoir.

Methods
Estimation of Runoff Water
Rainfall is the primary source of water that runs off the surface of small agricultural watersheds. The main factors affecting the volume of rainfall that runs off are the kind of soil and the type of vegetation in the watershed (USDA/SCS, 1991). The runoff equation can be written as follows:

$$Q = \{R - [2(100 - CN)/ CN]\}^2 \div \{R + [8(100 - CN)/CN]\} \quad (1)$$

Where : Q = runoff (inches), R = effective rainfall (inches), CN is runoff curve number which is dependent on both the hydrologic soil group and type of land cover. The hydrologic groups of the major soils are used to determine CN's for different land covers in the watershed.

Soil & water sampling
Wagon Train (WT) watershed lake is a 128-hectare (315-acre) reservoir. The total drainage area encompass 4,042 hectare (9,984 acre) of agricultural land. Most of the area (70%) is cultivated with crops while the rest of the watershed is covered with grassland. We used the Soil Survey Report of Lancaster County, Nebraska (Brown *et al.* 1980) to determine the major soil series in WT watershed. In total, 72 soil samples from cropland and 24 from grassland were collected. Water samples taken along the main stream were assumed to represent the surface water runoff generated from the entire watershed. During the rainy season period from April to October, monthly samples were collected from three locations along the main stream and the reservoir. The soil and water sampling locations are shown in Figure 1.

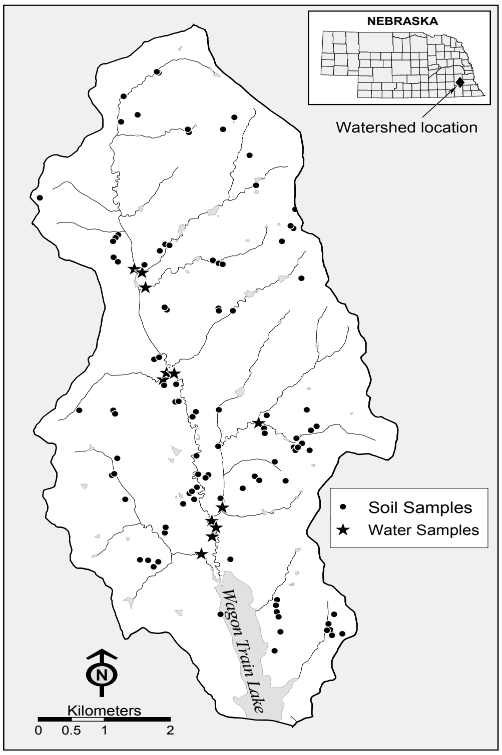

Figure 1. Soil and water sampling locations in Wagon Train watershed, Lancaster County, Nebraska.

Determining dissolved P in soils and water
Soil samples were collected from major soils under various land covers in the watershed. Soil properties were analyzed on air-dried < 2-mm soil by methods described in Soil Survey Investigations Report (SSIR) No. 42 (USDA/NRCS 2004). Soil water-extractable P was determined according to the Soil Survey Laboratory procedure (4D2b1) (USDA/NRCS, 2004), where P was measured in the filtrate by the Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) (Perkin Elmer 3300 DV). During the entire rainy season, water samples were collected (grab) in the main stream and reservoir. Phosphorus concentration in water was determined by ICP-OES.

GIS digital mapping
Digital maps for water and P losses from agricultural land in the watershed were generated by Geographical Information Systems (GIS) software. The GIS software: ArcView 9.2 (ESRI 2006).

Results
Predicted loss of water by runoff
Generally, the loss of water by runoff was slightly higher for fallow than cropland while grassland produced relatively lower values. The predicted average of runoff water was 1242, 1122, and 939 m^3/ha/yr for fallow, cropland, and grassland, respectively. These results accounted for 17.0, 15.4, and 12.9 % of the annual rainfall for fallow, cropland, and grassland, respectively. The total annual loss of runoff water from the 12 major soils was 4.15 million m^3. The area of the 12 major soils (3885 ha) cover about 96% of the entire watershed. Thus, when the entire watershed area (4042 ha) was considered the total annual runoff accounted for 4.31 million m^3 of water.

Predicted and observed monthly water inflow for WT reservoir
The runoff model (USDA/SCS 1991) appeared to underestimate the observed water flow to the reservoir for February and March while overestimating the inflow for August and September. According to the historic record of Lancaster County (NWCC 2003), a total of 607 mm (23.9 inches) of snow falls during the winter. Usually, a large portion of this snow remains on the ground because of the cold weather. The moderate temperature in early spring could melt much of the snow which increases the water inflow for the reservoir. This snow melt might explain the underestimation of the inflow for February and March. During the hot summer period, crops such as corn and soybean are in full growth and have a high demand for water.

Further, the high temperature and low relative humidity could dry the surface soil and increase evapotranspiration by plants. These combined factors could reduce the runoff and reservoir inflow and thus explain the overestimation for August and September. The underestimation in early spring appeared to offset the summer's overestimation and kept the predicted annual runoff water (4.31 million m^3) in good agreement with the observed annual inflow (4.25 million m^3).

Predicted P loss by runoff
The average annual runoff P was 243 g/ha for fallow, 217 g/ha for cropland and 190 g/ha for grassland in the watershed. No large livestock feedlots or intensive cattle grazing are currently present in the WT watershed area. Phosphorus fertilizer (50-60 kg P_2O_5/ha) is usually applied to cropped soils during the preparation for summer crop while grassland soils receive smaller amounts and less frequent fertilizer application as well as occasional animal-waste additions. The fact that the soil sampling had been completed prior to fertilizer application might explain the relatively low P content found particularly for cropped soils and runoff waters.

Predicted monthly P loading
We used the predicted average P concentration in surface water runoff generated from the entire watershed (196 µg P/L) and the volume of monthly surface water runoff to estimate the monthly P loading (kg) for WT reservoir, which is illustrated in Figure 2. Expectedly, the results indicated that P loading into the reservoir was least during the winter and averaging about 20 kg/month. Most of P loading in the reservoir occurred during the spring and summer (93 kg/month) due to the rainfall pattern. The predicted annual loading for WT reservoir is 846 kg P which was generated from the entire area of the watershed (4042 ha).

Conclusion
The technique predicted annual runoff water of 4.31 million m^3 with an average P concentration of 196 µg/L for Wagon Train (WT) watershed. The predicted and observed values for the runoff and P loss appeared to have reasonable agreement, particularly when factors affecting P concentration in streams are considered. The technique offers a cost-effective, quick, and reliable tool to conduct exploratory evaluation for large area of agricultural watershed. Thus, lengthy and site-specific studies could be focused on certain areas of high risk. Even in the absence of potential sources of P contamination such as animal feedlot, intensive cattle grazing, heavy P fertilization or P-enriched soil minerals, the agricultural land in WT watershed still can release enough P in runoff to cause eutrophication of freshwaters. Management practices or nutrient attenuation mechanisms (i.e., riparian wetland) that can reduce P concentration in runoff waters before discharging into freshwater bodies should be considered. To be most effective, P management efforts should be targeted to identified hot spot areas within a watershed that are most vulnerable to P loss.

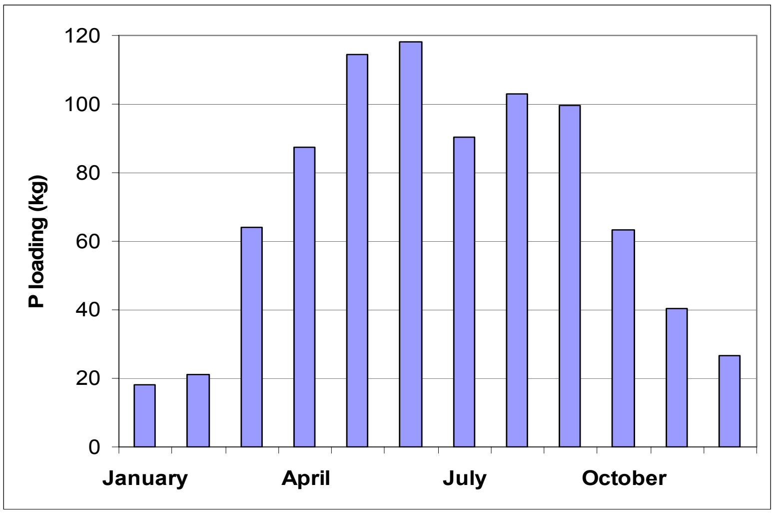

Figure 2. Predicted average monthly phosphorus loading by runoff water (kg) in Wagon Train reservoir

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

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