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Application of Soil Survey To Assess the Effects of Land Management Practices on Soil and Water Quality

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Cover Photo Caption

Eutrophication in this freshwater lake is an indication of phosphorus and/or nitrogen contamination of surface water.

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Introduction

Managing nonpoint sources of contamination on agricultural land is technically complex. Contamination sources commonly occur over a large geographic area and are difficult to identify. Identifying “hot spots” within a watershed, or areas that are the most vulnerable, enables more efficient use of funds to alleviate potential problems and protect water resources. There are models that can estimate the impact of nonpoint sources of contamination from agricultural watersheds, but these models are complex and expensive because they require very extensive data input.

The Natural Resources Conservation Service (NRCS) developed an exploratory technique (Elrashidi, Mays, and Jones, 2003; Elrashidi et al., 2004, 2005a, 2005b, 2007a, 2007b, 2008, 2009) to estimate element loss by runoff and leaching for agricultural watersheds. The NRCS technique applies the USDA runoff curve number (USDA/SCS, 1991) and a percolation model (Williams and Kissel, 1991) to estimate losses of runoff and leaching water from soils by rainfall. The technique assumes that dissolved inorganic chemicals are lost from a specific depth of surface soil that interacts with runoff and leaching water. These chemicals may include any essential plant nutrients (e.g, nitrogen, phosphorus, copper, and zinc) and environmentally toxic elements, such as lead, cadmium, nickel, and arsenic. Geographical information systems (GIS) (ESRI, 2006) are used to present data spatially in watershed maps.

The NRCS technique is quick and cost effective because it utilizes existing climatic, hydrologic, and soil survey information. The Soil Survey Geographic database (SSURGO) (USDA/NRCS, 1999) is used to identify major soils, areas, and locations in the watershed. Land cover databases (NLCD, 1992) and data from the National Agricultural Statistics Service (NASS, 2003) are used to identify cropland, pasture, forestland, and other areas. Information on precipitation and other climate data are accessed from the National Water and Climate Center (NWCC, 2003). The United States Geological Survey (USGS, 2007) maintains streamflow gauging stations in major streams and rivers in the United States. The water-flow data along with information about the extent of the drainage area can be applied to calculate the observed surface runoff from the watershed. This calculation can be used to validate values predicted by the runoff and percolation models.

The NRCS Technique

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:

$$\mathbf{Q = (R - 0.2S)^2 \div (R + 0.8S)} \qquad (1)$$

where Q = runoff (inches), R = rainfall (inches), and S = potential maximum retention (inches) after runoff begins.

The potential maximum retention (S) can range from zero on a smooth and impervious surface to infinity in deep gravel. The S value is converted to a runoff curve number (CN), which is dependent on both the hydrologic soil group and the type of land cover, by the following equation:

$$\mathbf{CN = 1000 \div (10 + S)} \qquad (2)$$

According to equation 2, the CN is 100 when S is zero and approaches zero as S approaches infinity. Runoff curve numbers (CNs) can be any value from zero to 100, but for practical applications they are limited to a range of 40 to 98. Substituting equation 2 into equation 1 gives:

$$\mathbf{Q = \{R - [2(100 - CN)/CN]\}^2 \div \{R + [8(100 - CN)/CN]\}} \qquad (3)$$

The hydrologic groups of the identified major soils are used to determine CNs for different land covers in the watershed.

The annual rainfall for the watershed is taken from the National Water and Climate Center Web site (NWCC, 2003). In equation 3, the effective rainfall (R) is the portion of annual rainfall that could generate runoff (Gebert et al., 1987). The hydrologic group for a given soil and related CNs for various types of land cover are published in the National Engineering Field Manual (USDA/SCS, 1991).

For agricultural land in the watershed, the effective rainfall (R) and the runoff curve numbers are determined first; then the runoff equation is applied to estimate the runoff water (Q) for soil under forest, pasture, and cropland. The equation calculates runoff water in inches (depth of water). Values are commonly converted to millimeters.

Estimation of Leaching Water

The amount of water that leaches from soil was determined by a model developed by Williams and Kissel (1991). The authors used an equation of the form used to estimate surface runoff water (equation 3) to develop their equation that predicts the percolation index (PI).

$$\mathbf{PI = (P - 0.4r)^2 / (P + 0.6r)} \qquad (4)$$

where PI is an estimate of average annual percolation in inches, P is the average annual rainfall in inches, and r is a retention parameter. The retention parameter (r) is related to a Percolation Curve Number (PCN) by using the equation:

$$\mathbf{r = (1000/PCN) - 10} \qquad (5)$$

The values of PCN are 28, 21, 17, and 15 for hydrologic soil groups A, B, C, and D, respectively (Williams and Kissel, 1991).

Another factor of considerable importance in estimating percolation is the seasonal rainfall distribution. Rainfall that occurs in the absence of land cover (vegetation) is much more likely to percolate than growing season rainfall (i.e., spring and summer) because evapotranspiration is low during the fall and winter. Williams and Kissel (1991) introduced the Seasonal Index (SI) to estimate the seasonal precipitation effects on percolation.

$$\mathbf{SI = (2\ PW/P)^{1/3}} \qquad (6)$$

where PW is the effective precipitation (rainfall occurring in the absence of land cover) and P is the annual precipitation. As an example, for a watershed in the Lost River basin in West Virginia, the effective precipitation (PW) for cropland is computed by summing the values for October through May. In calculating PW for pastureland, it is assumed that evapotranspiration is very low during the winter (December, January, and February). For forestland, PW is calculated for fall and early spring (November through April).

The Leaching Index (LI) is estimated by combining equations 4 and 6 as follows:

$$\mathbf{LI = (PI)(SI)} \qquad (7)$$

For the major soils investigated in the watershed, the amount of leaching water is calculated by using the LI for various types of land cover (i.e., forestland, pastureland, and cropland).

Determining Dissolved Elements in Soils and Water

Soil samples are collected from major soils under various types of land cover in the watershed. Sampling locations are selected randomly, but care is taken to ensure that sites are distributed evenly over the entire area of the watershed. At the randomly selected sampling sites, three cores are taken from the top 30-cm soil layer and mixed thoroughly in a stainless steel tray. A composite sample of approximately 2 kg is packed and sealed in a plastic bag.

Soil samples are analyzed from air-dried soil material less than 2 mm in size by methods described in Soil Survey Investigations Report 42 (USDA/NRCS, 2004). Alphanumeric codes in parentheses next to each method represent specific standard operating procedures. Particle-size analysis is performed by sieve and pipette method (3A1). Cation-exchange capacity (CEC) is conducted by NH_4OAc buffered at pH 7.0 (5A8b). Total carbon (C) content is determined by dry combustion (6A2f), and $CaCO_3$ equivalent is estimated by electronic manometer method (6E1g). Organic C in soil is estimated from both the total C and $CaCO_3$ C. Soil pH is measured in a 1:1 soil/water suspension (8C1f). Bulk density (BD) is estimated from particle-size analysis and organic matter content (Rawls, 1983). Liquid limit is determined by the American Society for Testing and Materials method D 4318 (ASTM, 1993).

Dissolved elements (nutrients and heavy metals) are determined in soils. Anion exchange resin (AER) extractable-P is determined by the method described in Elrashidi, Mays, and Jones (2003). Soluble nitrate-N is extracted with 1.0 M KCl solution and measured by the flow injection, automated ion analyzer LACHAT Instruments (6M2a). Water-extractable elements (Al, As, B, Ba, Fe, Ca, Cd, Co, Cr, Cu, K, Mg, Mn, Mo, Na, Ni, P, Pb, Si, Sr, and Zn) for soils are determined in the Equilibrium Water Extract (EWE) according to the Soil Survey Laboratory procedure (4D2b1) (USDA/NRCS, 2004). In this method (4D2b1), the soil:water system (20 g of soil and 100 ml of d.w.) is allowed to equilibrate at room temperature for 23 hours before the suspension is shaken for 1 hour. The supernatant is passed through a 0.45-μm filter. Elements are determined in the filtrate by the Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) (Perkin Elmer 3300 DV). Nitrate-N, nitrite-N, sulfate-S, chloride (Cl), and fluoride (F) concentrations in the filtrate are determined by the High Pressure Ion Chromatograph (6M1c) (HPIC, Dionex Corp.). The pH in the water extract is measured with the combination electrode and digital pH/ion meter, Model 950, Fisher Scientific (8C1a), as described in the Soil Survey Laboratory methods manual (USDA/NRCS, 2004).

Water samples are collected (grab) in midstream by using 2-L polyethylene bottles that have been rinsed twice with stream water prior to sample collection. The water samples are taken immediately to the laboratory and refrigerated at 4 degrees C. Stream-water samples are filtered by using a glass syringe equipped with Whatman 25-mm GD/X disposable nylon filter media (0.45 μm pore size). Phosphorus concentration is determined by the modified phospho-molybdate/ascorbic acid method (Olsen and Sommers, 1982) or the Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) (Perkin Elmer 3300 DV). Nitrate-N, nitrite-N, sulfate-S, chloride (Cl), and fluoride (F) concentrations in the filtrate are determined by the High Pressure Ion Chromatograph (6M1c) (HPIC, Dionex Corp.). Element concentrations in the filtrate (Al, As, B, Ba, Fe, Ca, Cd, Co, Cr, Cu, K, Mg, Mn, Mo, Na, Ni, P, Pb, Si, Sr, and Zn) are determined by the Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) (Perkin Elmer 3300 DV) (4I3a). The pH in the water is measured with the combination electrode and digital pH/ion meter, Model 950, Fisher Scientific (8C1a), as described in the Soil Survey Laboratory methods manual (USDA/NRCS, 2004).

Estimating Element Loss by Runoff and Leaching

Nutrients, such as N, K, and P, and other agricultural chemicals are released from a thin layer of surface soil that interacts with rainfall and runoff. In chemical transport models, the thickness of the interaction zone is determined by model calibration with experimental data, with depths ranging from 2.0 to 6.0 mm (Donigian et al., 1977). Frere, Ross, and Lane (1980), however, suggested an interaction zone of 10 mm, assuming that only a fraction of the chemical present in this depth interacts with rainfall water. In previous studies in this laboratory, Elrashidi and others (Elrashidi, Mays, and Jones, 2003; Elrashidi et al., 2004, 2005a, 2005b, 2007a, 2007b, 2008, and 2009) successfully used a fixed soil thickness of 10 mm to estimate the loss of nutrients and heavy metals by runoff from agricultural land.

In this technique, we use an interaction zone of 10 mm to calculate the amount of element released from surface soils by runoff. Also, it is assumed that during the runoff occurrence, water content in the surface 10-mm soil depth is at the liquid limit, the moisture content at which the soil passes from a plastic to a liquid state. Thus, during the runoff occurrence, the total amount of water (where an element in the 10-mm soil depth is dissolved) is the sum of water within the soil body (liquid limit) and water on the surface of the soil (runoff water). The volume of water in the 10-mm soil depth is typically very small when compared with runoff water. Only elements in runoff water are removed and lost during the runoff occurrence.

Hubbard, Leonard, and Johnson (1991) and Lowrance (1992) studied nitrate-N losses from a small watershed (0.34 ha) in southern Georgia. They found that most of the nitrate-N losses were leached from the top 30-cm soil layer when 620 mm of natural rainfall followed the application of fertilizer. Further, in a field experiment in Wisconsin, Olsen et al. (1970) investigated the effect of spring and summer rainfall (average 55 cm) on downward movement of N for soils under corn that had received 336 kg NH_4NO_3/ha. At the end of summer, they found that less than 10 percent of applied N remained within the top 30 cm of the soil.

The downward movement of water (carrying the dissolved element) from the upper 30 cm of soil is the major mechanism by which a dissolved element is lost from the root zone. In their work on watersheds in southeast Nebraska, Elrashidi et al. (2004, 2005a, 2005b, 2007a, and 2007b) found that a leaching index (LI) equivalent to the annual rainfall of 730 mm can remove dissolved elements beneath the root zone (30-cm soil depth). In this technique, the loss of element is dependent on the predicted depth of annual water leaching through the top 30 cm of soil. The ratio of predicted leaching water depth (mm/yr) to leaching index (LI) equivalent to 730 (mm/yr) is used to estimate the downward movement (loss) of dissolved element from the top 30 cm of soil. For example, a predicted leaching water depth of 73 (mm/yr) for a soil will result in downward movement of 10 percent (73/730) of the element present in the top 30 cm of soil. For each soil, we used the predicted leaching water (mm/yr) and concentration of dissolved element (mg/kg soil) in the surface 30 cm of soil to calculate the annual loss of the element by leaching for soils under various types of land cover.

GIS Digital Mapping

Digital maps for water and nutrient losses from agricultural land in the watershed are generated by the geographical information system (GIS) software ArcView 9.2 (ESRI, 2006). The input data required to generate the GIS map include spatial data layers (soil series and land cover) and the tabular data from both the runoff and leaching (amount of water and nutrient loss from soils and concentrations in both runoff water and leaching water).

The principal spatial data layer used is the Soil Survey Geographic (SSURGO) database (USDA/NRCS, 1999). Both the National Land Cover (NLCD, 1992) and National Agricultural Statistics Service (NASS, 2003) spatial layers are used to identify areas of forest, pasture, and cropland within the watershed. Other types of land cover, such as urban areas, water, or marsh, are typically not mapped for the watershed. The proposed technique calculated water and nutrient losses as well as concentrations in runoff and leaching water for soils under forest, pasture, and cropland. Thus, GIS mapping of agricultural land in the watershed includes data layers for soils and land cover as well as water and elements.

Case Study I: Loss of Phosphorus by Runoff from the Wagon Train Watershed, Lancaster County, Nebraska

When P applied to agricultural land by applications of fertilizer and manure exceeds P removal by harvested crops, repeated applications can lead to an accumulation in the surface soil. Carpenter et al. (1998) reported that, during the period from 1950 to 1995, an average P surplus of 26 kg/ha/yr accumulated on agricultural soils in the United States.

The accumulation increases the potential for P movement from soils through runoff and leaching, which can result in the pollution of surface water and ground water. The downward transport of P through the vadose zone is limited because of the high sorption capacity of most acidic and alkaline soils (Lindsay, 1979). Except for sandy soils in areas of high rainfall, the leaching of P from agricultural land plays an insignificant role in contaminating freshwaters (Novak et al., 2000; Elrashidi et al., 2001). On the other hand, surface runoff from agricultural land is considered a major nonpoint source of P pollution for many lakes, rivers, estuaries, and coastal oceans (Carpenter et al., 1998).

Phosphorus is lost from agricultural land to surface water bodies in sediment-bound and dissolved forms. Sediment-bound P includes P associated with minerals and organic matter. Dissolved P constitutes 10 to 40 percent of the P transported from most cultivated soils to water bodies through runoff (Sharpley et al., 1992). Sharpley et al. (1992) reported that surface runoff from grassland, forest, and cultivated soils carries little sediment and carries dominantly dissolved forms of P. Unlike sediment-bound P, dissolved P is readily bioavailable and thus is the main cause of eutrophication.

Dissolved P concentrations as low as 20 µg/L in water can cause eutrophication (USEPA, 1996; Sharpley et al., 1999). There is no regulatory threshold for P concentration in surface water or ground water. To minimize the impact on freshwater bodies, however, the U.S. Environmental Protection Agency recommended a limit of 50 µg/L for total P in streams that enter lakes and 100 µg/L for total P in flowing water (USEPA, 1986).

The transport of soil P from agricultural land to surface waters depends on many factors, including climate, soil type and hydrology, soil P content, agronomic practices, and landscape (Lemunyon and Gilbert, 1993). Most of these factors were considered by the NRCS technique (Elrashidi, Mays, and Jones, 2003; Elrashidi et al., 2005b and 2008) in estimating P release from soils by rainfall and quantifying runoff P for agricultural land.

Eutrophication of some freshwater bodies in the Wagon Train (WT) watershed (Lancaster County, Nebraska) raised public concern regarding the role of agricultural land as a nonpoint source of P contamination. The overall goal of the project was to apply the NRCS technique in evaluating the role of agricultural land and how it might affect surface water bodies in the WT watershed. The objectives were (1) to estimate water loss from soils by runoff and (2) to estimate P loss from soils by runoff and loading in the WT reservoir.

Materials and Methods

Description of the Study Area

The Wagon Train (WT) watershed lake is a 128-hectare (315-acre) reservoir located on the Hickman Branch of Salt Creek (Platte River Basin) in Lancaster County, Nebraska (figure 1). The reservoir was constructed by the U.S. Army Corps of Engineers in 1962, primarily as a flood-control structure. The total drainage area encompasses 9,984 acres (4,042 hectares) of agricultural land. Most of the area (70 percent) is cultivated with crops, including soybeans (*glycine willd*), corn (*zea mays L.*), wheat (*triticum aestivum L.*), sunflowers (*helianthus L.*), and alfalfa (*medicago sativa L.*). Much of the rest of the watershed is covered with grassland, and forestland, wetland, and urban development account for small areas.

The topography of the watershed is moderately sloping, and most soils are well drained. The land relief consists of uplands, stream terraces, and bottom land. There are 53 km (33 miles) of streams in the watershed and 40 ponds, ranging in size from 0.3 acre to 6.5 acres (0.12 hectare to 2.6 hectares). Overland flow enters the reservoir through intermittent tributaries. From the dam, the water flows into the Hickman Branch of Salt Creek, which flows west and north to Lincoln and eventually into the Platte River near Ashland.

We used the soil survey information from the SSURGO database (USDA/NRCS, 1999) to determine the major soils in the watershed. Both the National Land Cover Data (NLCD, 1992) and data from the National Agricultural Statistics Service (NASS, 2003) were used to identify different types of land cover. The watershed has three major soil associations. The Wymore-Pawnee association consists of deep, nearly level to sloping soils on ridgetops and side slopes. The Pawnee-Burchard association consists of deep, gently sloping to steep, loamy and clayey upland soils that formed in glacial till. The Kennebec-Nodaway-Zook association consists of deep, nearly level and gently sloping, silty soils that formed in alluvium on flood plains. Nine soil series—Wymore, Pawnee, Nodaway, Sharpsburg, Mayberry, Colo, Judson, Burchard, and Kennebec—account for 96.1 percent of the agricultural land. Nearly three-quarters of the watershed consists of Wymore and Pawnee soils.

Soil and Water Sampling

Soil sampling included three widely extensive phases of Wymore soils (WtB, WtC2, and WtD3) and two widely extensive phases of Pawnee soils (PaC2 and PaD2) along with the other seven soil series. This approach gave a total of 12 soil map units. Recently, updated soil survey activities have split Sharpsburg into three series (Tomek, Yutan, and Aksarben). The new classification, however, should not affect results given in this study.

To obtain representative soil samples, we divided the watershed area into six sections. For each of the 12 soil map units, one sample was taken from an area of cropland within each of the six sections of the watershed. For each soil map unit, however, only two grassland samples were collected because of the limited area covered with grass. Thus, in total, 72 soil samples from cropland and 24 from grassland were collected. At the randomly selected sampling sites, three cores were taken from the top 30-cm soil layer and mixed thoroughly in a stainless steel tray. A composite sample of approximately 2 kg was packed and sealed in a plastic bag. Sampling was completed during April of 2003 prior to fertilizer application for the summer crop.

Many small streams receive surface water runoff from the agricultural land in the watershed. Eventually, streams located north of the reservoir join in a single stream that runs toward the south about 0.5 km before entering the reservoir near the northern

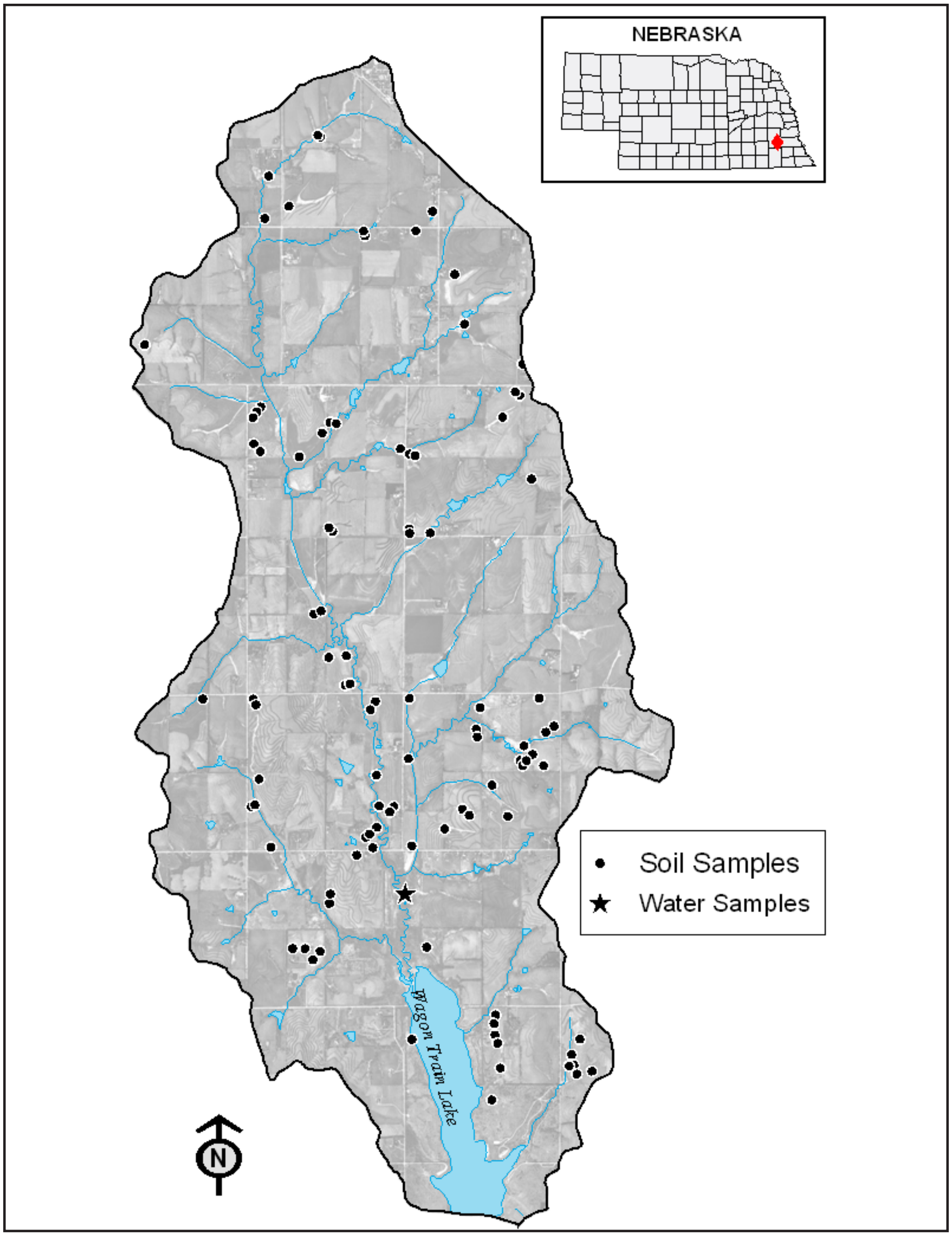

Figure 1.—Soil and water sampling locations in the Wagon Train watershed, Lancaster County, Nebraska.

edge. Water samples taken along the main stream were assumed to represent the surface water runoff generated from the entire watershed.

Most of the surface water runoff from the agricultural land in the WT watershed and water inflow for the WT reservoir is expected during the rainy season in the spring, summer, and early fall (March through October). In the middle of March, water samples were collected at 12 locations for major streams in the watershed (figure 1).

These samples included three from locations along the main stream before it enters the reservoir. Phosphorus analysis for major streams proved that samples taken from the main stream are good representatives for runoff generated from the entire watershed. Accordingly, during the period from April through October, monthly samples were collected only from the three locations along the main stream.

Water samples were collected (grab) in midstream using 1-L polyethylene bottles that had been rinsed twice with stream water prior to sample collection. The water samples were taken immediately to the laboratory and refrigerated at 4 degrees C. The water analysis was completed within a week. The soil and water sampling locations are shown in figure 1.

Soil and water samples were analyzed as described above under the heading "The NRCS Technique." Classifications of the soils and selected properties of the soils under cropland and grass in the WT watershed are given in table 1.

Results and Discussion

Runoff Water

The predicted loss of surface water by runoff (m^3/ha/yr) for 12 soils under different types of land cover in the WT watershed is given in table 2. Although fallow (till without planting) was rare in the watershed, it was included to provide a worst-case scenario should heavy storms and runoff events occur during crop field preparations or early growth stages for the summer crop (April to June). Accordingly, the area of cropped soils (70 percent of the watershed) also was used to predict the runoff water for fallow. Grass covered the remainder of the watershed.

Generally, the loss of water by runoff was slightly higher for fallow than for cropland, while grassland produced relatively lower values. The predicted average (area-weighted) of runoff water was 1,242, 1,122, and 939 m^3/ha/yr for fallow, cropland, and grassland, respectively. These results accounted for 17.0, 15.4, and 12.9 percent of the annual rainfall for fallow, cropland, and grassland, respectively. Similar values were reported for 13 United States soils of humid regions (rainfall amounts higher than 800 mm/yr), where the average was 16 percent for fallow, 15 percent for cropland, and 12 percent for grassland (Elrashidi, Mays, and Jones, 2003).

These values, however, were relatively higher than those reported for Lancaster County, Nebraska, where the WT watershed is located (Elrashidi et al., 2004). This difference could be attributed to the slow rate of water infiltration (hydrologic group D) for the dominant soils (Wymore, Pawnee, and Mayberry) in the watershed. These three soils make up approximately 80 percent of the agricultural land in the watershed. Figure 2, which illustrates the water loss by runoff, indicates that these soils with poor hydrologic properties and high runoff potential (runoff rate of more than 100 mm/yr) are evenly distributed throughout the watershed.

Table 2 shows the total volume of water generated from each of the 12 major soils (m^3/soil/yr) in the watershed under different types of land cover. The results indicated that Wymore (WtC2), irrespective of land cover, produced the highest volume of runoff, mainly because of its extent in the watershed. As might be expected, Kennebec soils, which make up a very limited area, generated the lowest amount of runoff water. The total annual loss of runoff water from the 12 major soils was 4.15 million m^3. Under the worst-case scenario, this value should increase (8 percent) to 4.47 million m^3. The area of the 12 major soils (3,885 ha) covers about 96 percent of the entire watershed. Thus, when the entire watershed area (4,042 ha) was considered, the total annual runoff accounted for 4.31 million m^3 of water.

Table 3 and Figure 3 show (1) the observed average monthly inflow for the WT reservoir for a 50-year period between 1951 and 2000 (USGS, 2001); (2) the predicted

Table 1

Classification and some properties for 12 major soils under cropland and grassland in the Wagon Train watershed, Lancaster County, Nebraska.

Soil (map unit)	Classification	Land use	Clay (%)	OM (%)	CEC (Cmol(+)/kg)	pH-water
Wymore (WtB)	Fine, smectitic, mesic Aquertic Argiudolls	Cropland	37.3	2.14	25.9	5.56
		Grassland	32.9	2.44	25.7	5.90
Wymore (WtC2)	Fine, smectitic, mesic Aquertic Argiudolls	Cropland	37.9	2.23	26.5	5.70
		Grassland	35.6	3.46	28.2	5.80
Wymore (WtD3)	Fine, smectitic, mesic Aquertic Argiudolls	Cropland	41.2	2.16	29.3	5.85
		Grassland	34.2	2.78	28.9	6.40
Pawnee (PaC2)	Fine, smectitic, mesic Oxyaquic Vertic Argiudolls	Cropland	35.2	1.94	24.9	5.64
		Grassland	29.3	2.38	21.7	5.55
Pawnee (PaD2)	Fine, smectitic, mesic Oxyaquic Vertic Argiudolls	Cropland	34.9	1.85	24.5	5.79
		Grassland	34.7	2.39	25.5	6.10
Nodaway (No, Ns)	Fine-silty, mixed, superactive, nonacid, mesic Mollic Udifluvents	Cropland	29.4	2.08	24.4	6.58
		Grassland	30.1	2.97	26.4	6.25
Sharpsburg (ShC, ShD, ShD2)	Fine, smectitic, mesic Typic Argiudolls	Cropland	39.7	1.94	27.6	5.70
		Grassland	37.4	2.05	27.0	6.15
Mayberry (MeC2, MeD2, MhC3)	Fine, smectitic, mesic Aquertic Argiudolls	Cropland	31.8	1.96	22.8	5.99
		Grassland	26.0	2.08	20.4	6.50
Colo (Co, Cp)	Fine-silty, mixed, superactive, mesic Cumulic Endoaquolls	Cropland	32.1	2.13	25.0	6.30
		Grassland	29.0	2.95	26.1	6.10
Judson (JuC)	Fine-silty, mixed, superactive, mesic Cumulic Hapludolls	Cropland	32.0	2.26	24.8	6.05
		Grassland	30.5	3.06	24.0	6.00
Burchard (BpF, BrD, BrE)	Fine-loamy, mixed, superactive, mesic Typic Argiudolls	Cropland	29.8	1.89	21.7	5.96
		Grassland	30.1	2.99	23.1	7.00
Kennebec (Ke)	Fine-silty, mixed, superactive, mesic Cumulic Hapludolls	Cropland	27.6	1.94	20.7	5.95
		Grassland	24.7	2.09	19.5	6.10
Average of all soils		Cropland	34.1	2.04	24.8	5.92
		Grassland	31.2	2.63	24.7	6.15

surface water runoff for the WT watershed; and (3) the historic monthly rainfall. The historical record of monthly rainfall for Lancaster County (NWCC, 2003) was used to predict the runoff water. The runoff model (USDA/SCS, 1991) appeared to underestimate the observed water flow to the reservoir for February and March and overestimate the inflow for August and September.

According to the historical 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, thereby increasing the water inflow for the reservoir. This snowmelt might explain the underestimation of the inflow for February and March. During the hot summer months, crops (such as corn and soybeans) are in

Table 2

Predicted loss of surface water by runoff † expressed as (m^3/ha/yr) and (1000m^3/soil/yr) for 12 soils under different types of land cover in the Wagon Train watershed.

Soil (map unit)	Area (ha)	Runoff water † Fallow	Cropland	Grassland	Runoff water † Fallow	Cropland	Grassland
		......................(m^3/ha/yr).........................			................(1000m^3/soil/yr)..............		
Wymore (WtB)	558	1280	1167	1000	500	456	167
Wymore (WtC2)	1815	1280	1167	1000	1626	1482	544
Wymore (WtD3)	177	1280	1167	1000	158	144	53
Pawnee (PaC2)	343	1280	1167	1000	307	280	103
Pawnee (PaD2)	77	1280	1167	1000	69	63	23
Nodaway (No, Ns)	203	1057	901	640	150	128	39
Sharpsburg (ShC, ShD, ShD2)	177	1057	901	640	131	111	34
Mayberry (MeC2, MeD2, MhC3)	157	1280	1167	1000	141	128	47
Colo (Co, Cp)	152	1195	1084	880	127	116	40
Judson (JuC)	101	1057	901	640	75	64	19
Burchard (BpF, BrD, BrE)	81	1057	901	640	60	51	16
Kennebec (Ke)	45	1057	901	640	33	28	9
Weighted average		**1242**	**1122**	**939**			
Total	**3885**				**3377**	**3051**	**1094**

† USDA/SCS, 1991.

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 agreement with the observed annual inflow (4.25 million m^3).

Runoff P

Land cover could affect the amount of P released from surface soil by rainfall in two different ways. First, it reduces the volume of surface water runoff generated by rainfall; second, it minimizes the area of surface soil exposed to direct rainfall energy. Table 2 indicates that the average runoff water generated by annual rainfall was 1,242 m^3/ha for bare soils (fallow), which was higher than that of either cropland (1,122 m^3/ha) or grassland (939 m^3/ha). The reducing effect on surface water runoff also was observed for crop residue. Gilley et al. (1986) and Gilley, Finkner, and Varvel (1986) used a rainfall simulator to measure runoff from plots on which corn, sorghum, and soybean residues were added at rates ranging from 0 to 13.5 t/ha. The authors found that an increased rate of surface cover resulted in reduced runoff.

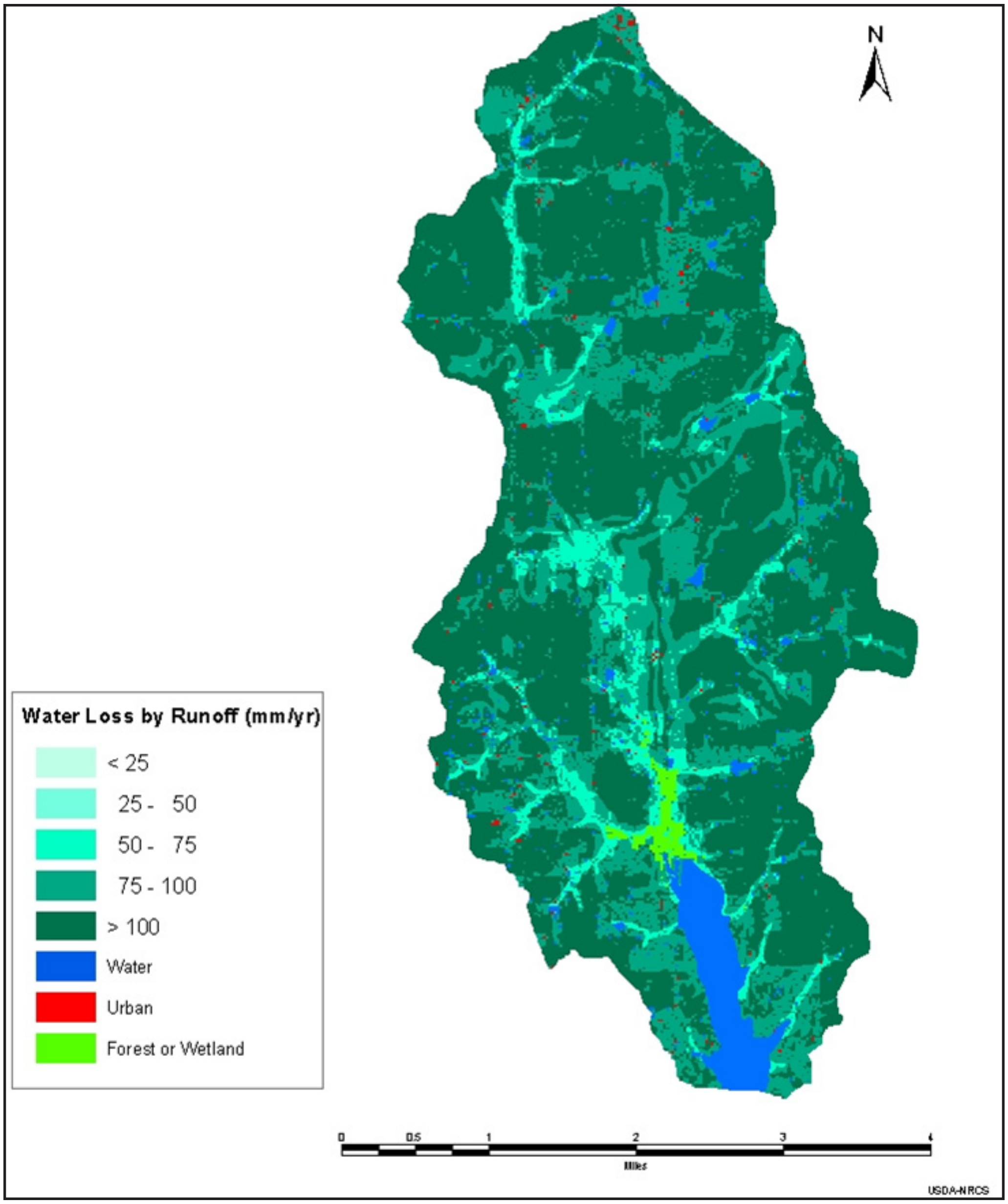

Figure 2.—Water loss by runoff for soils (mm/yr) in the Wagon Train watershed, Lancaster County, Nebraska.

The effectiveness of a vegetation canopy in reducing the energy of rainfall striking the soil surface is dependent on the area covered by the canopy. For permanent pasture or grass, the canopy covers a relatively constant area during the entire year in comparison to the wide range of coverage for most agronomic crops. It is difficult to estimate the magnitude of reduction in runoff P caused by different types of land cover. In comparison to cropland and grassland, however, fallow (bare soil) releases a higher amount of P in runoff water and represents the worst-case scenario.

The results displayed in table 4 indicate that the average annual runoff P in the watershed was 243 g/ha for fallow, 217 g/ha for cropland, and 190 g/ha for grassland. These values are on the low side but still within the range for 24 U.S. soils for which the estimated average ranged from 0.09 to 8.3 (fallow), 0.06 to 7.5 (cropland), and

Table 3

Average monthly rainfall (mm), observed inflow † (m^3) for the Wagon Train (WT) reservoir, and predicted surface water runoff ‡ (m^3) for the WT watershed.

Month	Rainfall (mm)	Observed inflow † (m^3)	Predicted runoff ‡ (m^3)
January	15	133860	91704
February	18	244371	108241
March	55	610517	327729
April	75	475674	446493
May	99	653013	583297
June	102	620296	602841
July	78	574396	461526
August	89	221684	524667
September	86	161071	508130
October	55	289677	323219
November	35	146678	205958
December	23	117571	135301
Year	729	4248808	4314713

† USGS, 2001

‡ USDA/SCS, 1991

0.01 to 6.0 kg P/ha/yr (grassland) (Elrashidi, Mays, and Jones, 2003). The authors reported that the high runoff P values were probably associated with soils treated with P fertilizer or manure. In a field experiment on an Iowa soil (fallow), Tabbara (2003) studied P loss to runoff water from a 90-minute rainfall event after application of manure or fertilizer. He found that the mean loss of dissolved P by runoff water ranged from 0.38 to 1.76 kg/ha.

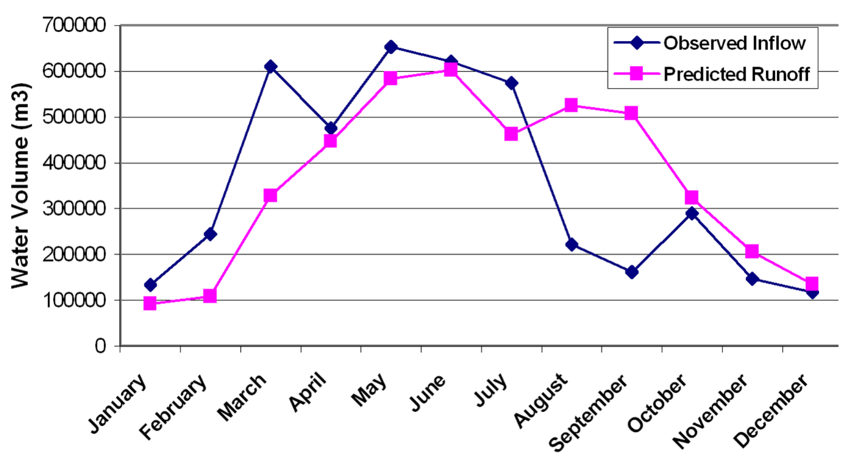

Figure 3.—Observed average monthly water inflow for the Wagon Train (WT) reservoir (m^3) and predicted surface water runoff for the WT watershed (m^3).

Table 4

Predicted P loss from soils by runoff expressed as (g/ha/yr) and (kg/soil/yr) and P concentration in runoff water (µg/L) generated from 12 soils under different types of land cover in the Wagon Train watershed.

	P loss from soils by runoff water						P concentration in runoff water		
Soil	**Fallow**	**Cropland**	**Grassland**	**Fallow**	**Cropland**	**Grassland**	**Fallow**	**Cropland**	**Grassland**
	....................(g/ha/yr).................			...................(kg/soil/yr).................			.....................(µg/L)......................		
Wymore (WtB)	161	147	344	63	57	58	126	126	344
Wymore (WtC2)	194	177	144	247	225	78	152	152	144
Wymore (WtD3)	251	229	377	31	28	20	196	196	377
Pawnee (PaC2)	142	130	87	34	31	9	111	111	87
Pawnee (PaD2)	108	98	89	6	5	2	84	84	89
Nodaway (No, Ns)	781	665	174	111	94	11	738	738	272
Sharpsburg (ShC, ShD, ShD2)	318	271	81	39	33	4	301	301	126
Mayberry (MeC2, MeD2, MhC3)	306	279	128	34	31	6	239	239	128
Colo (Co, Cp)	643	583	533	68	62	24	538	538	605
Judson (JuC)	201	172	182	14	12	6	190	190	284
Burchard (BpF, BrD, BrE)	84	72	97	5	4	2	80	80	152
Kennebec (Ke)	261	222	81	8	7	1	247	247	127
Weighted average	**243**	**217**	**190**				**195**	**194**	**202**
Total				**660**	**591**	**221**			

No large livestock feedlots or intensive cattle grazing operations are currently in the WT watershed area. Phosphorus fertilizer (50 to 60 kg P_2O_5/ha) is usually applied to cropped soils during the preparation for the summer crop, whereas grassland soils receive smaller and less frequent fertilizer applications and occasional additions of animal waste. The fact that the soil sampling was completed before fertilizer was applied might explain the relatively low P content found, particularly in cropped soils and in runoff water. We found that five cropped soils (Wymore WtB and WtD3, Colo, Judson, and Burchard) were depleted of P by the previous year's cropping, with a runoff P lower than that of soils under grass. This condition might appear in contradiction with Sonzogni et al. (1980), who stated that cropped soils, in general, generate higher P concentrations in runoff water than grassland soils.

Phosphorus Loss and Loading

For the agricultural land in the WT watershed, we assumed that most of the P loss from soils by runoff was transported eventually to the WT reservoir. Table 4 shows the estimated P loss by runoff for the 12 soils under different types of land cover in the watershed. As mentioned, we included fallow in this study in order to estimate the worst-case scenario, when all cropland areas could be considered as fallow due to heavy spring storms. Under the worst-case scenario, the annual P loss by runoff from soils would increase by 8.5 percent, from 812 to 881 kg. As illustrated in table 2, the runoff water would increase by 8 percent, from 4.15 to 4.47 million m^3. This change, however, would not have any significant effect on the average P concentration in runoff water generated from the entire watershed area.

Table 4 shows that the predicted P concentration varied widely in runoff water generated from different soils and different types of land cover. For cropped soils, the P concentration in runoff water ranged from 80 to 738 µg/L with an average of 194 µg/L. It ranged from 87 to 605 µg P/L with an average of 202 µg P/L for soils under grass. The predicted area-weighted average P concentration for the runoff water generated from the entire watershed (cropland and grassland) was 196 µg/L.

Phosphorus loss from soils generally occurs in hydrologically active areas of a watershed, where surface runoff contributing to streamflow is coincident with areas of high soil P (Gburek and Sharpley, 1998; Gburek et al., 2000). The authors of these two studies concluded that P loss may be most efficiently managed by focusing on controlling soil P levels and fertilizer as well as manure applications in the watershed zones most likely to produce surface runoff. Accordingly, management practices to prevent P loss from agricultural watersheds should focus on defining, targeting, and remediating the critical source areas of P loss (hot spots).

We applied GIS technology to present the data in the watershed map (figure 4). This approach allowed us to identify the area and location of hot spots as well as soils generating runoff water with high P concentrations. The dark area on the map shows Nodaway, Colo, and Sharpsburg soils, which produced runoff water exceeding 300 µg P/L.

Soluble P concentration of at least 20 µg/L in fresh water can cause eutrophication (USEPA, 1996). To reduce the impact on surface water bodies, the U.S. Environmental Protection Agency has recommended a limit of 50 µg/L for total P in streams that enter lakes and 100 µg/L for total P in flowing water (USEPA, 1986). The data in table 4 and figure 4 indicate that the predicted P concentration in runoff water exceeded the recommended limits and could cause an environmental problem for the WT reservoir.

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 (table 3) to estimate the monthly P loading (kg) for the WT reservoir. This information is illustrated in figure 5. As might be expected, the results indicate that P loading into the reservoir was lowest during the winter and averaged about 20 kg/month. Most of the P loading in the reservoir occurred during the spring and summer (93 kg/month) as a result of the rainfall pattern. The predicted annual loading for the WT reservoir is 846 kg P, which was generated from the entire area of the watershed (4,042 ha).

The Lower Platte South Natural Resources District (LPSNRD, 2004) collected monthly surface water samples from five locations in the WT reservoir for the purpose of monitoring the concentration of P and other contaminants. The dissolved P concentration ranged from 70 to 260 µg/L and averaged 140 µg/L. This average was lower than the predicted average P concentration in the surface water runoff of 196 µg/L. The difference could be attributed to the high pH values observed for water in the reservoir. The LPSNRD (2004) reported a pH value ranging from 7.33 to 9.64 with an average of 8.49 for the five water samples collected at different locations in the reservoir.

The water pH values for the 12 cropped soils were mainly within the acidic range; they fluctuated between 5.56 and 6.58 and averaged 5.92 (table 1). Under grass, pH values ranged from 5.55 to 7.00 with an average of 6.15. Mono-calcium phosphate [$Ca(H_2PO_4)^2$] is the major form of phosphate fertilizer typically added to these soils. Changing pH of the runoff water in the reservoir from acidic and near neutral to the alkaline range could transform the $Ca(H_2PO_4)^2$ to $CaHPO_4$ or $Ca_3(PO_4)^2$, both of which have lower solubility in water (Lindsay, 1979). Further, large populations of

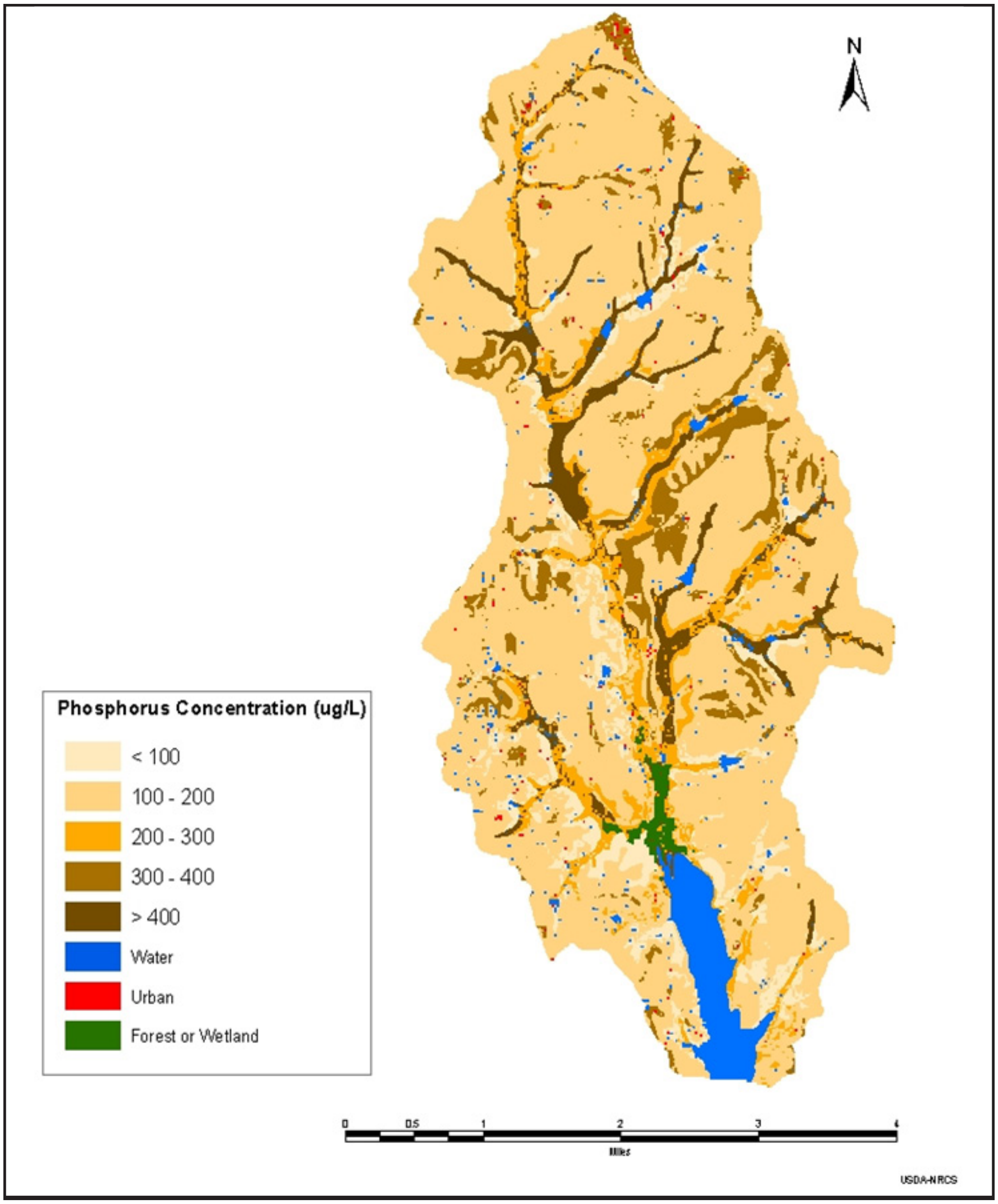

Figure 4.—Phosphorus concentration in runoff water from soils (µg/L) in the Wagon Train watershed.

algae, weeds, and aquatic plants in the reservoir could assimilate P and reduce the concentration in water.

Most of the runoff from agricultural land in the WT watershed is expected during the spring, summer, and early fall (figure 3). Phosphorus concentration from major streams at the beginning of spring (March) ranged from 99 µg/L to 240 µg/L with an average of 162 µg/L (SD = 40 µg/L). The predicted value of 196 µg P/L is greater than (and is within one standard deviation of) the observed average P concentration in streams. Meanwhile, the pH value in stream water samples ranged from 8.10 to 8.57

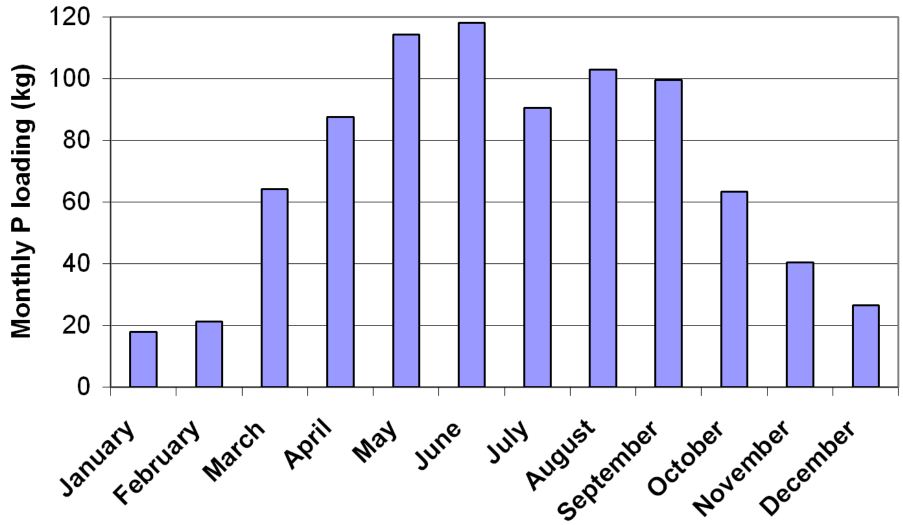

Figure 5.—Predicted average monthly phosphorus loading by runoff water (kg) in the Wagon Train reservoir.

with an average of 8.39. This pH was higher than the average pH value (about 6.00) measured in soils (table 1). The technique used in this study predicted P concentration in runoff at the edge of a field. The increase in water pH as well as P removal by aquatic weeds and algae could be the cause of the lower P concentration observed in stream water.

Furthermore, the average P concentration observed in the mainstream samples for the entire rainy season (March through October) ranged from 157 µg/L (March) to 346 µg/L (July) with an average of 252 µg/L (SD = 65 µg/L) (figure 6). This average rainy season P concentration is greater than the predicted P concentration of 196 µg/L. Field applications of P fertilizer (April and May) for the summer crops could contribute to the relatively higher observed P concentration (May through August) in water. However, the predicted P value is within one standard deviation of the observed stream P concentration for the entire rainy season.

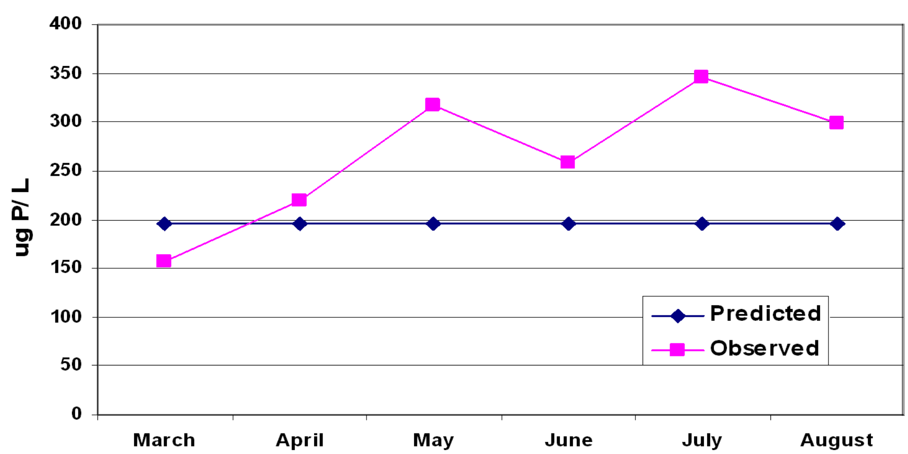

Figure 6.—Predicted and observed average monthly phosphorus concentration (µg/L) in the Wagon Train watershed stream water.

In conclusion, we need to emphasize that the predicted P value was calculated for runoff water generated at field sites and not in the WT streams or reservoir. Factors affecting P concentration in runoff water after it leaves field sites, such as change in water chemistry and P removal by aquatic weeds and algae, should be taken into consideration. The data suggested that the two factors have lowered P concentration by approximately 17 percent (from 196 to 162 µg/L). Therefore, if we consider factors affecting P concentration in runoff after it leaves field sites, the technique could provide a reasonable estimation of P concentration in stream water.

Case Study II: Loss of Nitrogen by Runoff and Leaching from the Lost River Watersheds, Hardy County, West Virginia

During the last 20 years, poultry production in Hardy County, West Virginia, has increased considerably. The waste byproducts of this industry (poultry litter or manure) are typically land applied, and concerns over water quality are widespread. State and Federal agencies recognized the need for a coordinated and comprehensive approach to protecting and enhancing the quality of surface water and ground water in Hardy County's Potomac Headwaters region. The county is divided into five major river basins: the North Fork of the South Branch of the Potomac River, the South Fork of the South Branch of the Potomac, the North River, the Cacapon River, and the Lost River. The Natural Resources Conservation Service (NRCS) identified 21 watersheds in Hardy County, 6 of which are in the Lost River basin (USDA/NRCS and West Virginia Conservation Agency, 2004).

The Lost River basin was identified as producing twice as much poultry litter, or manure, as the available agricultural land (USDA/NRCS and West Virginia Conservation Agency, 2004). Accordingly, the Lost River was designated at the top of the USDA/NRCS priority list for implantation of agricultural Best Management Practices (BMPs). Both private and government programs are in place to move poultry litter out of the Lost River watersheds, but it is generally accepted that considerable amounts of manure are applied to the soil. This situation has led to an expectation that excess N and P must be polluting the Lost River and other Potomac Headwaters streams.

The presence of nitrates and other soluble forms of nitrogen and phosphorus in surface water and ground water can result in the deterioration of water quality in relation to freshwater eutrophication and potability. Soluble N and P compounds are related to the undesirable growth of algae and aquatic plants, which deplete oxygen and kill fish and other aquatic life in surface freshwater bodies (Fruh, 1967). The United States Public Health Service and Environmental Protection Agency have established 10 mg/L nitrate-N as the maximum contaminant limit (MCL) in drinking water for humans and animals (USEPA, 1992). Levels above 10 mg/L can lead to methemoglobinemia, or "blue baby" syndrome, which is caused by the reduction of the oxygen-carrying capacity of blood and can lead to brain damage and death (Johnson et al., 1987).

The NRCS technique applies the USDA runoff curve number (USDA/SCS, 1991) and a percolation model (Williams and Kissel, 1991) to estimate losses of runoff and leaching water from soils by rainfall. The technique assumes that soluble nutrients, such as nitrate-N, are lost from a specific depth of surface soil that interacts with runoff and leaching water. The objective of this study was to apply this exploratory technique to investigate the loss of nitrate-N by runoff and leaching from two watersheds in the Lost River basin—Cullers Run (CR) and Upper Cove Run (UCR)—and to estimate the impact (nonpoint source of nitrate-N contamination) on water quality.

Materials and Methods

Description of the Study Area

Hardy County is in the eastern panhandle of West Virginia. It has an area of approximately 1,512 km^2 (584 mi^2). The 467 farms in the county produce cattle, hogs, sheep, poultry, and crops. Hardy County ranks first in West Virginia in terms of poultry production. The latest Census of Agriculture indicates that the county is 73 percent forestland, 19 percent pastureland, 6 percent cropland, 1 percent urban land, and 1 percent recreational land (USDA/NRCS and West Virginia Conservation Agency, 2004).

The topography of the county is rugged, characterized by a series of mountain ranges. The only comparatively level land in the county is the bottom land along the major rivers, notably the South Branch of the Potomac, the South Fork of the South Branch, and the Lost River. Elevation ranges from 220 m (725 ft) above mean sea level on the South Branch, at the Hampshire-Hardy County line, to 1,009 m (3,320 ft) above mean sea level on South Branch Mountain, near the center of the county.

The climate of Hardy County is characterized by warm summers, cold winters, stormy springs, and mild autumns. The average annual temperature for the area is 10.7 degrees C (51.3 degrees F) with monthly extremes ranging from -1.9 degrees C (28.6 degrees F) in January to 22.4 degrees C (72.4 degrees F) in July. The average annual precipitation for the county is 867 mm (34.12 in); the maximum is 87.4 mm (3.44 in) in July, and the minimum is 51.1 mm (2.01 in) in February. The area receives approximately 584 mm (23.0 in) of snowfall per year, usually during the period from December to March, and relative humidity ranges daily from 53 to 78 percent.

Two upstream watersheds in the Lost River basin (CR and UCR) were selected for this study. The two watersheds have a drainage area of approximately 17,068 ha (42,158 acres). They are covered mainly with forest (72 percent) and pasture (22 percent); cropland makes up less than 5 percent of the area. This region contains the most intensive agricultural operations in the Lost River basin, dominated by the integrated poultry industry. A woody riparian corridor occurs along much of each of the Lost River tributaries. Along the Lost River's main stream, however, most of the trees were removed many years ago and cropland and pastureland typically extend to the river's edge.

We used the soil survey information from the SSURGO database (USDA/NRCS, 1999) to determine the 15 major soils in the two watersheds. These soils accounted for approximately 98 percent of the agricultural land. Both the National Land Cover Data (NLCD, 1992) and data from the National Agricultural Statistics Service (NASS, 2003) were used to identify different types of land cover.

Soil and Water Sampling

A total of 15 soil map units were sampled in the two watersheds. These units represented the 15 major soil series in the area. Samples were collected from soils under forest, pasture, and cropland vegetation; however, no single soil had all three types of land cover. Ten soils (Berks, Dekalb, Laidig, Buchanan, Murrill, Clarksburg, Potomac, Ernest, Lehew, and Calvin) supported mainly forest or pasture, and the other five (Tioga, Chagrin, Lindside, Melvin, and Monongahela) supported only cropland. Ten samples from forestland and six from pastureland were collected from each of the ten soils that support these types of land cover, and four samples from cropland were collected from each of the other five soils. The different number of replicates used reflects in some degree the area of land cover for the soil. For the two watersheds, a total of 100, 60, and 20 samples were collected from soils under forest, pasture, and crops, respectively. Sampling locations were selected randomly and distributed evenly over the entire area of the study. At the randomly selected sampling sites, three cores were taken from the top 30-cm soil layer and mixed thoroughly in a stainless steel tray. A composite sample of approximately 2 kg was packed and sealed in a plastic bag. Sampling was completed during April of 2006.

Many small streams receive surface water runoff from the agricultural land in the CR and UCR watersheds. Eventually, small streams discharge into a larger stream (the Lost River), which runs northward through the middle section of the two watersheds. Twelve monthly water samples (January through December, 2006) were taken from the Lost River. The samples were taken from a location in the Lost River just before it leaves the UCR watershed and enters the next watershed to the north (Kimsey Run watershed). Accordingly, these water samples represent the surface runoff generated from the entire area of the CR and UCR watersheds.

Water samples were collected (grab) in midstream, using 2-L polyethylene bottles that had been rinsed twice with stream water prior to sample collection. The water samples were taken immediately to the laboratory and refrigerated at 4 degrees C. The soil and water sampling locations are shown in figure 7.

Figure 7.—Soil and water sampling locations in Cullers Run (CR) and Upper Cove Run (UCR) watersheds, Hardy County, West Virginia.

Soil and water samples were analyzed as described above under the heading “The NRCS Technique.” Classifications of the soils and selected properties of the soils under cropland and grass in two watersheds are given in table 5.

Table 5

Soil classification, some properties, and nitrate-N (mg/kg) for 15 major soils under forest, pasture, and cropland in the Cullers Run and Upper Cove Run watersheds, Hardy County, West Virginia.

Soil (map unit)	Classification	Land cover	Clay %	OM %	CEC cmol/kg	pH (water)	BD (g/cm^3)	Liquid limit (ml/kg)	NO_3-N (mg/kg)
Berks (Bk)	Loamy-skeletal, mixed, mesic Typic Dystrochrepts	Forest	16.68	11.23	18.65	4.28	0.88	305	108.9
		Pasture	18.32	5.52	13.35	5.30	1.04	305	166.2
		Cropland							
Dekalb (Dk)	Loamy-skeletal, mixed, mesic Typic Dystrochrepts	Forest	9.26	12.03	16.49	4.25	0.89	210	77.4
		Pasture	14.20	8.81	15.49	5.43	0.98	210	170.6
		Cropland							
Laidig (Ld)	Fine-loamy, mixed, mesic Typic Fragiudults	Forest	10.69	13.55	16.56	4.06	0.91	225	51.4
		Pasture	14.47	3.94	9.08	5.63	1.19	225	78.3
		Cropland							
Buchanan (Bu)	Fine-loamy, mixed, mesic Aquic Fragiudults	Forest	19.76	12.02	18.38	4.14	0.90	275	169.9
		Pasture	15.02	5.49	11.52	5.10	1.07	275	143.3
		Cropland							
Murrill (Mr)	Fine-loamy, mixed, mesic Typic Hapludults	Forest	14.17	12.80	18.45	4.15	0.86	300	168.6
		Pasture	18.75	7.84	14.72	5.43	1.01	300	194.5
		Cropland							
Clarksburg (Ck)	Fine-loamy, mixed, mesic Typic Fragiudalfs	Forest	14.06	12.17	17.27	4.14	0.85	275	153.9
		Pasture	22.90	7.41	15.70	5.73	0.98	275	108.8
		Cropland							
Potomac (Pt)	Sandy-skeletal, mixed, mesic Typic Udifluvents	Forest	16.32	4.69	11.65	4.74	1.21	150	95.6
		Pasture	17.84	5.51	12.00	5.33	1.17	150	153.6
		Cropland							
Ernest (Er)	Fine-loamy, mixed, mesic Aquic Fragiudults	Forest	18.22	9.26	15.03	3.99	0.96	300	91.3
		Pasture	19.01	4.42	12.15	5.46	1.10	300	98.8
		Cropland							
Lehew (Lh)	Loamy-skeletal, mixed, mesic Typic Dystrochrepts	Forest	9.53	9.34	13.78	4.02	0.96	225	64.5
		Pasture	12.53	5.10	11.63	5.22	1.14	225	127.4
		Cropland							
Calvin (Cv)	Loamy-skeletal, mixed, mesic Typic Dystrochrepts	Forest	11.36	11.99	17.99	4.41	0.92	275	97.0
		Pasture	15.62	5.42	13.20	5.57	1.07	275	130.7
		Cropland							
Tioga (Ti)	Coarse-loamy, mixed, mesic Dystric Fluventic Eutrochrepts	Forest							
		Pasture							
		Cropland	16.23	2.42	9.83	5.88	1.24	150	65.4
Chagrin (Cg)	Fine-loamy, mixed, mesic Dystric Fluventic Eutrochrepts	Forest							
		Pasture							
		Cropland	19.95	3.66	11.93	6.08	1.18	275	58.9
Lindside (Ln)	Fine-silty, mixed, mesic Fluvaquentic Eutrochrepts	Forest							
		Pasture							
		Cropland	18.00	2.82	10.15	6.43	1.24	275	41.7
Melvin (Me)	Fine-silty, mixed, nonacid, mesic Typic Fluvaquents	Forest							
		Pasture							
		Cropland	29.98	4.56	16.28	6.40	1.08	300	32.7
Monongahela (Mo)	Fine-loamy, mixed, mesic Typic Fragiudults	Forest							
		Pasture							
		Cropland	17.50	4.18	11.83	5.98	1.12	275	92.1

Results and Discussion

Surface Runoff Water

The predicted loss of surface water by runoff from the 15 major soils under different types of land cover is given as m^3/ha/yr in table 6 and as mm/yr in the map of the CR and UCR watersheds (figure 8). The loss of water from soil by runoff followed this order: cropland > pastureland > forestland. The average (area-weighted) runoff water was 4,869, 4,580, and 4,296 m^3/ha/yr for cropland, pastureland, and forestland, respectively. These results accounted for 54.2, 51.0, and 47.8 percent of the annual rainfall for cropland, pastureland, and forestland, respectively. The predicted average (area-weighted) runoff for the agricultural land in the two watersheds was 4,374 m^3/ha/yr.

Table 6

Predicted runoff and leaching water (m^3/ha/yr) from 15 major soils under various types of land cover in the Cullers Run and Upper Cove Run watersheds, Hardy County, West Virginia.

Soil	Runoff water				Leaching water			
	Forest	Pasture	Cropland	Average	Forest	Pasture	Cropland	Average
	....................(m^3/ha/yr)....................				....................(m^3/ha/yr)....................			
Berks	4,404	4,654		4,461	931	711		882
Dekalb	4,404	4,654		4,461	931	711		882
Laidig	4,404	4,654		4,460	931	711		882
Buchanan	4,404	4,654		4,462	931	711		882
Murrill	3,781	4,225		3,900	1,712	1,307		1,602
Clarksburg	4,404	4,654		4,472	931	711		884
Potomac	2,234	3,147		2,498	2,976	2,273		2,823
Ernest	4,404	4,654		4,457	931	711		879
Lehew	4,404	4,654		4,455	931	711		879
Calvin	4,404	4,654		4,467	931	711		882
Tioga			4,694	4,548			1,932	1,478
Chagrin			4,694	4,521			1,932	1,453
Lindside			4,957	4,653			1,051	1,013
Melvin			5,063	4,720			630	812
Monongahela			4,957	4,654			1,051	1,015
Average	**4,296**	**4,580**	**4,869**	**4,372**	**1,043**	**797**	**1,385**	**993**

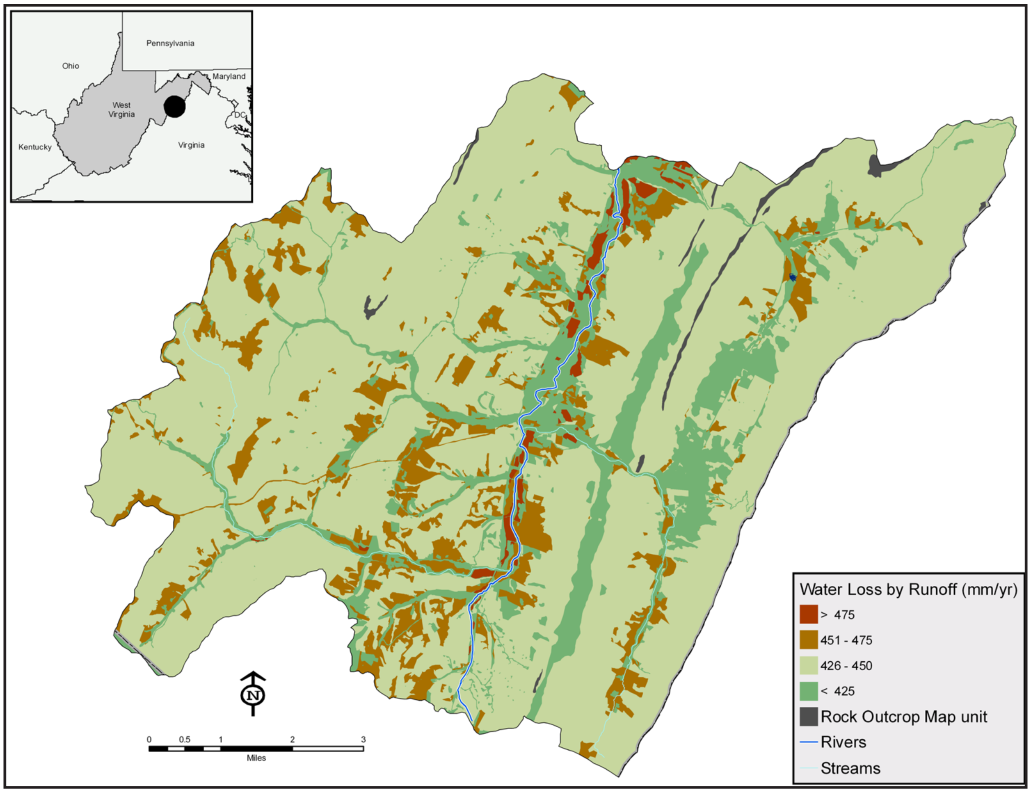

Figure 8.—Predicted runoff water (mm/yr) from 15 major soils under various types of land cover for Cullers Run (CR) and Upper Cove Run (UCR) watersheds, Hardy County, West Virginia.

The results given in table 6 indicate that the Berks soil (8,231 ha), irrespective of land cover, produced the highest volume of runoff water (36,716,183 m^3/yr), mainly because of its extent in the watershed. On the other hand, the five soils dominated by cropland (Tioga, Chagrin, Lindside, Melvin, and Monongahela) had very limited area and generated the lowest amount of runoff water. For the CR and UCR watersheds, the forestland (12,304 ha) generated the highest volume of runoff water (52,865,052 m^3/yr), followed by pastureland (17,495,712 m^3/yr), which occupied 3,821 ha. A relatively modest volume of runoff (1,442,258 m^3/yr) was generated from cropland (298 ha). These data reflect the area occupied by the three types of land cover.

Leaching Water

The predicted loss of water by leaching from the 15 major soils under different types of land cover is given as m^3/ha/yr in table 6 and as mm/yr in the map of the CR and UCR watersheds (figure 9). The predicted amount of water loss by leaching was generally much lower than that caused by runoff. Regarding the types of land cover, the amount of water loss by leaching was greater from forestland than from pastureland for each of the 10 soils dominated by these two types of land cover. The average loss of water by leaching was 1,043 m3/ha/yr for the forestland and 797 m^3/ha/yr for the pastureland. For the other 5 soils, covered totally by crops, the water loss by leaching ranged from 630 to 1,932 m^3/ha/yr with an average of 1,385 m^3/ha/yr. These results indicate that the water loss by leaching was generally greater from cropland than from forestland or pastureland.

As might be expected, soil hydrology appeared to have a strong effect on leaching. The four dominant soils of large extent in the two watersheds (Berks, Dekalb, Laidig, and Buchanan) have poor hydraulic conductivity (hydrologic group C). The water loss by leaching was predicted at 931 m^3/ha/yr for forestland and 711 m^3/ha/yr for pastureland. For Murrill, Tioga, and Chagrin soils with adequate hydraulic conductivity (hydrologic group B), the water loss by leaching was greater than that predicted for the four dominant soils. The water loss by leaching was 1,712, 1,307, and 1,932 m^3/ha/yr for forestland, pastureland, and cropland, respectively. Conversely, the sandy Potomac soil with its fast hydraulic conductivity (hydrologic group A) had the highest water loss by leaching; the predicted value was 2,976 m^3/ha/yr for forestland and 2,273 m^3/ha/yr for pastureland. When all 15 major soils in the watershed were considered, the predicted average loss of water by leaching was 1,043 m^3/ha/yr for forestland, 797 m^3/ha/yr for pastureland, and 1,385 m^3/ha/yr for cropland. Irrespective of land cover, the average water loss by leaching was 993 m^3/ha/yr for all soils in the two watersheds. Obviously, this average was much less than the respective value calculated for runoff water (4,372 m^3/ha/yr).

These results accounted for 11.6 percent of the annual precipitation for forestland, 8.9 percent for pastureland, and 15.4 percent for cropland. The values were within the range reported by Gast, Nelson, and Randall (1978) in their work on corn grown continuously in an area of Webster clay loam in southern Minnesota. The authors found that the loss of water by leaching (into tile lines) constituted from 7 to 22 percent of the annual precipitation during the 3-year study. Relatively lower values for leaching water were reported for an agricultural watershed in Lancaster County, Nebraska,

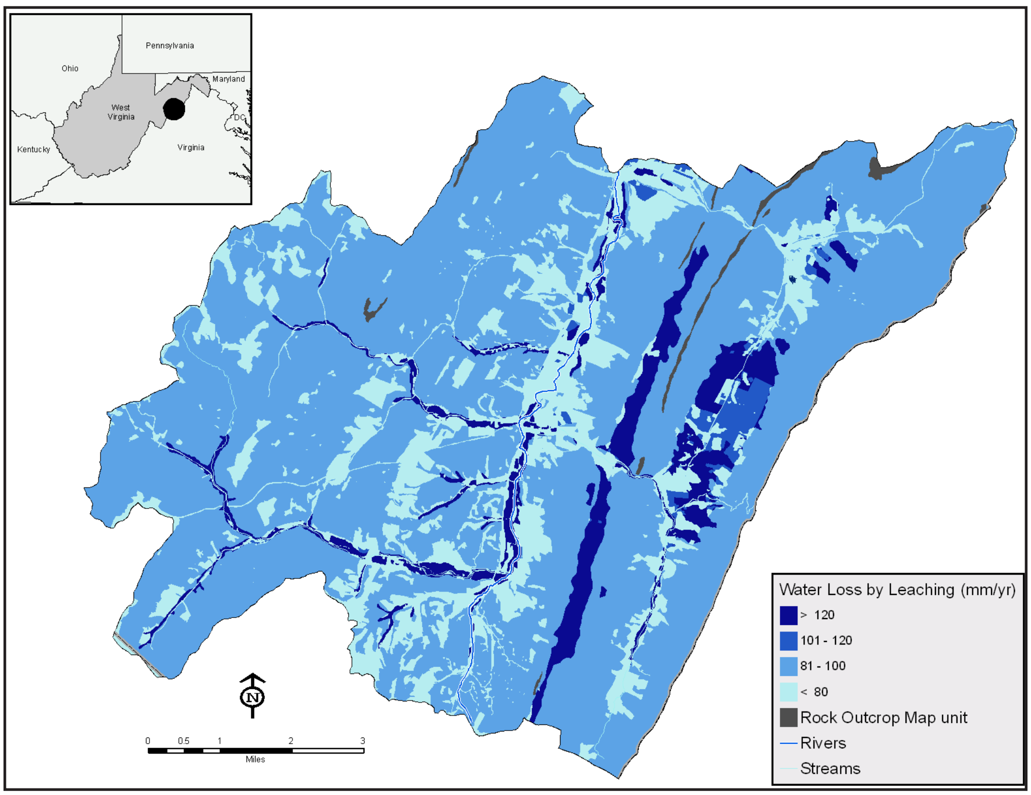

Figure 9.—Predicted loss of water by leaching (mm/yr) from 15 major soils under various types of land cover for Cullers Run (CR) and Upper Cove Run (UCR) watersheds, Hardy County, West Virginia.

where the average water loss by leaching was 8.0 percent of the annual precipitation for cropland and 4.3 percent for grassland (Elrashidi et al., 2004).

The predicted annual amount of water leached from the agricultural land in the two watersheds was approximately 17.0 million m^3, which accounted for 11.1 percent of the annual precipitation. Five major soils (Berks, Dekalb, Laidig, Calvin, and Lehew) accounted for approximately 80 percent of the area in the two watersheds. These soils are shallow and well drained and are mainly on ridgetops, benches, and hillsides (USDA/SCS, 1989). Also, the slope of these soils ranges from 8 to 65 percent. On the other hand, alluvial soils on flood plains (e.g., Tioga, Chagrin, Melvin, and Monongahela) occupy a very small area in the two watersheds. Under these conditions, it was reasonable to assume that leaching water along with runoff water could drain directly into the numerous small streams and then discharge eventually into the Lost River. Hubbard and Sheridan (1983) reported similar results for soils having horizons of low permeability at a relatively shallow depth (i.e., 75 to 200 cm). They concluded that water loss from such soils into surface water bodies may occur as surface runoff and/or shallow subsurface flow. In their study on water and nitrate-N losses from a Coastal Plain watershed in Georgia, Hubbard and Sheridan (1983) reported that the major water loss from the watershed was found to be subsurface flow, accounting for 79 percent of the total loss. Consequently, the authors concluded that approximately 99 percent of the total nitrate-N loss from soils was transported to surface water bodies by subsurface flow.

Nitrate-N Loss From Soils

The loss of nitrate-N by runoff and leaching water for forestland, pastureland, and cropland (kg/ha/yr) in the CR and UCR watersheds is presented in table 7. The loss of nitrate-N by runoff followed this order: pastureland > forestland > cropland, where the average loss was 14.8, 10.3, and 6.49 kg/ha/yr, respectively. For 110 counties in the High Plains region in the United States, Wu et al. (1997) used five categories to evaluate N loss by runoff: *low* (less than 1.68 kg/ha), *medium-low* (1.68 to 3.36 kg/ha), *medium* (3.36 to 5.04 kg/ha/yr), *medium-high* (5.04 to 6.72 kg/ha), and *high* (more than 6.72 kg/ha). Accordingly, most soils under forest and pasture cover in the two watersheds were in the high category, and most cropland soils were categorized as medium-high. This result could be attributed to the high rainfall and heavy application of poultry litter to agricultural land in the CR and UCR watersheds.

On the other hand, the loss of nitrate-N by leaching, irrespective of land cover, was greater than that by runoff. The average loss of nitrate-N by leaching followed the same order detected for runoff data (pastureland > forestland > cropland), where the average loss of nitrate-N was 53.5, 42.53, and 38.21 kg/ha/yr, respectively. Expectedly, the loss by leaching was greater in soils with a high or moderate water infiltration rate (hydrologic groups A and B) than in soils with a slow or very slow water infiltration rate (hydrologic groups C and D). For the former, the loss of nitrate-N ranged from 106 to 168 kg/ha/yr for pastureland, 102 to 141 kg/ha/yr for forestland, and 55.2 to 64.4 kg/ha/yr for cropland. For the latter, the range was 27.2 to 50.5 kg/ha/yr for pastureland, 17.9 to 58.5 kg/ha/yr for forestland, and 9.15 to 44.6 kg/ha/yr for cropland. In a moderately well drained Goldsboro soil in North Carolina, Gambrell, Gilliam, and Weed (1975) found an average nitrate-N of 46 kg/ha/yr, which was lost from a cornfield via outflow in both tile drainage and movement to shallow ground water.

Wu et al. (1997) designated five categories to evaluate nitrate-N loss by leaching for 110 counties in the High Plains region of the United States. These categories were *low* (less than 1.12 kg/ha), *medium-low* (1.12 to 2.24 kg/ha), *medium* (2.24 to 3.36 kg/ha), *medium-high* (3.36 to 4.48 kg/ha), and *high* (more than 4.48 kg/ha). When we compared nitrate-N losses by leaching in the CR and UCR watersheds (Appalachians) with those across the High Plains, all soils, irrespective of land cover, were classified

Table 7

Predicted amount of nitrate-N loss by runoff and leaching (kg/ha/yr) from 15 major soils under different types of land cover in the Cullers Run and Upper Cove Run watersheds, Hardy County, West Virginia.

Soil	Nitrate-N loss by runoff			Nitrate-N loss by leaching		
	Forest	Pasture	Cropland	Forest	Pasture	Cropland
	...(kg/ha/yr)...			...(kg/ha/yr)...		
Berks	10.38	15.85		36.67	50.53	
Dekalb	7.20	15.88		26.35	48.87	
Laidig	5.37	8.18		17.90	27.24	
Buchanan	16.64	14.03		58.54	44.83	
Murrill	15.64	18.06		101.96	105.53	
Clarksburg	14.00	9.90		50.05	31.18	
Potomac	11.29	18.18		141.48	167.88	
Ernest	9.34	10.11		33.56	31.76	
Lehew	6.74	13.31		23.71	42.47	
Calvin	9.59	12.93		34.17	40.88	
Tioga			8.07			64.37
Chagrin			6.90			55.18
Lindside			5.14			22.35
Melvin			3.51			9.15
Monongahela			10.25			44.56
Average	**10.31**	**14.84**	**6.49**	**42.53**	**53.47**	**38.21**

in the high category. As mentioned above, this result could be attributed to the high rainfall and heavy application of poultry litter. Spalding and Exner (1993), in a review of the occurrence of nitrate-N in ground water in the United States, reported that high nitrate-N concentrations in ground water frequently were encountered in areas of intensive poultry and livestock production.

Several studies in the north-central region of the United States reported values similar to those determined in our study for the loss of nitrate-N by leaching from soils in Wisconsin (Olsen et al., 1970) and Minnesota (Gast, Nelson, and Randall, 1978). Further, Timmons and Dylla (1981) reported average annual nitrate-N leaching losses ranging from 29 to 112 kg/ha for a cornfield (Estherville sandy loam) during a 5-year period in central Minnesota. For St. Joseph County in southwest Michigan, Rasse et al. (1999) found that application of 101 and 202 kg N/ha to maize fields (sand and sandy loam) during a 5-year period generated an average nitrate-N leaching loss of 26 and 60 kg/ha/yr, respectively.

Nitrate-N Loading in the Lost River

One of the objectives of this study was to estimate the impact of nitrate-N loss by runoff and leaching from soils in the CR and UCR watersheds on the water quality in the Lost River (nonpoint source of nitrate-N contamination). The predicted nitrate-N concentration (mg/L) in runoff and leaching water generated from soils under forestland, pastureland, and cropland is given in table 8. The average nitrate-N concentration in runoff water was 2.40, 3.24, and 1.34 mg/L for forestland, pastureland, and cropland, respectively. Meanwhile, irrespective of land cover, the average nitrate-N concentration was 2.57 mg/L in runoff water from all soils in the two watersheds. Similar concentrations in runoff water were obtained by Soileau et al. (1994) in their work on a 3.8-ha watershed in the Limestone Valley region of northern Alabama. The annual mean nitrate-N concentrations in runoff ranged from 1.3 to 2.2 mg/L during the 6-year study.

Table 8

Predicted nitrate-N concentration in runoff water and leaching water (mg/L) from 15 major soils under different types of land cover in the Cullers Run and Upper Cove Run watersheds, Hardy County, West Virginia.

Soil	NO_3-N in runoff water			NO_3-N in leaching water		
	Forest	Pasture	Cropland	Forest	Pasture	Cropland
	......................(mg/L).....................			......................(mg/L)......................		
Berks	2.36	3.41		39.37	71.03	
Dekalb	1.64	3.41		28.30	68.69	
Laidig	1.22	1.76		19.22	38.29	
Buchanan	3.78	3.02		62.85	63.01	
Murrill	4.14	4.28		59.57	80.72	
Clarksburg	3.18	2.13		53.74	43.83	
Potomac	5.05	5.78		47.55	73.86	
Ernest	2.12	2.17		36.03	44.65	
Lehew	1.53	2.86		25.45	59.70	
Calvin	2.18	2.78		36.68	57.46	
Tioga			1.72			33.32
Chagrin			1.47			28.56
Lindside			1.04			21.26
Melvin			0.69			14.53
Monongahela			2.07			42.39
Average	**2.40**	**3.24**	**1.34**	**40.77**	**67.08**	**30.91**

On the other hand, the predicted average nitrate-N concentration in the leaching water was much higher than that in the runoff water. The respective concentrations were 40.8, 67.1, and 30.9 mg/L for forestland, pastureland, and cropland. The predicted average nitrate-N concentration was 45.1 mg/L in leaching water generated from soils in the entire area of the CR and UCR watersheds.

The predicted nitrate-N concentration in the runoff water from various soils under various types of land cover is illustrated in figure 10. The dark (black) area in the map indicates soils producing runoff water with nitrate-N concentrations higher than 3.50 mg/L. It includes Buchanan, Murrill, and Potomac soils under forest and Murrill and Potomac soils under pasture. The total area of these soils (map units) is 2,371 ha, which account for 14 percent of the agricultural land in the two watersheds.

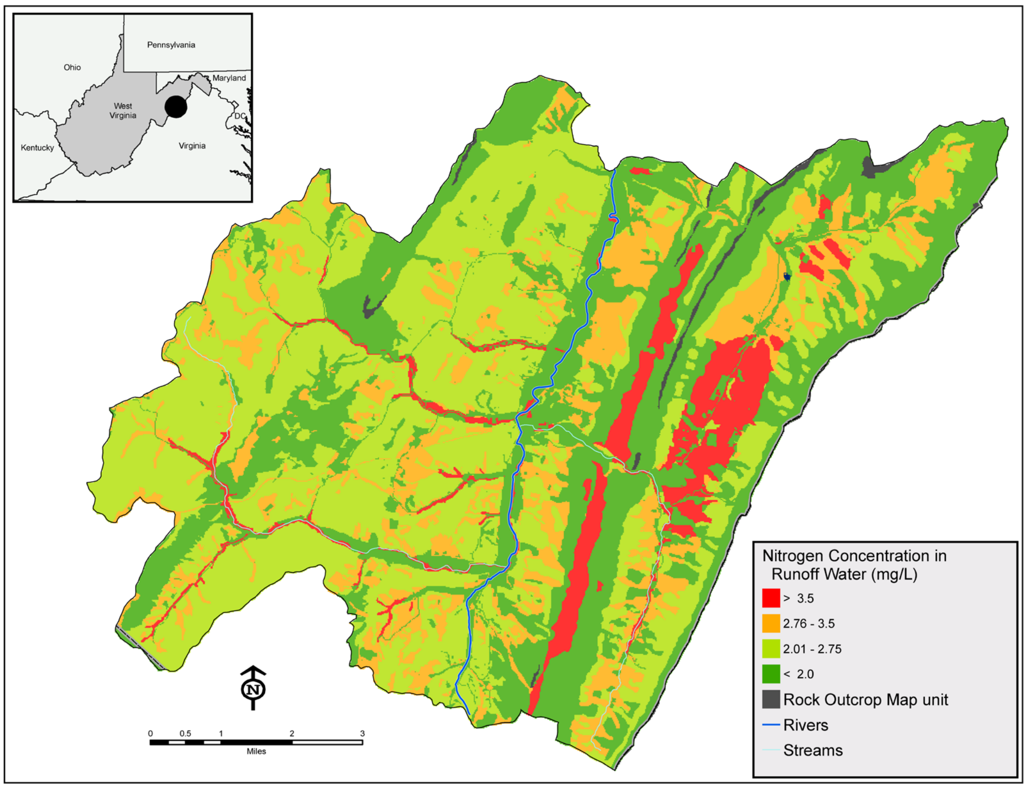

Figure 10.—Predicted nitrate-N concentration in runoff water (mg/L) from 15 major soils under various types of land cover in the Cullers Run (CR) and Upper Cove Run (UCR) watersheds, Hardy County, West Virginia.

The predicted nitrate-N concentration in leaching water from different soils is shown in figure 11. Approximately 20 percent (3,423 ha) of the area of the two watersheds (mainly in areas of Dekalb and Laidig soils) generated leaching water with nitrate-N concentrations of less than 35 mg/L. Meanwhile, an area of 44 percent (7,550 ha) of the watersheds (mainly in areas of Berks soils) produced leaching water with nitrate-N concentrations ranging from 35 to 50 mg/L. The remaining soils in the CR and UCR watersheds (36 percent) generated leaching water with nitrate-N concentrations of more than 50.0 mg/L. Thus, all soils in the entire area of the two watersheds generated leaching water with nitrate-N concentrations higher than the EPA MCL of 10 mg/L

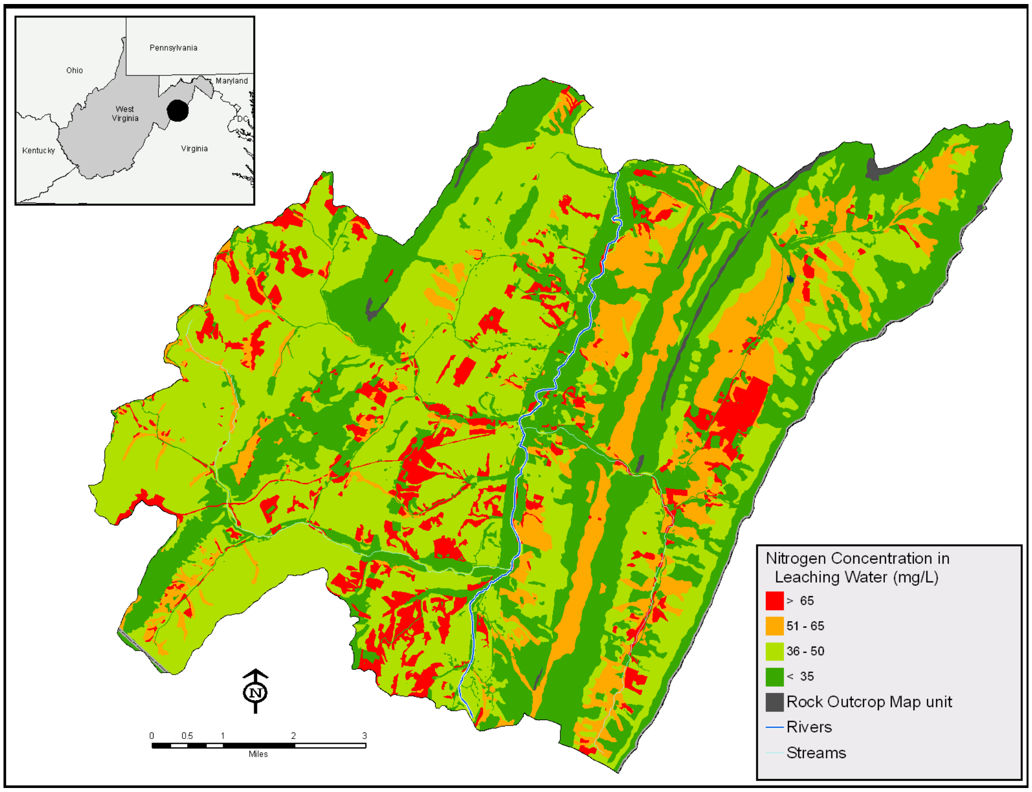

Figure 11.—Predicted nitrate-N concentration in leaching water (mg/L) from 15 major soils under various types of land cover in the Cullers Run (CR) and Upper Cove Run (UCR) watersheds, Hardy County, West Virginia.

(USEPA, 1992). The 10 mg/L is significant because the U.S. Public Health Service established 10 mg/L nitrate-N as the maximum allowable concentration in drinking water for humans and animals. Levels above 10 mg/L can lead to methemoglobinemia, or “blue baby” syndrome, as it is commonly called (Johnson et al., 1987). The ingested nitrate-N reduces the oxygen-carrying capacity of the blood and can lead to brain damage or death in severe cases.

High nitrate-N concentrations in ground water frequently were encountered in areas of intensive poultry and livestock production. Spalding and Exner (1993) reported that excessive leachate from field application of animal wastes and fertilizers resulted in Lancaster County having some of the worst nitrate-N concentrations in Pennsylvania. Well drained soils and the presence of several nitrate-N sources cause the ground water in recharge areas of the Delmarva Peninsula to be vulnerable to nitrate-N contamination (Ritter and Chirnside, 1984). The highest incidence of contamination was in an area of intensive broiler production in coastal Sussex County, where 37 percent of the wells exceeded the MCL. Leachates from poultry manure appeared to be the major contributor of nitrate-N to the ground water in four of the five problem areas.

We used the predicted average nitrate-N concentrations and the average monthly runoff and leaching water generated from the CR and UCR watersheds to estimate the average monthly nitrate-N loading for the Lost River (figure 12). The annual nitrate-N loading was approximately 956 Mg, of which 80 percent was derived from nitrate-N in the leaching water. For watersheds in southwestern Iowa, Timmons and Dylla (1981) reported that nitrate-N in subsurface discharge accounted for 84 to 95 percent

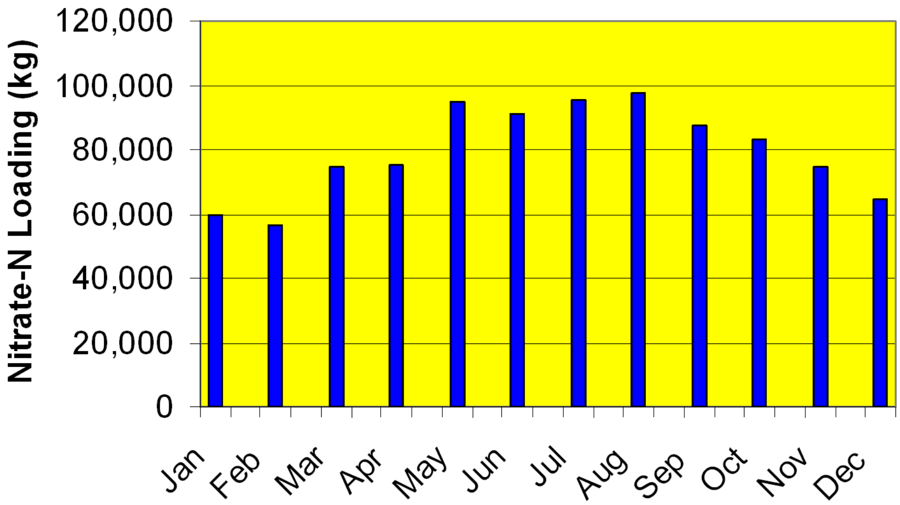

Figure 12.—Predicted average monthly nitrate-N loading (kg) by runoff and leaching for the Lost River, Hardy County, West Virginia.

of the total soluble N in streamflow. Most of the nitrate-N loading for the Lost River occurred during the summer, when the monthly nitrate-N loading ranged from 91 to 98 Mg. The lowest monthly nitrate-N loading took place during the winter, when it was generally below 65 Mg. The data of nitrate-N loading for different seasons followed the precipitation pattern in Hardy County.

Observed Nitrate-N Concentration

The nitrate-N concentrations in the 12 monthly samples collected from the Lost River ranged from 2.41 to 19.9 mg/L with an average of 7.11 mg/L (SD = 4.68 mg/L). The observed concentrations in eleven monthly water samples were lower than the predicted average nitrate-N concentration (10.4 mg/L) in waters removed (by runoff and leaching) from soils to the Lost River (figure 13). However, the high nitrate-N concentration (19.9 mg/L) detected in the water sample for July could be attributed to the fact that warm temperatures had increased the mineralization of organic N in poultry manure present in both soil and water. Mineralized natural organic N was a source of NO_3 contamination in the Montana saline seep area (Miller et al., 1981) and a potential contaminant in southwestern Nebraska (Boyce et al., 1976). Logan, Randall, and Timmons (1980) showed that N-rich leachates from cropped land were discharged to surface waters. Moreover, they used that fact to explain the occurrence of nitrate-N in concentrations above the MCL in the Scioto River near Columbus, Ohio, during the spring.

Further, the low nitrate-N concentrations observed in the Lost River could be attributed to biological processes. Large populations of algae, weeds, and aquatic plants in streams could assimilate N and reduce the concentration in water. Also, the loss of N gases from water to air could be associated with denitrification. Linn and Doran (1984), Smith, Howes, and Duff (1991), and Paul and Clark (1996) reported that under anaerobic conditions, soil nitrate is biologically reduced to NO and N_2O gases where low oxygen concentration and a soluble carbon source provide energy for the reaction. Similar processes could take place in freshwater bodies where heavy growth of algae and aquatic plants consume oxygen and excrete soluble carbon compounds, which enhance nitrate reduction and emission of gaseous nitrogen oxides.

We need to emphasize that the predicted nitrate-N value was calculated for water generated at field sites and not in stream water. Factors affecting N concentration

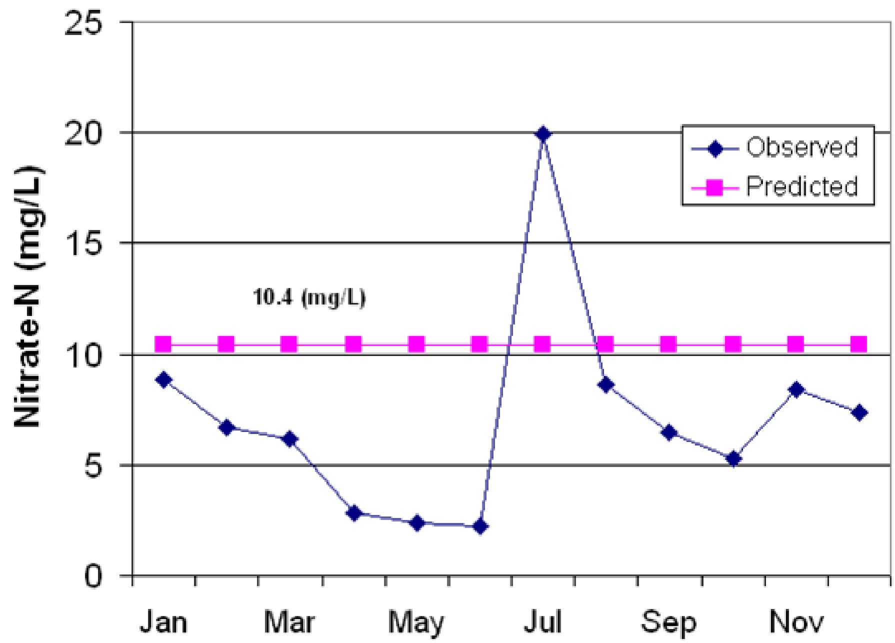

Figure 13.—Predicted and observed average monthly nitrate-N concentrations (mm/yr) for the Lost River, Hardy County, West Virginia.

in runoff and leaching water after it leaves field sites, such as N removal by aquatic weeds and algae as well as denitrification, should be taken into consideration. The data suggested that these biological factors have lowered nitrate-N concentrations in the Lost River water by approximately 32 percent and contributed to an annual removal of 305 Mg of nitrate-N. Therefore, if we consider possible factors affecting N concentrations in water after it leaves field sites, the technique could provide a reasonable estimation of nitrate-N concentrations in stream water.

Conclusion

Nutrients (e.g., P and N) and other water-soluble chemicals can be transported from agricultural land by surface runoff and subsurface leaching to surface freshwater bodies. Management activities on cultivated land in areas of high rainfall may pose a risk to water quality. The NRCS exploratory technique utilizes existing climatic, hydrologic, and soil survey databases to estimate the loss of nutrients and chemicals by runoff and leaching from agricultural land. The technique applies runoff and percolation models to estimate water loss from agricultural watersheds. The interaction between both runoff and leaching waters and dissolved nutrients in the root zone of the soil is used to estimate the loss of nutrients from the soil. GIS software, which utilizes available spatial soil and land cover layers as well as the predicted data for water and nutrient losses, can be applied to develop digital maps. These maps improve data presentation and communication with the clientele and help to identify trouble areas within a watershed.

Phosphorus and most nutrients are mainly lost from soils by runoff to surface freshwater bodies. In sandy soils, P can also be lost by leaching to ground water. Nitrate, however, because of its high mobility in the soil profile, can be transported from agricultural land by both surface runoff and subsurface leaching. Nutrients and agricultural chemicals are released from a thin layer of surface soil that interacts with rainfall and runoff water. The thickness of the interaction zone used in our studies is 10 mm; it was assumed that only a fraction of the chemical present in this depth interacts with rain water.

Even in the absence of potential sources of P contamination, such as animal feedlots, intensive cattle grazing, heavy P fertilization, or P-enriched soil minerals, the agricultural land still can release enough P in runoff to cause eutrophication of freshwater bodies. Compliance with the recommended P limits for confined and flowing water systems appears to be a formidable task. Management practices or nutrient attenuation mechanisms (e.g., riparian wetland) that can reduce P concentrations in runoff waters before they are discharged into freshwater bodies should be considered. To be most effective, P management efforts should be targeted to identified “hot spots” within a watershed, or areas that are most vulnerable to P loss.

The downward movement of water (carrying dissolved nutrients) from the topsoil is the major mechanism by which dissolved elements are lost from the root zone. For cropped soils, we assumed that the dissolved nutrient is lost when it is removed from below a 30-cm soil depth. The 30-cm depth was used extensively by environmental and soil scientists and agronomists to estimate loss of nutrients by runoff from cropped soils. Using the 30-cm soil depth made it easy to compare our data with information from other watersheds in different parts of the United States. However, a larger soil depth could be used to estimate loss of nutrients from soil cultivated with deep-rooted crops, such as fruit trees.

Both the slope and the soil depth appeared to play major roles in subsurface leaching water and chemical loading into surface water bodies. In our study in Nebraska, most of the soils in the Wagon Train watershed are gently sloping or moderately sloping and are deep. Under these conditions, we found that the leaching water with dissolved N had a minor effect on the surface water body (WT reservoir).

Thus, it was assumed that only N loss from soils to runoff water has contributed to N loading into the reservoir. In the West Virginia study, most of the soils in the Lost River basin are shallow and well drained and occur mainly on ridgetops, benches, and hillsides. Also, the slope ranges from 8 to 65 percent. It was reasonable to assume that leaching water along with runoff water could drain into the numerous small streams and then discharge eventually into the Lost River. Thus, N losses from soils as a result of both runoff and leaching have contributed to N loading into the Lost River.

We need to emphasize that the predicted nutrient concentration was calculated for runoff water generated at field sites and not in surface water bodies, such as streams, rivers, or lakes. Factors affecting nutrient concentrations in runoff water after it leaves field sites should be taken into consideration. These factors may include biological uptake for both P and N (presence of heavy growth of algae, weeds, and aquatic plants), biological reactions for N (denitrification and mineralization), and chemical precipitation for P. If the effects of these factors on nutrient concentrations in transported waters are taken into consideration, the technique could provide a reasonable estimation of nutrient concentrations in surface water bodies.

Finally, we concluded that the NRCS exploratory technique could be used to conduct quick and cost-effective evaluations and identify hot spots for a small watershed (20 to 40 ha) or a large area of agricultural land that may include thousands of hectares. Thus, lengthy and site-specific studies could be focused on certain areas of high risk.

References

American Society for Testing and Materials (ASTM). 1993. Annual book of ASTM standards. Construction. Section 4. Soil and rock; dimension stone; Geosynthesis. Vol. 04.08. ASTM, Philadelphia, PA.

Boyce, J.S., J. Muir, A.P. Edwards, E.C. Seim, and R.A. Olson. 1976. Geologic nitrogen in Pleistocene loess of Nebraska. Journal of Environmental Quality 5: 93-96.

Carpenter, S.R., N.F. Caraco, D.L. Correl, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8: 559-568.

Donigian, A.S., Jr., D.C. Beyerlein, H.H. Davis, Jr., and N.H. Crawford. 1977. Agricultural runoff management (ARM) model—version II. Refinement and testing. EPA 600/3-77-098. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Elrashidi, M.A., A.K. Alva, Y.F. Huang, D.V. Calvert, T.A. Obreza, and Z.L. He. 2001. Accumulation and downward transport of phosphorus in Florida soils and relationship to water quality. Communications in Soil Science and Plant Analysis 32: 3099-3119.

Elrashidi, M.A., D. Hammer, M.D. Mays, C. Seybold, and S.D. Peaslee. 2007a. Loss of alkaline earth elements by runoff from agricultural watersheds. Soil Science 172: 313-332.

Elrashidi, M.A., D. Hammer, M.D. Mays, C. Seybold, and S.D. Peaslee. 2007b. Loss of heavy metals by runoff from agricultural watersheds. Soil Science 172: 876-894.

Elrashidi, M.A., M.D. Mays, A. Fares, C.A. Seybold, J.L. Harder, S.D. Peaslee, and Pam VanNeste. 2005a. Loss of nitrate-N by runoff and leaching for agricultural watersheds. Soil Science 170: 969-984.

Elrashidi, M.A., M.D. Mays, J.L. Harder, D. Schroeder, P. Brakhage, S.D. Peaslee, and C. Schaecher. 2005b. Loss of phosphorus by runoff for agricultural watersheds. Soil Science 170: 543-558.

Elrashidi, M.A., M.D. Mays, and P.E. Jones. 2003. A technique to estimate release characteristics and runoff phosphorus for agricultural land. Communications in Soil Science and Plant Analysis 34: 1759-1790.

Elrashidi, M.A., M.D. Mays, S.D. Peaslee, and D.G. Hooper. 2004. A technique to estimate nitrate-nitrogen loss by runoff and leaching for agricultural land, Lancaster County, Nebraska. Communications in Soil Science and Plant Analysis 35: 2593-2615.

Elrashidi, M.A., C.A. Seybold, D.A. Wysocki, S.D. Peaslee, R. Ferguson, and L.T. West. 2008. Phosphorus in runoff from two watersheds in Lost River Basin, West Virginia. Soil Science 173: 792-806.

Elrashidi, M.A., L.T. West, C.A. Seybold, D.A. Wysocki, E. Benham, R. Ferguson, and S.D. Peaslee. 2009. Nonpoint source of nitrogen contamination from land management practices in Lost River Basin, West Virginia. Soil Science 173: 792-806.

Environmental Systems Research Institute (ESRI). 2006. ArcGIS version 9.2 http://www.esri.com

Frere, M.H., J.D. Ross, and L.J. Lane. 1980. The nutrient sub-model. Chapter 4. *In* CREAMS: A field-scale model for chemicals, runoff, and erosion from agricultural management systems. W.G. Knisel, editor. U.S. Department of Agriculture, Science and Education Administration, Conservation Research Report 26 1: 65-86.

Fruh, G.E. 1967. The overall picture of eutrophication. Journal of the Water Pollution Control Federation 39: 1449-1463.

Gambrell, R.P., J.W. Gilliam, and S.B. Weed. 1975. Nitrogen losses from soils of the North Carolina Coastal Plain. Journal of Environmental Quality 4: 317-323.

Gast, R.G., W.W. Nelson, and G.W. Randall. 1978. Nitrate accumulation in soils and loss in tile drainage following nitrogen application to continuous corn. Journal of Environmental Quality 7: 258-262.

Gburek, W.J., and A.N. Sharpley. 1998. Hydrologic controls on phosphorus loss from upland agricultural watersheds. Journal of Environmental Quality 27: 267-277.

Gburek, W.J., A.N. Sharpley, L. Heathwaite, and G.J. Folmar. 2000. Phosphorus management at the watershed scale: A modification of the phosphorus index. Journal of Environmental Quality 29: 130-144.

Gebert, W.A., D.J. Graczyk, and W.R. Krug. 1987. Average annual runoff in the United States, 1951-80. Hydrologic Investigations Series, National Atlas HA-710. U.S. Geological Survey, Reston, VA.

Gilley, J.E., S.C. Finkner, R.G. Spomer, and L.N. Mielke. 1986. Runoff and erosion as affected by corn residue: Part I, Total losses. Transactions of the American Society of Agricultural Engineers 29: 157-160.

Gilley, J.E., S.C. Finkner, and G.E. Varvel. 1986. Runoff and erosion as affected by sorghum and soybean residue. Transactions of the American Society of Agricultural Engineers 29: 1605-1610.

Hubbard, R.K., R.A. Leonard, and A.W. Johnson. 1991. Nitrate transport on a sandy coastal plain soil underlain by plinthite. Transactions of the American Society of Agricultural Engineers 34: 802-808.

Hubbard, R.K., and J.M. Sheridan. 1983. Water and nitrate-nitrogen losses from a small, upland, Coastal Plain watershed. Journal of Environmental Quality 12: 291-295.

Johnson, C.J., P.A. Bonrud, T.L. Dosch, A.W. Kilness, K.A. Senger, D.C. Busch, and M.R. Meyer. 1987. Fatal outcome of methemoglobinemia in an infant. Journal of the American Medical Association 257: 2796-2797.

Lemunyon, J.L., and R.G. Gilbert. 1993. The concept and need for a phosphorus assessment tool. Journal of Production Agriculture 6: 483-486.

Lindsay, W.L. 1979. Chemical equilibria in soils. John Wiley & Sons, New York.

Linn, D.M., and J.W. Doran. 1984. Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and nontilled soils. Soil Science Society of America Journal 48: 1267-1272.

Logan, T.J., G.W. Randall, and D.R. Timmons. 1980. Nutrient content of tile drainage from cropland in the North Central region. North Central Regional Research Publication 268. Ohio Agricultural Research and Development Center, Wooster, OH.

Lower Platte South Natural Resources District (LPSNRD). 2004. A community-based watershed management plan for Wagon Train Lake, Lancaster County, Nebraska. Nebraska Department of Environmental Quality, Lincoln, NE.

Lowrance, R. 1992. Nitrogen outputs from a field-size agricultural watershed. Journal of Environmental Quality 21: 602-607.

Miller, M.R., P.L. Brown, J.J. Donovan, R.N. Bergatino, J.L. Sonderegger, and F.A. Schmidt. 1981. Saline seep development and control in the North American Great Plains. Agricultural Water Management 4: 115-141.

National Agricultural Statistics Service (NASS). 2003. http://www.nass.usda.gov/ne. U.S. Department of Agriculture, Washington, DC.

National Land Cover Data for West Virginia (NLCD). 1992. Version 05-07-00 nominal thematic mapper. http://landcover.usgs.gov/natllandcover.html

National Water and Climate Center (NWCC). 2003. http://www.WCC.NRCS.gov/water/W_CLIM.html

Novak, J.M., D.W. Watts, P.G. Hunt, and K.C. Stone. 2000. Phosphorus movement through a Coastal Plain soil after a decade of intensive swine manure application. Journal of Environmental Quality 29: 1310-1315.

Olsen, R.J., R.F. Hensler, O.J. Attoe, S.A. Witzel, and L.A. Peterson. 1970. Fertilizer nitrogen and crop rotation in relation to movement of nitrate nitrogen through soil profiles. Soil Science Society of America Journal 34: 448-452.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. *In* Methods of Soil Analysis, 2nd edition, Part 2, Chemical and Microbiological Properties. A.L. Page, R.H. Miller, and D.R. Keeney, editors. Pages 403-430. American Society of Agronomy and Soil Science Society of America, Madison, WI.

Paul, E.A., and F.E. Clark. 1996. Soil microbiology and biochemistry. 2nd edition. Academic Press, San Diego, CA.

Rasse, D.P., J.T. Ritchie, W.R. Peterson, T.L. Loudon, and E.C. Martin. 1999. Nitrogen management impacts on yield and nitrate leaching in inbred maize systems. Journal of Environmental Quality 28: 1365-1371.

Rawls, W.J. 1983. Estimating soil bulk density from particle size analysis and organic matter content. Soil Science 135: 123-125.

Ritter, W.F., and A.E. Chirnside. 1984. Impact of land use on groundwater quality in southern Delaware. Ground Water 22: 38-47.

Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, and R. Parry. 1999. Agricultural phosphorus and eutrophication. U.S. Department of Agriculture, Agricultural Research Service, ARS 149.

Sharpley, A.N., S.J. Smith, O.R. Jones, W.A. Berg, and G.A. Coleman. 1992. The transport of bioavailable phosphorus in agricultural runoff. Journal of Environmental Quality 21: 30-35.

Smith, R.L., B.L. Howes, and L.H. Duff. 1991. Denitrification in nitrate-contaminated groundwater: Occurrence in steep vertical geochemical gradients. Geochimica et Cosmochimica Acta 55: 1815-1825.

Soileau, J.M., J.T. Touchton, B.F. Hajek, and K.H. Yoo. 1994. Sediment, nitrogen, and phosphorus runoff with conventional- and conservation-tillage cotton in a small watershed. Journal of Soil and Water Conservation 49: 82-89.

Sonzogni, W.C., G. Chesters, D.R. Coote, D.N. Jeffs, J.C. Konrad, R.C. Ostry, and J.B. Robinson. 1980. Pollution from land runoff. Environmental Science and Technology 14(2): 148-153.

Spalding, R.F., and M.E. Exner. 1993. Occurrence of nitrate in groundwater—a review. Journal of Environmental Quality 22: 392-402.

Tabbara, H. 2003. Phosphorus loss to runoff water twenty-four hours after application of liquid swine manure or fertilizer. Journal of Environmental Quality 32: 1044-1052.

Timmons, D.R., and A.S. Dylla. 1981. Nitrogen leaching as influenced by nitrogen management and supplemental irrigation level. Journal of Environmental Quality 10: 421-426.

United States Department of Agriculture, Natural Resources Conservation Service. 1996. Soil survey laboratory methods manual. Soil Survey Investigations Report 42, Version 3.

United States Department of Agriculture, Natural Resources Conservation Service. 1999. Soil survey geographic (SSURGO) database for Lancaster County, Nebraska. http://www.ftw.nrcs.usda.gov/ssur_data.html

United States Department of Agriculture, Natural Resources Conservation Service. 2004. Soil survey laboratory methods manual. Soil Survey Investigations Report 42, Version 4.

United States Department of Agriculture, Natural Resources Conservation Service, and West Virginia Conservation Agency. 2004. Hardy County water resources assessment.

United States Department of Agriculture, Soil Conservation Service. 1989. Soil survey of Grant and Hardy Counties, West Virginia.

United States Department of Agriculture, Soil Conservation Service. 1991. National engineering field manual. Chapter 2: Estimating runoff and peak discharges.

United States Environmental Protection Agency (USEPA). 1986. Water quality criteria for water. Report 440/5-86-001. Office of Water, Washington, DC.

United States Environmental Protection Agency (USEPA). 1992. Managing nonpoint source pollution: Final report to Congress on Section 319 of the Clean Water Act. EPA-506/9-90. Washington, DC.

United States Environmental Protection Agency (USEPA). 1996. Clean water action plan: Restoring and protecting America's waters.

United States Geological Survey (USGS). 2001. Platte River basin, Lower Platte River Basin, Salt Creek at Roca. *In* Water Resource Data, Nebraska Water Year 2000. Water-Data Report NE-00-1, pages 180-181.

United States Geological Survey (USGS). 2007. Water resources. National Water Information System: Web Interface. http://waterdata.usgs.gov/wv/nwis/inventory/

Williams, J.R., and D.E. Kissel. 1991. Water percolation: An indicator of nitrogen-leaching potential. Chapter 4 *in* Managing Nitrogen for Groundwater Quality and Farm Profitability, pages 59-83. R.F. Follett, D.R. Keeney, and R.M. Cruse, editors. Soil Science Society of America, Madison, WI.

Wu, J.J., D.J. Bernardo, H.P. Mapp, S. Geleta, M.L. Teague, K.B. Watkins, G.J. Sabbagh, R.L. Elliott, and J.F. Stone. 1997. An evaluation of nitrogen runoff and leaching potential in the High Plains. Journal of Soil and Water Conservation 52(1): 73-80.