Nonpoint Source of Nitrogen Contamination From Land Management Practices in Lost River Basin, West Virginia

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Abstract: Poultry production in Hardy County, West Virginia, has increased considerably since the early 1990s. The Lost River basin contains the highest density of poultry facilities in the county. Most of the N-rich poultry litter produced is land applied, and concerns over water quality are widespread. The objective was to apply the Natural Resources Conservation Service exploratory technique on two watersheds (Cullers Run and Upper Cove Run) in the Lost River basin to estimate the loss of nitrate-N from soils by runoff and leaching and to predict the impact on water quality. The predicted annual nitrate-N loss by runoff was 192 Mg, whereas that by leaching was 764 Mg, and their combined amount represented the annual loading for the Lost River. The predicted averages of nitrate-N concentration in runoff and leaching water were 2.57 and 45.1 mg/L, respectively. These data would give an estimated average nitrate-N concentration of 10.4 mg/L in the Lost River. The observed nitrate-N concentration in 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 (S.D., 4.68 mg/L). The relatively low nitrate-N concentrations observed in the river could be attributed to assimilation by algae, weeds, and aquatic plants, as well as denitrification in stream water under anaerobic conditions. When factors affecting N concentration in streams are considered, the technique could estimate the impact on water quality. We concluded that the exploratory technique could provide a quick estimation and identify hot spots for large areas of agricultural land. Thus, lengthy and site-specific studies could be focused on certain areas of high risk.

Key words: Agricultural watershed, runoff nitrogen, leaching nitrogen, poultry litter, eutrophication, Lost River

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During the last 20 years, poultry production in Hardy County, West Virginia, has considerably increased. The waste by-products 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 surface water and groundwater quality 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] USDA/NRCS, 2004a) identified 21 watersheds in Hardy County, which include six watersheds in the Lost River basin.

The Lost River basin was identified as producing twice as much poultry litter, or manure, as that existing agricultural land could safely handle for disposal (USDA/NRCS, 1996). Accordingly, the Lost River was designated no. 1 on the US Department of Agriculture (USDA)-NRCS priority list for implementation of agricultural Best Management Practices. 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 has led to an expectation that excess N and phosphorus (P) must be polluting the Lost River and other Potomac Headwater streams.

The presence of nitrates and other soluble forms of N and P in surface water and groundwater can deteriorate water quality in relationship 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 US Public Health Service and the US Environmental Protection Agency has 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 (USEPA, 1992).

Managing nonpoint sources of contamination from agricultural land is technically complex. Contamination sources often are located over a large geographic area and are difficult to identify. Identifying hot spots within a watershed enables more efficient use of funds to alleviate potential problems and protect water resources. 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 NRCS developed an exploratory technique (Elrashidi et al., 2004) to estimate nitrate-N loss by runoff and leaching for agricultural watersheds. The technique is quick and cost-effective because it uses existing climatic, hydrologic, and soil survey information.

The NRCS technique applies the USDA runoff curve number ([*CN*] 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. A brief description of the technique is reported in the Materials and Methods section. 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] watersheds) and to estimate the impact (nonpoint source of nitrate-N contamination) on water quality.

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MATERIALS AND METHODS

Study Area

Hardy County is located in the eastern panhandle of West Virginia, encompassing approximately 1512 km^2 (584 mi^2). There are 467 farms in the county that include cattle, hogs, sheep, poultry, and cropland. Hardy County ranks first in West Virginia with regard to poultry production. The latest Census of Agriculture indicates that the county is 73% forestland, 19% pastureland, 6% cropland, 1% urban area, and 1% recreational land (USDA/NRCS, 2004b).

The topography of the county is rugged, being composed of 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. Elevations range from 220 m (725 ft) above mean sea level on the South Branch, at Hampshire-Hardy County line to 1009 m (3,320 ft) above mean sea level on the South Branch mountain, near the center of the county.

The climate of Hardy County is seasonal in nature, with warm summers, cold winters, stormy springs, and mild fall seasons. The average annual temperature for the area is 10.7 °C (51.3 °F) with monthly extremes ranging from −1.9 °C (28.6 °F) in January to 22.4 °C (72.4 °F) in July. The average annual precipitation for the county is 867 mm (34.12 in.) with the maximum of 87.4 mm (3.44 in.) in July and the minimum of 51.1 mm (2.01 in.) in February. The area experiences approximately 584 mm (23.0 in.) of snowfall per year, usually during the December to March winter season, and relative humidity ranges daily between 53% and 78%.

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 acre), covered mainly with forest (72%) and pasture (22%), whereas cropped land contributes less than 5%. This region contains the most intensive agricultural operations in the Lost River basin, dominated by the integrated poultry industry. A woody riparian corridor exists along much of each of the Lost River tributaries. However, this is not the case along the Lost River's main stream, where most trees were removed many years ago and cropland as well as pastureland typically extend to the river's edge.

We used the soil survey information, Soil Survey Geographic Database (USDA/NRCS, 1999), to determine the 15 major soils in the two watersheds, which accounted for approximately 98% of the agricultural land. Both the National Land Cover Data (NLCD, 1992) and National Agricultural Statistics Service (NASS, 2003) were used to identify different land covers.

Soil and Water Sampling

Soil sampling included 15 major soil series that produced a total of 15 soil map units to sample in the two watersheds. Samples were collected from soils under forest, pasture, and crop. However, none of the 15 soils had all the three land covers. Ten soils (Berks, Dekalb, Laidig, Buchanon, Murrill, Clarksburg, Potomac, Ernest, Lehew, and Calvin) had mainly forest and pasture, whereas the remaining five soils (Tioga, Chagrin, Lindside, Melvin, and Monongahela) had only cropland.

Representative samples were taken from soils under forest, pasture, and crop. For each of the 10 soils (Berks, Dekalb, Laidig, Buchanon, Murrill, Clarksburg, Potomac, Ernest, Lehew, and Calvin), 10 samples from forestland and 6 samples from pastureland were collected. For each of the other five soils (Tioga, Chagrin, Lindside, Melvin, and Monongahela), four samples from cropland were collected. 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 crop, 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. An approximately 2-kg composite sample was packed in a plastic bag and sealed. 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 (Lost River), which runs northernly through the middle section of the two watersheds. Twelve monthly water samples (January-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 before sample collection. The water samples were taken immediately to the laboratory and refrigerated at 4 °C. The soil and water sampling locations are shown in Fig. 1.

Soil and Water Analysis

Soil samples were analyzed on air-dried less than 2-mm soil by methods described in the Soil Survey Investigations Report No. 42 (USDA/NRCS, 2004b). Alphanumeric codes in parentheses next to each method represent specific standard operating procedures. Particle-size analysis was performed by sieve and pipette method (3A1). Cation exchange capacity was conducted by NH_4OAc buffered at pH 7.0 (5A8b). Total carbon (C) concentration was determined by dry combustion (6A2f), and $CaCO_3$ equivalent was estimated by the electronic manometer method (6E1g). Organic C in soil was estimated from both the total C and $CaCO_3$-C. Soil pH was measured in a 1:1 soil-water suspension (8C1f). Bulk density was estimated from particle-size analysis and organic matter content (Rawls, 1983). Liquid limit was determined by the American Society for Testing and Materials method D 4318 (ASTM, 1993). Soluble nitrate-N was extracted with 1.0 *M* KCl solution and measured by flow injection automated ion analyzer LACHAT Instruments (6M2a). Classification and selected properties for soils under forest, pasture, and crop in the two watersheds are given in Table 1.

Stream-water samples were filtered by using a glass syringe equipped with Whatman 25-mm GD/X disposable nylon filter media (0.45-μm pore size). Nitrate-N concentration in the filtrate was determined by high-pressure ion chromatography (6M1c) (HPIC, Dionex Corp) and pH with a combination electrode and digital pH/ion meter, Model 950, Fisher Scientific (8C1a), as described in USDA/NRCS (1996).

NRCS Technique

The technique applies USDA runoff (USDA/SCS, 1991) and percolation models (Williams and Kissel, 1991) to estimate water loss from agricultural watersheds. The interaction between both runoff and leaching waters and dissolved nitrate-N in root-zone soil are used to estimate nitrate-N loss from soils. Geographical Information Systems ([GIS] ESRI, 2006) are used to present data spatially in watershed maps.

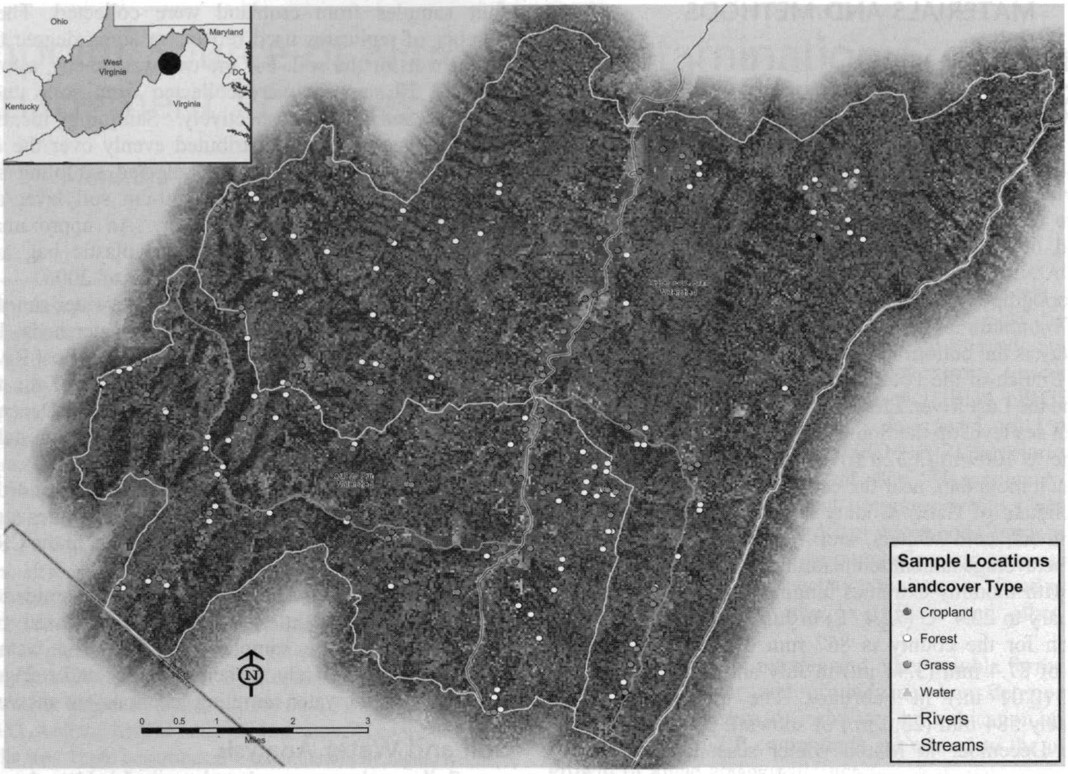

FIG. 1. Soil and water sampling locations in CR and UCR watersheds, Hardy County, West Virginia.

Estimation of Runoff Water

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

$$Q = (R-0.2S)^2 \div (R+0.8S) \quad (1)$$

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 CN, which is dependent on both the hydrologic soil group and type of land cover by the following equation:

$$CN = 1000 \div (10+S) \quad (2)$$

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

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

In this study, hydrologic groups of the 15 soils investigated were used to determine CN for forestland, pastureland, and cropland. The annual rainfall for the watershed (Hardy County, WV) was taken from the USDA/NRCS National Water & Climate Center (NWCC, 2003).

Soil Conservation Service hydrologists (USDA/SCS, 1991) developed the runoff equation (Eq.[3]) to estimate runoff from agricultural watersheds by 24-h rainfall event. It was assumed that the 24-h storm was an effective rainfall (R) that could generate runoff. In this work and six previous studies in this laboratory (Elrashidi et al., 2003, 2004, 2005a, b, 2007a, b), the runoff equation was applied to estimate runoff by an annual rainfall. It was assumed that a certain percentage of an annual rainfall (depending upon geography, topography, and climate) would generate runoff. Information on average annual runoff in the United States (Gilbert et al., 1987) was used to derive that assumption. In these studies, a good agreement was obtained between the observed and predicted runoff values.

In a previous study on the CR and UCR watersheds in the Lost River basin, Hardy County, West Virginia, Elrashidi et al. (2008) applied the runoff equation, assuming that 60% of an annual rainfall would generate runoff. Thus, in Eq.(3), the effective rain (R) = (annual rainfall × 0.6). The predicted average runoff for the two watersheds was 4374 m^3/ha per year. The US Geological Survey maintains stream flow gauging stations in six other watersheds in Hardy County (USDA/NRCS, 2004b; USGS, 2007). Elrashidi et al. (2008) used the values of monthly average stream flow and drainage area to calculate the observed annual surface runoff water for the six watersheds (4267 m^3/ha per year), which was in agreement with the predicted value. In this study, we assumed that 60% of the annual rainfall in the Lost River basin would generate runoff.

For agricultural land in the two watersheds, the effective rainfall (R), and the runoff CN were determined first, then the runoff equation was applied to estimate the runoff water (Q) for soil under forest, pasture, and crop. The equation calculated runoff water in inches (depth of water). Values were converted to millimeters for this study.

TABLE 1. Soil classification, selected properties, and nitrate-N (milligrams per kg) for 15 major soils under forest, pasture, and crop in CR and UCR watersheds, Hardy County, West Virginia

Soils (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
I. Berks	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
		Crop							
II. Dekalb	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
III. Laidig	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
		Crop							
IV. Buchanan	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
		Crop							
V. Murrill	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
		Crop							
VI. Clarksburg	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
		Crop							
VII. Potomac	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
		Crop							
VIII. Ernest	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
		Crop							
IX. Lehew	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
		Crop							
X. Calvin	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
		Crop							
XI. Tioga	Coarse loamy, mixed, mesic Dystric Fluventic Eutrochrepts	Forest							
		Pasture							
		Crop	16.23	2.42	9.83	5.88	1.24	150	65.4
XII. Chagrin	Fine-loamy, mixed, mesic Dystric Fluventic Eutrochrepts	Forest							
		Pasture							
		Crop	19.95	3.66	11.93	6.08	1.18	275	58.9
XIII. Lindside	Fine-silty, mixed, mesic Fluvaquentic Eutrochrepts	Forest							
		Pasture							
		Crop	18.00	2.82	10.15	6.43	1.24	275	41.7
XIV. Melvin	Fine-silty, mixed, nonacid, mesic Typic Fluvaquents	Forest							
		Pasture							
		Crop	29.98	4.56	16.28	6.40	1.08	300	32.7
XV. Monongahela	Fine-loamy, mixed, mesic Typic Fragiudults	Forest							
		Pasture							
		Crop	17.50	4.18	11.83	5.98	1.12	275	92.1

BD: bulk density; CEC: cation exchange capacity.

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 Eq.(3) to develop their equation that predicts the percolation index (*PI*).

$$PI = (P-0.4r)^2 / (P+0.6r) \quad (4)$$

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

$$r = (1000/PCN) - 10 \quad (5)$$

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.

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

where PW is the effective precipitation (rainfall occurs in the absence of land cover), and P is the annual precipitation. The PW for cropland in the two watersheds was computed by summing the values for October through May. Assuming evapotranspiration was very low during the winter, the total precipitation for December, January, and February were used to calculate PW for pastureland. For forestland, PW was calculated for fall and early spring period (November through April).

The leaching index (LI) was estimated by combining Eq.(4) and Eq.(6) as follows:

$$LI = (PI)\,(SI) \quad (7)$$

For the 15 soils investigated, the amount of leaching water was calculated by using the LI for forestland, pastureland, and cropland.

Estimating Nitrate-N Loss by Runoff and Leaching

Nutrients such as N, K, 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 between 2.0 and 6.0 mm (Donigian et al., 1977). Frere et al. (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 other studies in this laboratory, Elrashidi et al. (2003, 2004, and 2005a,b) used a fixed soil thickness of 10 mm to estimate P and nitrate-N loss by runoff for agricultural land. In the present study, the nitrate-N measured in soil is the net product of all chemical and biological reactions affecting nitrate-N in soil (i.e., mineralization, nitrification, and immobilization).

We used an interaction zone of 10 mm to calculate the amount of nitrate-N released from surface soils by runoff. In addition, it was 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 nitrate-N in the 10-mm soil depth is dissolved) is the sum of water within the soil body (liquid limit) and that on the surface of soil (runoff water). The volume of water in the 10-mm soil depth is usually very small when compared with runoff water. Only nitrate-N in runoff water is removed and lost during the runoff occurrence.

Hubbard et al. (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 fertilizer application. Furthermore, 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. At the end of summer, they found that less than 10% of applied N (336 kg NH_4NO_3/ha) remained within the top 30 cm of the soil.

The downward movement of water (carrying dissolved nitrate-N) from the top soil (30-cm soil depth) is the major mechanism by which nitrate-N is lost from the root zone. In their work on watersheds in southeast Nebraska, Elrashidi et al. (2005b) found that an LI equivalent to the annual rainfall of 730 mm can remove nitrate-N beneath the root zone (30-cm soil depth). In this study, the loss of nitrate-N is dependent on the predicted depth of annual water leaching through the top 30 cm of soil. The ratio of predicted leaching water depth (millimeters per year) to LI equivalent to 730 (millimeters per year) is used to estimate the downward movement (loss) of nitrate-N from the top 30 cm of soil. For example, a predicted leaching water depth of 73 mm per year for a soil will result in downward movement of 10% (73/730) of nitrate-N present in the top 30 cm of soil. For each soil, we used the predicted leaching water (millimeters per year) and concentration of nitrate-N (milligrams per kilogram soil) in the surface 30 cm of soil to calculate the annual loss of nitrate-N by leaching for soil under forest, pasture, and crop.

GIS Digital Mapping

Digital maps for water and N losses from agricultural land in the two watersheds, Hardy County, West Virginia, were generated by the GIS software. The GIS software used was ArcView 9.2 (ESRI, 2006). The input required to generate the map included spatial data layers (soil series and land cover) and the tabular data from both the runoff and leaching (amount of water and N loss from soils and concentrations in both runoff and leaching waters).

The principal spatial data layer used was the Soil Survey Geographic Database (USDA/NRCS, 1999). Both the National Land Cover (NLCD, 1992) and National Agricultural Statistics Service (NASS, 2003) spatial layers were used to identify areas of forest, pasture, and crop within the CR and UCR watersheds. Other types of land cover, such as urban, water, or marsh were not mapped for the two watersheds. The proposed technique calculated water and N losses as well as N concentrations in runoff and leaching water for soils under different types of land cover (forest, pasture, and crop). Thus, GIS mapping of agricultural land in the CR and UCR watersheds included data layers for soils and land cover as well as water or N.

RESULTS AND DISCUSSION

Surface Runoff Water

The predicted loss of surface water by runoff from the 15 major soils under different land covers is given as cubic meters per hectare per year in Table 2 and as (millimeters per year) in map of the CR and UCR watersheds (Fig. 2). The loss of water

TABLE 2. Predicted runoff and leaching water (cubic meters per hectare per year) from 15 major soils under various land covers for CR and UCR watersheds, Hardy County, West Virginia

	Runoff Water				Leaching Water			
Soils	Forest	Pasture	Crop	Average	Forest	Pasture	Crop	Average
	m^3/ha per year				m^3/ha per year			
Berks	4404	4654		4461	931	711		882
Dekalb	4404	4654		4461	931	711		882
Laidig	4404	4654		4460	931	711		882
Buchanan	4404	4654		4462	931	711		882
Murrill	3781	4225		3900	1712	1307		1602
Clarksburg	4404	4654		4472	931	711		884
Potomac	2234	3147		2498	2976	2273		2823
Ernest	4404	4654		4457	931	711		879
Lehew	4404	4654		4455	931	711		879
Calvin	4404	4654		4467	931	711		882
Tioga			4694	4548			1932	1478
Chagrin			4694	4521			1932	1453
Lindside			4957	4653			1051	1013
Melvin			5063	4720			630	812
Monongahela			4957	4654			1051	1015
Area-weighted average	4296	4580	4869	4374	1043	797	1385	993

from soil by runoff followed this order: cropland > pastureland > forestland. The average (area-weighted) runoff water was 4869, 4580, and 4296 m^3/ha per year for cropland, pastureland, and forestland, respectively. These results accounted for 54.2%, 51.0%, and 47.8% 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 4374 m^3/ha per year.

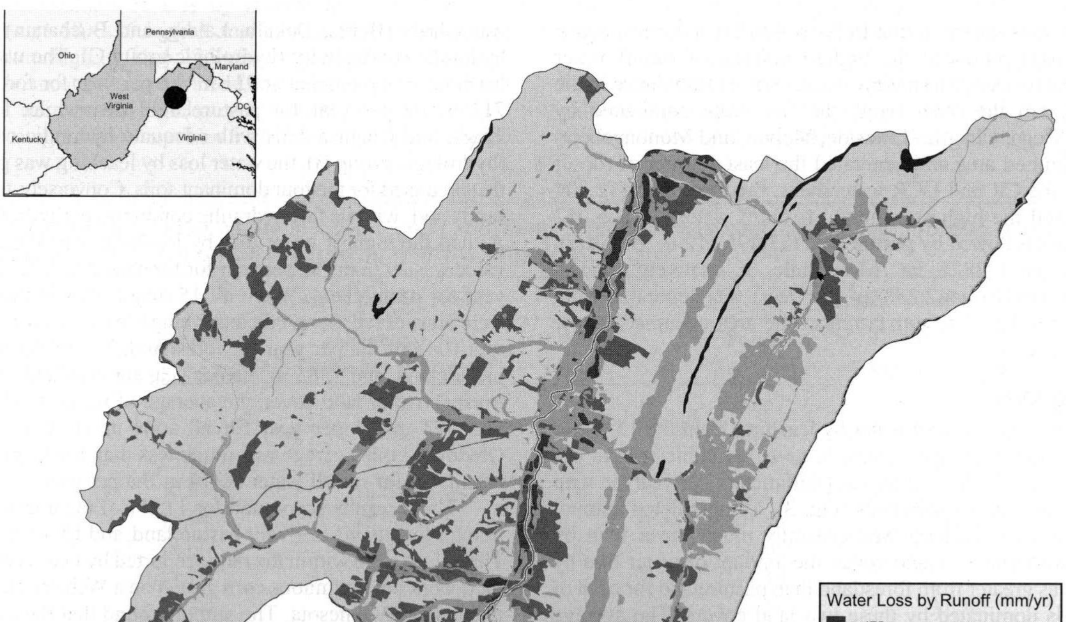

FIG. 2. Predicted runoff water (millimeters per year) from 15 major soils under various land covers for CR and UCR watersheds, Hardy County, West Virginia.

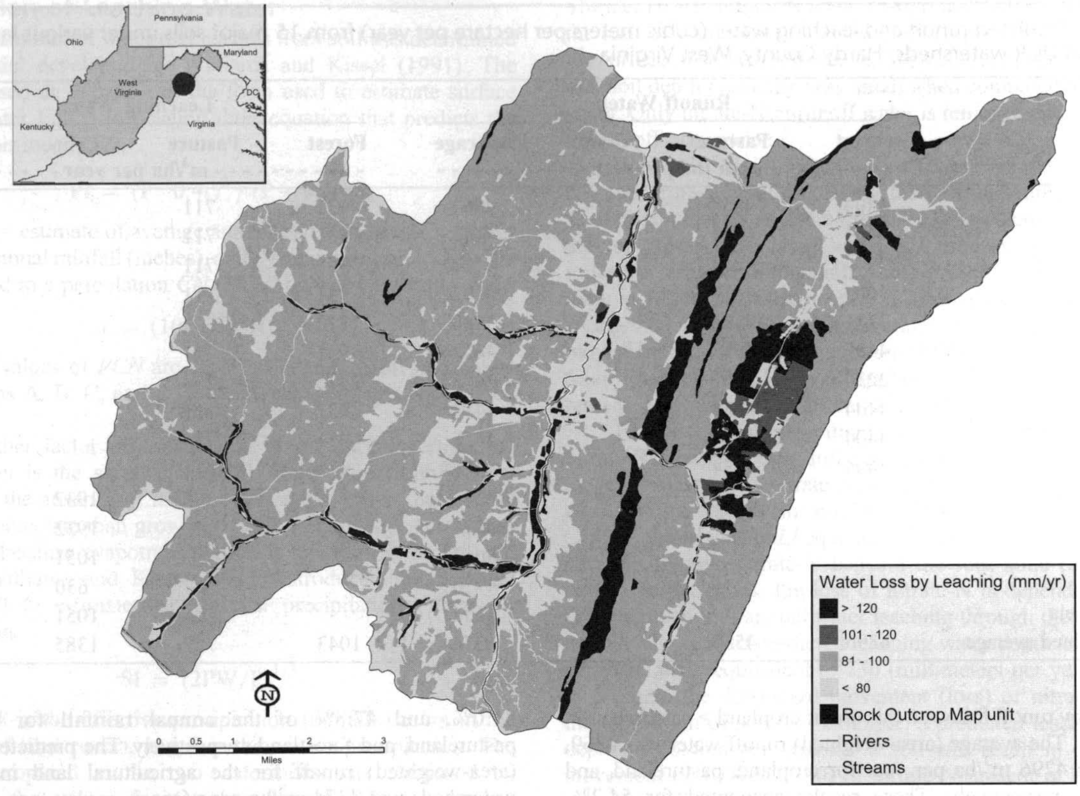

FIG. 3. Predicted leaching water (millimeters per year) from 15 major soils under various land covers for CR and UCR watersheds, Hardy County, West Virginia.

The results indicated that Berks soil (8231 ha), irrespective of land cover, produced the highest volume of runoff water (36,716,183 m^3 per year) mainly because of its abundance 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 least 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 per year), followed by pastureland (17,495,712 m^3 per year), which occupied 3821 ha. Meanwhile, a relatively modest volume of runoff (1,442,258 m^3 per year) was generated from cropland (298 ha). These data reflect the area occupied by the three land covers.

Leaching Water

The predicted loss of water by leaching from the 15 major soils under different land covers is given as cubic meters per hectare per year in Table 2 and as (millimeters per year) in map of the CR and UCR watersheds (Fig. 3). The predicted amount of water loss by leaching was generally much lower than by runoff. With respect to land cover, the amount of water loss by leaching was greater from forestland than pastureland for each of the 10 soils dominated by these two land covers. The average loss of water by leaching was 1043 m^3/ha per year for the forestland and 797 m^3/ha per year for the pastureland. For the other 5 soils, covered totally by crop, the water loss by leaching ranged from 630 to 1932 m^3/ha per year, with an average of 1385 m^3/ha per year. These results indicated that the water loss by leaching was generally greater from cropland than forestland and pastureland.

Expectedly, soil hydrology seemed to have a strong effect on leaching. The four dominant soils with large areas 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 per year for forestland and 711 m^3/ha per year for pastureland. Meanwhile, 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. Conversely, the Potomac sandy soil, with its fast hydraulic conductivity (hydrologic group A) had the highest water loss by leaching, where the predicted value was 2976 m^3/ha per year for forestland and 2273 m^3/ha per year for pastureland. When all 15 major soils in the watershed were considered, the predicted average loss of water by leaching was 1043 m^3/ha per year for forestland, 797 m^3/ha per year for pastureland, and 1385 m^3/ha per year for cropland. Meanwhile, irrespective of land cover, the average of water loss by leaching was 993 m^3/ha per year for all soils in the two watersheds. Obviously, this average was much less than the respective value calculated for runoff water (4374 m^3/ha per year).

These results accounted for 11.6% of the annual precipitation for forestland, 8.9% for pastureland, and 15.4% for cropland. The values were within the range reported by Gast et al. (1978) in their work on continuous corn grown on a Webster clay loam soil in southern Minnesota. The authors found that the loss of water by leaching (into tile lines) constituted from 7% to 22% of the annual precipitation during the 3-year study. Relatively lower values for leaching water were reported for agricultural watershed in Lancaster County, Nebraska, where the average water loss by leaching was 8.0% and 4.3% of the annual precipitation for cropland and grassland, respectively (Elrashidi et al., 2004).

The predicted annual amount of leaching water from the agricultural land in the two watersheds was approximately

17.0 million m^3, which accounted for 11.1% of the annual precipitation. Five major soils (Berks, Dekalb, Laidig, Calvin, and Lehew), accounted for approximately 80% of the area in the two watersheds, are considered shallow, well drained, and present mainly on ridgetops, benches, and hillsides (USDA-SCS, 1989). Besides, the slope of these soils range from 8% to 65%. On the other hand, alluvial soils in flood plains (i.e., Tioga, Chagrin, Melvin, and Monongahela) occupy 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 in the Lost River. Similar results have been reported by Hubbard and Sheridan (1983) for soils having horizons of low permeability at relatively shallow depths (i.e., 75–200 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% of the total loss. Consequently, the authors concluded that approximately 99% 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 (kilograms per hectare per year) in the CR and UCR watersheds are presented in Table 3. 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 per year, 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 (<1.68 kg/ha), medium-low (1.68–3.36 kg/ha), medium (3.36–5.04 kg/ha per year), medium high (5.04–6.72 kg/ha), and high (>6.72 kg/ha). Accordingly, most soils under forest and pasture cover in the two watersheds were in the high category, whereas most cropland soils were categorized as medium high. This 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 per year, respectively. Expectedly, the loss by leaching was greater in soils with a fast water infiltration rate (hydrologic groups A and B) than in those soils with a slow water infiltration rate (hydrologic groups C and D). For the former, the loss of nitrate-N ranged from 106 to 168 kg/ha per year for pastureland, 102 to 141 kg/ha per year for forestland, and 55.2 to 64.4 kg/ha per year for cropland. For the latter, the range was 27.2 to 50.5, 17.9 to 58.5, and 9.15 to 44.6 kg/ha per year for pastureland, forestland, and cropland, respectively. In a moderately well-drained Goldsboro soil in North Carolina, Gambrell et al. (1975) found an average nitrate-N of 46 kg/ha per year, which was lost from a corn field via outflow in both tile drainage and movement to shallow groundwater.

Wu et al. (1997) designated five categories to evaluate nitrate-N loss by leaching for 110 counties in the High Plains region in the United States. These categories were low (<1.12 kg/ha), medium-low (1.12–2.24 kg/ha), medium (2.24–3.36 kg/ha), medium-high (3.36–4.48 kg/ha), and high (>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 at high category. As previously mentioned, it could be attributed to the high rainfall and heavy application of poultry litter. Spalding and Exner (1993) published a review on the occurrence of nitrate-N in groundwater in the United States, reported that high nitrate-N concentrations in groundwater frequently were encountered in areas of intensive poultry and livestock production.

Several studies on the north central region of the United States (i.e., Olsen et al., 1970; Gast et al., 1978) reported similar values (to our study) for the loss of nitrate-N by leaching from soils in Wisconsin and Minnesota, respectively. Furthermore,

TABLE 3. Predicted amount of nitrate-N loss by runoff and leaching (kilograms per hectare per year) from 15 major soils under different land covers in CR and UCR watersheds, Hardy County, West Virginia

	Nitrate-N loss by runoff			Nitrate-N loss by leaching		
	Forest	Pasture	Crop	Forest	Pasture	Crop
Soils	kg/ha per year			kg/ha per year		
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

TABLE 4. Predicted nitrate-N concentration in runoff and leaching water (milligrams per liter) from 15 major soils under different land covers in CR and UCR watersheds, Hardy County, West Virginia

	NO^3-N in runoff water			NO^3-N in leaching water		
Soils	Forest	Pasture mg/L	Crop	Forest	Pasture mg/L	Crop
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

Timmons and Dylla (1981) reported average annual nitrate-N leaching losses to range from 29 to 112 kg/ha for a corn field (Estherville sandy loam soil) 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 soils) during a 5-year period generated average nitrate-N leaching losses of 26 and 60 kg/ha per year, 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 (CR and UCR watersheds) on the water quality in the Lost River (nonpoint source of nitrate-N contamination). The predicted nitrate-N concentration (milligrams per liter) in runoff and leaching water generated from soils under forest, pasture, and crop is given in Table 4. 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 3.8-ha watershed in the Limestone Valley region of northern Alabama. They found that the annual mean nitrate-N concentrations in runoff ranged from 1.3 to 2.2 mg/L during a 6-year study.

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 and land covers are illustrated in the map of the two watersheds (Fig. 4). The dark (black) area in the map

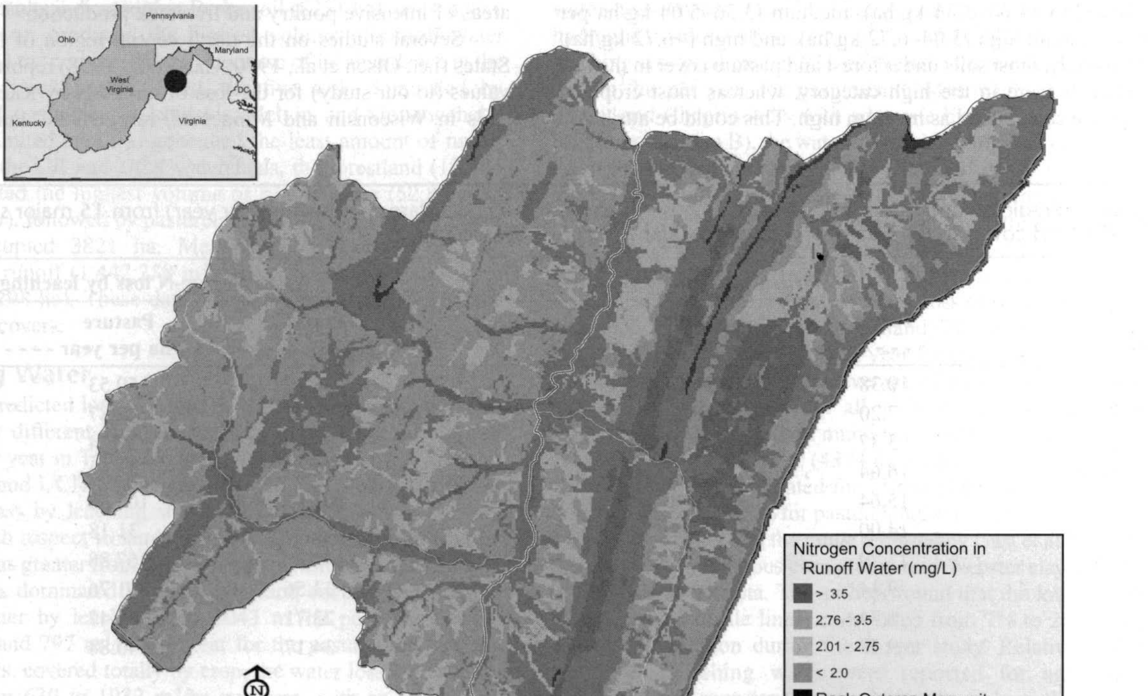

FIG. 4. Predicted nitrate-N concentration in runoff water (milligrams per liter) from 15 major soils under various land covers for CR and UCR watersheds, Hardy County, West Virginia.

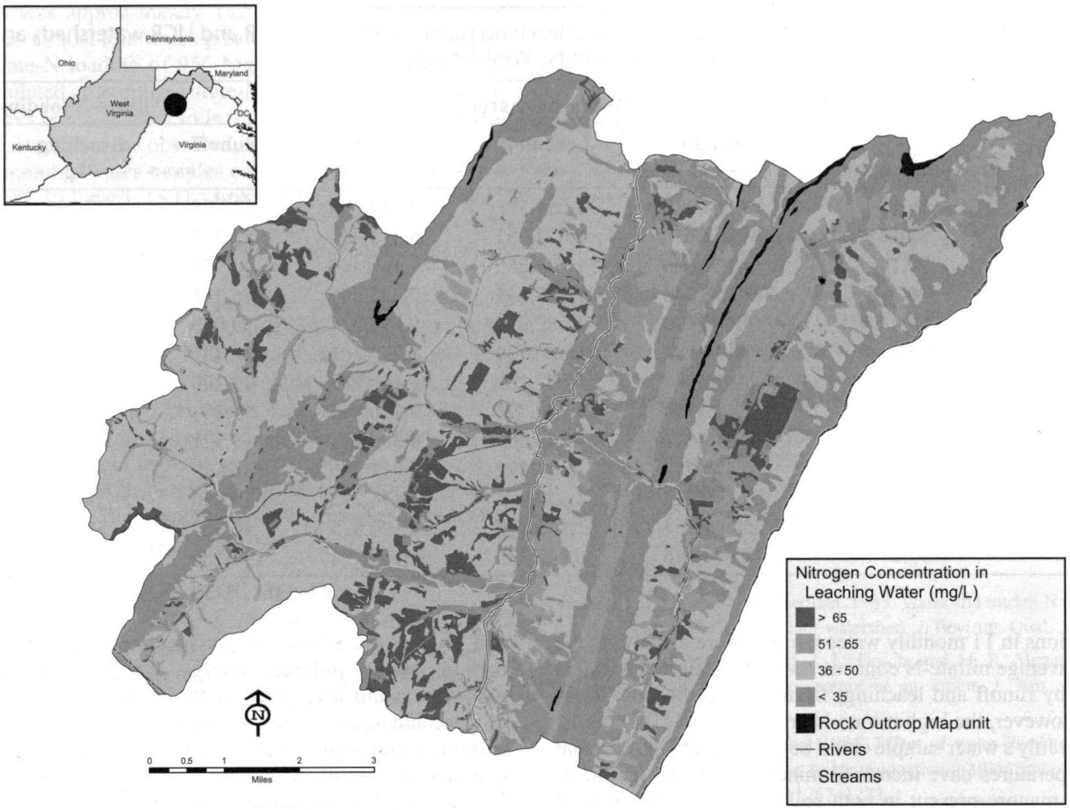

FIG. 5. Predicted nitrate-N concentration in leaching water (milligrams per liter) from 15 major soils under various land covers for CR and UCR watersheds, Hardy County, West Virginia.

indicates soils producing runoff water with nitrate-N concentration higher than 3.50 mg/L. It includes Buchanan, Murrill, and Potomac soils under forest as well as Murrill and Potomac soils under pasture. The total area of these soils (map units) was 2371 ha, which accounted for 14% of the agricultural land in the two watersheds.

The predicted nitrate-N concentration in leaching water from different soils is shown in the map of watersheds (Fig. 5). Approximately 20% (3423 ha) of the area of the two watersheds (mainly in Dekalb and Laidig soils) generated leaching water with nitrate-N concentration less than 35 mg/L. Meanwhile, an area of 44% (7550 ha) of the watersheds (mainly in Berks soil) produced leaching water with nitrate-N concentration ranging between 35 and 50 mg/L. The remaining soils in the CR and UCR watersheds (36%) generated leaching water with nitrate-N concentration greater than 50.0 mg/L. Thus, all soils in the entire area of the two watersheds generated leaching water with nitrate-N concentration higher than the Environmental Protection Agency MCL of 10 mg/L (USEPA, 1992). The 10 mg/L is significant because the US 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 groundwater 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 caused Lancaster County to have some of the worst nitrate-N concentrations in Pennsylvania. Well-drained soils and the presence of several nitrate-N sources cause the groundwater 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 the intensive broiler-producing area of coastal Sussex County, where 37% of the wells exceeded the MCL. Leachates from poultry manure seemed to be the major contributor of nitrate-N to the groundwater 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 (Table 5). The annual nitrate-N loading was approximately 956 Mg, where 80% 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% of the total soluble N in stream flow. Most of the nitrate-N loading for the Lost River occurred during the summer, where the monthly loading ranged between 91 and 98 Mg nitrate-N. The least monthly nitrate-N loading took place during the winter, where it was generally less than 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 concentration 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 (S.D., 4.68 mg/L). The observed

TABLE 5. Predicted monthly water discharge by runoff and leaching (cubic meters) from CR and UCR watersheds and monthly nitrate-N (kilograms) loading for the Lost River, Hardy County, West Virginia

		Water discharge			Nitrate-N loading		
		Runoff	Leaching	Total	Runoff	Leaching	Total
Month	Precipitation, mm		m^3			kg	
January	56.1	4,664,722	1,059,571	5,724,293	11,988	47,765	59,754
February	53.1	4,411,434	1,002,037	5,413,471	11,337	45,172	56,509
March	70.1	5,825,626	1,323,265	7,148,890	14,972	59,653	74,625
April	70.9	5,888,948	1,337,648	7,226,596	15,135	60,301	75,436
May	89.2	7,408,676	1,682,847	9,091,524	19,040	75,863	94,903
June	85.9	7,134,281	1,620,520	8,754,801	18,335	73,053	91,388
July	89.9	7,471,998	1,697,231	9,169,229	19,203	76,511	95,714
August	91.7	7,619,750	1,730,792	9,350,541	19,583	78,024	97,607
September	82.0	6,817,671	1,548,603	8,366,274	17,521	69,811	87,332
October	78.0	6,479,953	1,471,892	7,951,845	16,653	66,353	83,006
November	70.4	5,846,733	1,328,059	7,174,792	15,026	59,869	74,895
December	60.7	5,044,654	1,145,870	6,190,525	12,965	51,656	64,621
Year	897.9	74,614,446	16,948,335	91,562,781	191,759	764,031	955,790

concentrations in 11 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 (Fig. 6). However, the high nitrate-N concentration (19.9 mg/L) detected in July's water sample could be attributed to the fact that warm temperatures have increased 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 et al. (1980) showed that N-rich leachates from cropped land were discharged to surface waters. Moreover, they used that to explain the occurrence of nitrate-N in concentrations above the MCL in Scioto River near Columbus, Ohio, during the spring.

Furthermore, the low nitrate-N concentrations observed in the Lost River could be attributed to biological processes. The presence of large populations of algae, weeds, and aquatic plants in streams could assimilate N and decrease the concentration in water. In addition, the loss of N gases from water to air could be associated with denitrification. Linn and Doran (1984), Smith et al. (1991), and Paul and Clark (1996) reported that under anaerobic conditions, soil nitrate is biologically reduced to NO

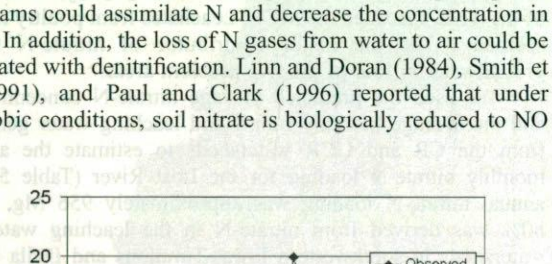

FIG. 6. Predicted and observed average monthly nitrate-N concentration (milligrams per liter) in Lost River, Hardy County, West Virginia.

and N_2O gases, where low oxygen concentration and soluble carbon source provides energy for the reaction. Similar processes could take place in freshwater where heavy growth of algae and aquatic plants consume oxygen and excrete soluble carbon compounds, which enhance nitrate reduction and emission of gaseous N 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 in runoff and leaching water after leaving 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 concentration in the Lost River water by approximately 32%, which amounted to an annual removal of 305 Mg of nitrate-N. Therefore, when we consider possible factors affecting N concentrations in water after leaving field sites, the technique could provide a reasonable estimation of nitrate-N concentrations in stream water.

SUMMARY AND CONCLUSIONS

Nitrate 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 high rainfall areas may pose a risk to water quality. An exploratory technique was developed that uses existing climatic, hydrologic, and soil survey databases to estimate the loss of nitrate-N 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 nitrate-N in root-zone soil is used to estimate nitrate-N loss from soil. The objective of this study was to apply this technique to investigate the loss of nitrate-N by runoff and leaching from soils (CR and UCR watersheds) and to estimate the impact on water quality.

The predicted average runoff water from soils was 4374 m^3/ha per year, which gave an annual water loss of 74.6 million m^3 for the CR and UCR watersheds. The respective average leaching water from soils was 993 m^3/ha per year, which accounted for an annual loss of approximately 17 million m^3. The estimated annual nitrate-N loss by runoff from the two watersheds was approximately 192 Mg, whereas the loss by leaching was almost four times greater, at 764 Mg. This gave an annual nitrate-N loading of 956 Mg for the Lost River. These results calculated an average nitrate-N concentration of 10.4 mg/L in all waters removed from soils (by runoff and leaching) to the Lost River. However, the observed average nitrate-N concentration in 12 monthly water samples collected from the Lost River was lower, at 7.11 mg/L (S.D., 4.68 mg/L). This low nitrate-N concentration observed in the river could be attributed to the presence of heavy growth of algae, weeds, and aquatic plants, as well as denitrification.

We need to emphasize that the predicted nitrate-N concentration was calculated for runoff water generated at field sites and not in stream water. When we consider factors affecting N concentration in runoff and leaching waters after leaving field sites, the technique could provide a reasonable estimation of nitrate-N concentration in stream water. We concluded that the NRCS procedure could be used as an exploratory technique to conduct quick evaluations and identify hot spots for large areas of agricultural land. Thus, lengthy and site-specific studies could be focused on certain areas of high risk.

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