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PHOSPHORUS IN RUNOFF FROM TWO WATERSHEDS IN LOST RIVER BASIN, WEST VIRGINIA

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The loss of nutrients in runoff from soils treated with heavy manure application is a major cause of poor surface water quality in the United States. Poultry production in the Hardy County, West Virginia, has increased considerably since the early 1990s. The Lost River basin contains the highest density of poultry houses in the county. Most of phosphorus (P)-rich manure produced is land applied, and concerns over water quality impacts are widespread. The objectives of this study were to apply the Natural Resources Conservation Service technique on two watersheds (Cullers Run and Upper Cove Run) in the Lost River basin to predict the loss of water and P from soils by runoff and to estimate the impact on water quality. The predicted average runoff was 4374 m^3/ha per year, and agreed with the observed average runoff of 4267 m^3/ha per year. This gives an annual runoff of 74.6 million m^3 for the two watersheds. The average P loss by runoff was 0.57, 1.98, and 5.51 kg/ha per year from soils under forest, pasture, and crop, respectively. The high P loss by runoff was probably associated with application of P fertilizer or poultry manure to cropped soils. The total annual loss of P from soils by runoff was estimated at 16,435 kg. The predicted P concentration varied widely in runoff water generated from different soils and land covers. The average P concentration in runoff water was 133, 432, and 1146 μg/L for forestland, pastureland, and cropland, respectively. The predicted average P concentration in runoff was 224 μg/L for the two watersheds. However, the observed P concentration was very low (1.3–13.3 μg/L) in the monthly water samples (January–December 2006) collected from the Lost River, where the pH ranged between 7.6 and 8.4. The average pH in soils was 4.22, 5.42, and 6.15 for forestland, pastureland, and cropland, respectively. Changing the pH of runoff water from acidic (soils) to the alkaline range in the Lost River could precipitate calcium phosphates and decrease P concentration in water. The technique predicted P concentration in runoff at the edge of field. The increase in water pH as well as P removal by aquatic weeds and algae could be the cause of the low P concentration observed in the Lost River. (Soil Science 2008;173:792–806)

Key words: Agricultural watershed, anion exchange resin, phosphorus release characteristics, runoff phosphorus, runoff water.

HARDY County is located in the eastern panhandle of West Virginia, encompasses 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.

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The only comparatively level land in the county is the bottom lands 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 (3320 ft) above mean sea level on 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%.

Hardy 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, 2004b) identified 21 watersheds in Hardy County that include six watersheds in the Lost River basin. In this study, we investigated runoff P from two of the Lost River watersheds, namely, Cullers Run (CR) and Upper Cove Run (UCR) watersheds. Unfortunately, the United States Geological Survey (USGS) has no stream flow gaging stations in these two watersheds. However, for six other watersheds in Hardy County, the USGS maintains stream flow gaging stations to monitor surface water runoff.

During the last 20 years, poultry production in Hardy County has increased considerably. The waste byproducts of this industry are typically land applied, and concerns over water quality impacts are widespread. State and federal agencies recognized the need for a coordinated and comprehensive approach to protecting and enhancing surface and groundwater quality in West Virginia's Potomac Headwaters region. The Lost River basin was identified by these agencies as producing twice as much poultry litter, or manure, as the available agricultural land

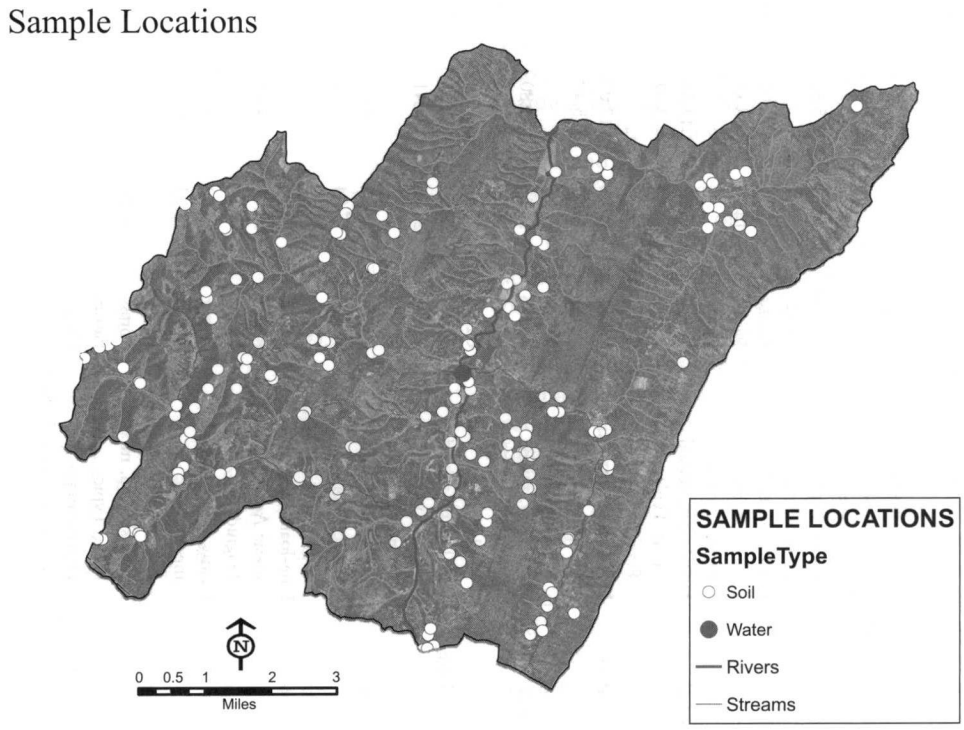

Fig. 1. Soil and water sampling locations in CR/UCR watersheds, Hardy County, West Virginia.

TABLE 1

Soil classification, some properties, and P extracted by five methods for 15 major soils under forest, pasture, and crop in CR/UCR watersheds, Hardy County, West Virginia

Soil	Classification	Land Cover, %	Clay, %	OM, %	CEC, cmol/kg	pH	Bulk density, g/cm^3	AER-1 h	AER-24 h	Water	Bray1	Mehlich3
								mg P/kg				
I. Berks	Loamy-skeletal, mixed,	Forest	16.68	11.23	18.65	4.28	0.88	12.93	31.65	0.203	22.43	36.92
	mesic Typic	Pasture	18.32	5.52	13.35	5.30	1.04	35.02	96.93	0.866	179.81	255.00
	Dystrochrepts	Crop										
II. Dekalb	Loamy-skeletal, mixed,	Forest	9.26	12.03	16.49	4.25	0.89	11.85	26.27	0.228	16.00	25.85
	mesic Typic	Pasture	14.20	8.81	15.49	5.43	0.98	10.24	23.00	0.167	16.15	30.44
	Dystrochrepts	Crop										
III. Laidig	Fine-loamy, mixed,	Forest	10.69	13.55	16.56	4.06	0.91	9.99	20.60	0.338	9.57	19.35
	mesic Typic	Pasture	14.47	3.94	9.08	5.63	1.19	41.66	126.95	1.156	301.95	368.02
	Fragiudults	Crop										
IV. Buchanan	Fine-loamy, mixed,	Forest	19.76	12.02	18.38	4.14	0.90	12.21	34.61	0.120	8.97	18.51
	mesic Aquic	Pasture	15.02	5.49	11.52	5.10	1.07	23.97	61.96	0.350	190.03	126.43
	Fragiudults	Crop										
V. Murrill	Fine-loamy, mixed,	Forest	14.17	12.80	18.45	4.15	0.86	11.33	27.90	0.136	17.13	29.61
	mesic Typic	Pasture	18.75	7.84	14.72	5.43	1.01	52.59	127.20	0.917	251.57	190.17
	Hapludults	Crop										
VI. Clarksburg	Fine-loamy, mixed,	Forest	14.06	12.17	17.27	4.14	0.85	17.92	40.76	0.445	29.55	44.62
	mesic Typic	Pasture	22.90	7.41	15.70	5.73	0.98	64.83	179.42	0.973	208.51	256.56
	Fragiudalfs	Crop										
VII. Potomac	Sandy-skeletal, mixed	Forest	16.32	4.69	11.65	4.74	1.21	6.92	17.68	0.072	9.50	20.34
	mesic Typic	Pasture	17.84	5.51	12.00	5.33	1.17	30.41	75.70	0.570	86.95	158.78
	Udifluvents	Crop										
VIII. Ernest	Fine-loamy, mixed,	Forest	18.22	9.26	15.03	3.99	0.96	10.46	22.20	0.168	9.85	18.20
	mesic Aquic	Pasture	19.01	4.42	12.15	5.46	1.10	46.41	125.16	1.007	150.70	261.06
	Fragiudults	Crop										
IX. Lehew	Loamy-skeletal, mixed,	Forest	9.53	9.34	13.78	4.02	0.96	9.42	22.16	0.128	11.07	27.41
	mesic Typic	Pasture	12.53	5.10	11.63	5.22	1.14	35.80	111.02	0.604	156.06	214.36
	Dystrochrepts	Crop										
X. Calvin	Loamy-skeletal, mixed,	Forest	11.36	11.99	17.99	4.41	0.92	10.99	23.20	0.290	9.41	18.15
	mesic Typic	Pasture	15.62	5.42	13.20	5.57	1.07	54.59	154.80	0.689	201.08	335.04
	Dystrochrepts	Crop										
XI. Tioga	Coarse loamy, mixed, mesic	Forest										
	Dystric Fluventic	Pasture										
	Eutrochrepts	Crop	16.23	2.42	9.83	5.88	1.24	75.83	183.33	1.592	274.27	375.57

XII. Chagrin	Fine-loamy, mixed, mesic Dystric Fluventic Eutrochrepts	Forest										
		Pasture										
		Crop	19.95	3.66	11.93	6.08	1.18	115.73	345.44	2.221	449.61	630.55
XIII. Lindside	Fine-silty, mixed, mesic Fluvaquentic Eutrochrepts	Forest										
		Pasture										
		Crop	18.00	2.82	10.15	6.43	1.24	97.94	278.09	1.857	291.71	426.65
XIV. Melvin	Fine-silty, mixed, nonacid, mesic Typic Fluvaquents	Forest										
		Pasture										
		Crop	29.98	4.56	16.28	6.40	1.08	45.80	137.83	0.659	58.89	140.80
XV. Monongahela	Fine-loamy, mixed, mesic Typic Fragiudults	Forest										
		Pasture										
		Crop	17.50	4.18	11.83	5.98	1.12	46.93	133.28	0.625	157.63	238.07

(USDA-NRCS, 1996). Accordingly, the Lost River was designated first on the USDA-NRCS priority list for implantation of agricultural Best Management Practices (BMP).

When the amount of manure produced substantially exceeds the amount needed to meet the nutrient requirements of forest trees, pasture, and crops, excess chemicals may have adverse effects on surface and groundwater (Keeney, 1989). Both private and government programs are in place to move poultry litter out of the Lost River watersheds; however, it is generally accepted that considerable amounts of manure are still applied to soil. This has led to an expectation that excess P must be polluting the Lost River and other Potomac Headwaters streams. The objectives of this study were to estimate the loss of water and P by runoff from two watersheds in the Lost River basin (CR/UCR watersheds) and to predict the impact on water quality.

MATERIALS AND METHODS

Soil and Water Sampling

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

Representative soil samples were taken from soils under forest, pasture and cropland. For each of 10 SMU (Berks, Dekalb, Laidig, Buchanon, Murrill, Clarksburg, Potomac, Ernest, Lehew, and Calvin), 10 samples from forestland and six samples from pastureland were collected. For each of the other five SMU (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 in the SMU. 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 taking into consideration to distribute it 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/UCR watersheds. Eventually, streams discharge into a larger stream (Lost River) that runs northerly through the middle section of the two watersheds. Monthly water samples (January–December 2006) were taken from two locations in the Lost River. The first water sampling location is near the border between CR and UCR watershed, and it represents the surface runoff from CR watershed. The second sample was 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, the second water sample represents the surface runoff from the entire area of CR/UCR watersheds.

Water samples were collected (grab) in midstream by using 2-L polyethylene bottles that have 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 Soil Survey Investigations Report No. 42 (USDA/NRCS, 2004a). Alphanumeric codes in parentheses next to each method represent specific standard operating procedures in the report. Particle size analysis was performed by sieve and pipette method (3A1). Cation exchange capacity (CEC) was conducted by NH_4OAc buffered at pH 7.0 (5A8b). Total carbon (C) content was determined by dry combustion (6A2f), and $CaCO_3$ equivalent was estimated by 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 (OM) content (Rawls, 1983). Classification and selected properties for soils under forest, pasture, and crop in the watershed are given in Table 1. Soil P was determined by water (4D2a), Bray1 (Bray and Kurtz, 1945), and Mehlich3 (Mehlich, 1984) methods. Anion exchange resin (AER) extractable P was determined by the method described in Elrashidi et al. (2003).

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). In the filtrate, pH was measured with a combination glass electrode and digital pH/ion meter (USDA/NRCS, 2004a), and P concentration was determined by the modified phosphomolybdate/ascorbic acid method (Olsen and Sommers, 1982).

NRCS Technique

The NRCS technique (Elrashidi et al., 2003) applies the AER method and runoff model to estimate runoff P for agricultural watersheds, which can be outlined as follows: (i) the AER method is used to determine phosphorus (P) release characteristics (PRC) for soils, (ii) the runoff model is applied to estimate runoff from soil by an annual rainfall, and (iii) an energy conversion factor that relates soil-water suspension (AER method) to rainfall energy is used to estimate runoff P.

Phosphorus Release Characteristics

The linear relationship between P released from soil by AER (in milligrams per kilogram of soil) and the logarithm of extraction period (in hours) is implemented. Two equations were developed to describe PRC for a soil. For the 1- to 48-h extraction region, the regression equation could be written as follows:

$$P = I + S2 \times \text{Log}\,h \qquad (1)$$

where P = P released (in mg/kg soil), I = intercept (in milligram P per kilogram of soil), S2 = slope, and h = extraction period in hours.

For the 1- to 60-minute extraction region, the regression equation is written as follows:

$$P = I + (I \div 1.78) \times \text{Log}\,h \qquad (2)$$

where $(I \div 1.78)$ = slope (S1).

In this study, the AER method was applied to estimate the PRC for the 15 major soils under forest, pasture, and crop in the watersheds. Parameters for the linear regression equations (Eq.[1] and Eq.[2]) developed to describe P released for the 1- to 60-min, and 1- to 24-h extraction regions are given in Table 2.

Estimation of Runoff Water

The Soil Conservation Service (USDA/SCS, 1991) developed the runoff equation to

TABLE 2

Linear regression equations† used to predict P released by AER for the 1- to 60-min and 1- to 24-h extraction region as well as the AER-1h-P and AER-24h-P for 15 major soils under forest, pasture, and crop in CR/UCR watersheds, Hardy County, West Virginia

Soil	Land cover	P parameters			AER extractable P	
		I, mg P/kg	S1, mg P/min	S2, mg P/h	1 h-P, mg P/kg	24 h-P, mg P/kg
Berks	Forest	12.97	7.29	13.20	12.93	31.65
	Pasture	35.20	19.80	43.46	35.02	96.93
	Crop					
Dekalb	Forest	13.55	7.62	11.35	11.85	26.27
	Pasture	12.94	7.28	10.94	10.24	23.00
	Crop					
Laidig	Forest	12.20	6.87	8.60	9.99	20.60
	Pasture	54.78	30.81	83.28	41.66	126.95
	Crop					
Buchanan	Forest	12.01	6.76	15.61	12.21	34.61
	Pasture	25.33	14.25	29.56	23.97	61.96
	Crop					
Murrill	Forest	12.58	7.08	13.36	11.33	27.90
	Pasture	44.08	24.80	45.59	52.59	127.20
	Crop					
Clarksburg	Forest	17.47	9.83	16.95	17.92	40.76
	Pasture	56.53	31.79	75.69	64.83	179.42
	Crop					
Potomac	Forest	7.14	4.02	8.52	6.92	17.68
	Pasture	29.88	16.81	33.69	30.41	75.70
	Crop					
Ernest	Forest	10.21	5.75	8.90	10.46	22.20
	Pasture	46.39	26.09	59.68	46.41	125.16
	Crop					
Lehew	Forest	9.06	5.10	9.18	9.42	22.16
	Pasture	35.00	19.69	51.73	35.80	111.02
	Crop					
Calvin	Forest	11.46	6.45	9.79	10.99	23.20
	Pasture	53.95	30.34	69.28	54.59	154.80
	Crop					
Tioga	Forest					
	Pasture					
	Crop	75.63	42.53	77.67	75.83	183.33
Chagrin	Forest					
	Pasture					
	Crop	114.88	64.61	164.78	115.73	345.44
Lindside	Forest					
	Pasture					
	Crop	97.23	54.69	129.70	97.94	278.09
Melvin	Forest					
	Pasture					
	Crop	45.80	25.76	66.69	45.80	137.83
Monongahela	Forest					
	Pasture					
	Crop	46.98	26.42	62.52	46.93	133.28

†P = I + S1 × (Log h) for 1 to 60 min; P = I + S2 × (Log h) for 1- to 24-h extraction region; where P = P released, I = intercept, S1 and S2 is slope, and h = extraction period (min for S1 and h for S2).

estimate runoff water from small watersheds by rainfall. The runoff equation is:

$$Q = \{R - [(200 - 2\ CN)/\ CN]\}^2 \div \{R + [(800 - 8\ CN)/\ CN]\} \quad (3)$$

where Q = runoff (in.), R = effective rainfall (in.), and CN = curve number that is dependent on both the hydrologic soil group and type of land cover (i.e., forest, pasture, or crop).

The annual rainfall for the watersheds (Hardy County, West Virginia) was taken from the USDA/NRCS National Water and Climate Center (NWCC, 2003). In Eq.(3), the effective rainfall (R) is the portion of annual rainfall that could generate runoff (Gilbert et al., 1987). The hydrologic group for a given soil and related CN numbers for various types of land cover are published in the USDA/NRCS National Engineering Field Manual (USDA/SCS, 1991).

For agricultural land in the watershed, the effective rainfall (R) and the runoff curve numbers 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.

Estimation of Runoff Phosphorus

Various forms of P-like moisture are held by soil particles at different energy levels. Kinetic energy exerted by raindrops on surface soil plays a major role in releasing P. The Soil Survey Laboratory developed the AER method to determine PRC for soils (Elrashidi et al., 2003). In this method, different levels of energy are applied by water on soil particles when soil suspension is shaken for various periods at a constant speed. Understanding the relationship between shaking and rainfall energy enabled the prediction of P released from surface soil by rainfall of known intensity and duration. Assuming a rainfall intensity of 50 mm/h, and that rain force affects the top 10-mm layer of soil, a conversion factor (shaking energy/rainfall energy) = 15 was calculated. Under the experimental conditions, the energy applied by shaking the soil suspension for 4 minutes was equivalent to an hour of rainfall event of an intensity of 50 mm/h.

In this study, we used the conversion factor of 15 to calculate the shaking period (in hours) equivalent to the total annual rainfall. The log of the calculated shaking period was applied in the respective regression Eq.(1) or Eq.(2) to estimate the amount of P released from soil by the annual rainfall (in milligrams per kilogram of soil). The values of annual rainfall (in millimeters), runoff water (in millimeters), and the amount of P released (in milligrams per kilogram of soil) were used to estimate the portion of released P that was removed from surface soil by runoff water (runoff P). With the knowledge of the soil bulk density and assumption that P was released from the top 10-mm of soil by the annual rainfall, P removed annually by runoff from a known area (i.e., hectare) could be estimated.

Digital maps for runoff water and P losses from agricultural land in the watersheds, Hardy County, West Virginia, were generated by Geographical Information Systems (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 model and AER method (water and P loss from soils and P concentration in runoff water).

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 CR/UCR watersheds. Other types of land cover, such as urban, water, or marsh were not mapped for the two watersheds. The proposed technique calculated runoff water and P losses and P concentration in runoff water for soils under different types of land cover (forest, pasture, and crop). Thus, GIS mapping of agricultural land in CR/UCR watersheds included data layers for soils and land cover as well as runoff water or P.

RESULTS AND DISCUSSION

Surface Runoff Water

There are no USGS stream flow gaging stations in CR/UCR watersheds. However, the USGS maintains stream flow gaging stations in six watersheds in Hardy County (USDA/NRCS, 2004b; USGS, 2007). We used the values of monthly average stream flow and drainage area to calculate the observed annual average surface runoff water for the six watersheds. The observed surface runoff ranged from 2936 m^3/ha per year for the South Fork South Branch Potomac River watershed to

TABLE 3

The annual average stream flow and total discharge at six USGS Stations, and the observed average runoff from six watersheds in Hardy County, West Virginia

Watershed	USGS Station†	Area, ha	Annual average stream flow, m^3/h	Total discharge, m^3/year	Runoff, m^3/ha per year
Waites Run	01610400	3263	1,887	16,528,791	5065
Cacapon River	01610300	46,879	34,544	302,606,316	6455
Lost River/Mccauley	01610200	40,145	19,183	168,040,233	4186
Fort Run	01608050	1256	473	4,139,637	3295
S Fork South Branch Potomac River	01608000	71,743	24,048	210,663,984	2936
South Branch Potomac River	01608070	321,419	155,992	1,366,489,190	4251
Total or weighted average		484,705		2,068,468,151	4267

†Available from http://waterdata.usgs.gov/WV/nwis/nwismap/.

6455 m^3/ha per year for Cacapon River watershed, with an average (area-weighted) of 4267 m^3/ha per year. The values for annual average stream flow (in cubic meters per year), drainage area (in hectares), and the total discharge (in cubic meters per year) at the USGS stations, along with the observed runoff (in cubic meters per hectare per year) for the six watersheds are given in Table 3.

Table 4 presents the area of 15 major soils under various land covers for CR/UCR watersheds. The predicted loss of surface water by runoff from the 15 SMU under different land covers is given as cubic meters per hectare per year and cubic meters per SMU per year in Table 5, and the depth of runoff water is given as milliliters per year in Fig. 2. The loss of water from soil by runoff followed this order: cropland greater than pastureland greater than forestland. The average (area-weighted) runoff water was 4835, 4580, and 4296 m^3/ha per year for cropland, pastureland, and forestland, respectively. These results accounted for 53.8%, 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, which was used for the unidentified cover area (676 ha). This predicted average value was in good agreement with the observed average runoff (4267 m^3/ha per year) calculated from the stream flow for the six watersheds in Hardy County (Table 3).

These results (Table 5) indicated that Berks soil, irrespective of land cover, produced the highest total volume of runoff water (36,716,183 m^3/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)

TABLE 4

Area of 15 major soils under various land covers in CR/UCR watersheds, Hardy County, West Virginia

Soil	Total area	Forestland	Pastureland	Cropland	Unidentified
Berks	8231	6124	1901	0	206
Dekalb	2691	2002	622	0	67
Laidig	1363	1014	315	0	34
Buchanan	1231	916	284	0	31
Murrill	946	704	219	0	24
Clarksburg	718	534	166	0	18
Potomac	546	406	126	0	14
Ernest	334	248	77	0	8
Lehew	279	207	64	0	7
Calvin	199	148	46	0	5
Tioga	126	0	0	64	63
Chagrin	104	0	0	52	51
Lindside	104	0	0	52	51
Melvin	64	0	0	32	32
Monongahela	132	0	0	66	65
Total	17,068	12,304	3820	266	676

†Values are expressed in hectares.

TABLE 5

Predicted runoff from 15 major soils under various land covers for CR/UCR watersheds, Hardy County, West Virginia

Soil	Forestland	Pastureland, m^3/ha per year	Cropland, m^3/ha per year	Unidentified,† m^3/ha per year	Forestland, m^3/soil per year	Pastureland, m^3/soil per year	Cropland, m^3/soil per year	Unidentified	Total
Berks	4404	4654		4374	26,967,448	8,848,777	0	899,958	36,716,183
Dekalb	4404	4654		4374	8,817,531	2,893,280	0	294,259	12,005,070
Laidig	4404	4654		4374	4,465,161	1,465,145	0	149,011	6,079,317
Buchanan	4404	4654		4374	4,033,904	1,323,637	0	134,620	5,492,161
Murrill	3781	4225		4374	2,662,270	923,668	0	103,489	3,689,427
Clarksburg	4404	4654		4374	2,351,342	771,541	0	78,732	3,201,615
Potomac	2234	3147		4374	908,204	397,108	0	61,236	1,366,548
Ernest	4404	4654		4374	1,093,400	358,775	0	36,489	1,488,665
Lehew	4404	4654		4374	912,936	299,560	0	30,467	1,242,963
Calvin		4404	4654	4374	652,856	214,220	0	21,787	888,863
Tioga			4694	4374	0	0	298,831	274,199	573,030
Chagrin			4694	4374	0	0	245,224	224,956	470,181
Lindside			4957	4374	0	0	258,989	224,956	483,946
Melvin			5063	4374	0	0	163,217	138,871	302,087
Monongahela			4957	4374	0	0	328,856	285,535	614,391
Average or total	4296	4580	4835	4374	52,865,052	17,495,712	1,295,117	2,958,565	74,614,446

†The value of runoff water for the unidentified (4374 m^3/ha) was taken from the average of runoff water for the cultivated land in the watersheds.

comprised a small area and generated the least volume of runoff water. For the entire area of CR/UCR watersheds (17,068 ha), the forestland (12,304 ha) generated the highest volume of runoff water (52.9 million m^3/year) followed by pastureland (17.5 million m^3/year), which occupies 3820 ha. Meanwhile, a relatively modest volume of runoff (1.3 million m^3/year) was generated from cropland (266 ha). Obviously, these runoff water data reflect mainly the area occupied by the three land covers. Furthermore, the unidentified cover area of 676 ha generated approximately 3.0 million m^3/year, which brought up the total runoff water for the two watersheds to 74.6 million m^3/year.

Runoff Phosphorus

Land cover (i.e., forest, pasture, and crop) could affect the amount of P released from surface soil by rainfall in two different ways: (i) it affects the volume of surface water runoff generated by rainfall, and (ii) it minimizes the area of surface soil exposed to direct rainfall energy. As previously mentioned, the runoff generated from agricultural land followed this order: cropland greater than pastureland greater than forestland. The effectiveness of vegetation canopy in reducing the energy of rainfall striking the soil surface is dependent on the area covered by canopy. For permanent pasture or trees, the canopy covers an area relatively constant during the entire year in comparison to the wide range of coverage for most agronomic crops.

The average runoff P was 0.57 kg/ha per year for forestland and 1.98 kg/ha per year for pastureland (Table 6). Cropland gave greater runoff P than both forestland and pastureland, where the average was 5.51 kg/ha per year. Both the runoff water volume and soil exposed to rainfall might have contributed to the higher runoff P for cropland when compared with both forestland and pastureland. The high runoff P value was probably associated with P fertilizer or poultry manure added to cropland. In a study on a watershed in southeast Nebraska, Elrashidi et al. (2005) reported runoff P averaging 0.24, 0.22, and 0.19 kg/ha per year for fallow, cropland, and grassland, respectively. These low runoff P values could be attributed to the low rainfall in the great plain area. On the other hand, similar values were reported for 24 US soils under cropland, where estimated runoff P ranged between 0.06 and 7.5 kg/ha per year (Elrashidi et al., 2003). The authors also reported runoff

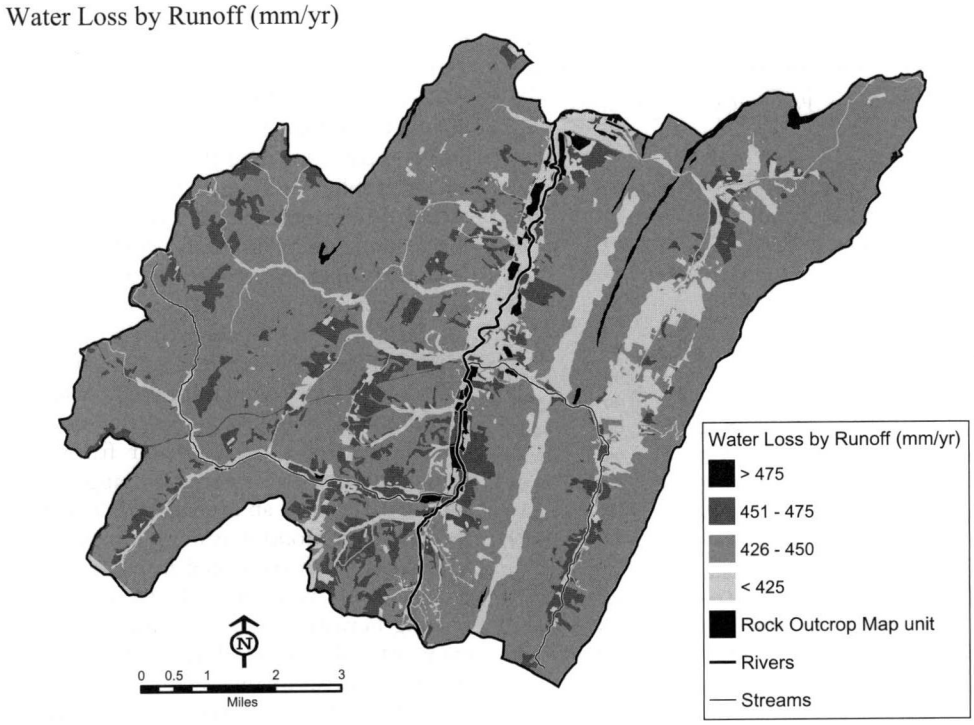

Fig. 2. Predicted loss of surface water by runoff (in cubic meters per hectare per year) from 15 major soils under various land covers in CR/UCR watersheds, Hardy County, West Virginia.

P ranging from 0.01 to 6.0 kg/ha per year for grassland. Sonzogoni et al. (1980) concluded that cropped soils, in general, generate higher P concentration in runoff water than grassland and forestland soils. Forest and pastureland soils usually receive smaller amounts and less frequent fertilizer application in comparison to cropped soils. However, animal manure might be added (soil amendment or disposal practice) to pastureland.

The predicted P concentration varied widely in runoff water generated from different soils and land covers (Table 7). For forestland, the P concentration in runoff water ranged from 101 to 185 μg/L, with an average of 133 μg/L, whereas it ranged from 113 to 790 μg P/L, with an average of 432 μg P/L for pastureland. Expectedly, greater P values were predicted for cropland, where the concentration ranged between 604 and 1650 μg P/L, with an average of 1146 μg P/L. For the area with unidentified land cover, the calculated P concentration in runoff water ranged from 102 to 141 μg P/L, with an average of 131 μg P/L. The predicted average (area-weighted) P concentration for the runoff water generated from the entire area of CR/UCR watersheds (17,068 ha) was 224 μg/L. This average was used for the area with unidentified land cover to estimate the total loss of P from the two watersheds. Similar average P concentration (196 μg P/L) was predicted for runoff generated from the Wagon Train watershed in southeast Nebraska (Elrashidi et al., 2005).

Phosphorus loss from soils generally occurs from hydrologically active areas of a watershed, where surface runoff contributing to stream flow is coincident with areas of high soil P (Gburek and Sharpley, 1998; Gburek et al., 2000). The authors 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 remediation of the critical source areas of P loss (hot spots).

We applied GIS to present P data in a watershed map (Fig. 3). This approach allowed us to identify the area and location of hot spots, as

TABLE 6

Average runoff P for 15 major soils under various land covers for CR/UCR watersheds, Hardy County, West Virginia

Soil	Forest	Pasture	Crop	Unidentified†	Total
Berks	0.61	2.10		0.99	0.97
Dekalb	0.55	0.53		0.99	0.56
Laidig	0.45	2.87		0.99	1.02
Buchanan	0.59	1.46		0.99	0.80
Murrill	0.44	2.80		0.99	1.00
Clarksburg	0.81	3.67		0.99	1.64
Potomac	0.23	1.35		0.99	0.62
Ernest	0.53	2.92		0.99	1.10
Lehew	0.48	2.35		0.99	0.93
Calvin	0.53	3.32		0.99	1.19
Tioga			5.31	0.99	3.15
Chagrin			7.64	0.99	4.38
Lindside			7.33	0.99	4.22
Melvin			3.08	0.99	2.04
Monongahela			3.20	0.99	2.11
Weighted average	0.57	1.98	5.51	0.99	0.99

Values are expressed in kilograms per hectare per year.
†The average runoff P for cultivated soils in the watersheds (0.99 kg/ha per year) was used for the unidentified land cover.

well as soils generating runoff water with high P concentration. The dark area in the map shows mainly cropped soils (Tioga, Chagrin, Lindside, Melvin, and Monongahela), which produced runoff water exceeding 600 μg P/L. Fortunately, the area of cropland is very limited in CR/UCR watersheds.

Soluble P concentration of at least 20 μg/L in fresh waters can cause eutrophication (USEPA, 1996). To reduce the impact on surface water bodies, USEPA (1986) 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. The data in Table 7 and Fig. 3 indicate that the predicted P concentration in runoff water exceeded the recommended limits and could cause an environmental problem for water quality in the Lost River.

However, the P concentration was very low in the monthly (January–December 2006) stream water samples collected from the Lost River. For monthly samples collected from the first location, which represents runoff water from the CR watershed, the P concentration ranged from 1.3 to 12.6 μg/L, with an average of 5.99 μg/L. The second set of monthly water samples, representing runoff water generated from the entire area of CR/UCR watersheds, had P concentrations ranging between 0 and 13.3 μg/L, with an average of 3.47 μg/L. These concentrations in stream water were far less than the predicted P concentration in the surface water runoff generated from the two watersheds (224 μg P/L). High pH values that were measured in stream water that ranged from 7.6 to 8.4 might contribute to the precipitation of P in the stream water.

Similar P concentration and pH values were reported by other scientists for stream water in

TABLE 7

Average P concentration in runoff water generated from 15 major soils under various land covers for CR/UCR watersheds, Hardy County, West Virginia

Soil	P concentration, μg/L				
	Forestland	Pastureland	Cropland	Unidentified	Total
Berks	140	450		224	214
Dekalb	125	113		224	122
Laidig	101	616		224	225
Buchanan	134	313		224	177
Murrill	117	665		224	254
Clarksburg	185	790		224	367
Potomac		103	431	224	250
Ernest		121	626	224	243
Lehew		109	510	224	205
Calvin		121	713	224	264
Tioga			1119	224	1119
Chagrin			1650	224	1650
Lindside			1500	224	1500
Melvin			604	224	604
Monongahela			653	224	653
Weighted average	133	432	1146	224	224

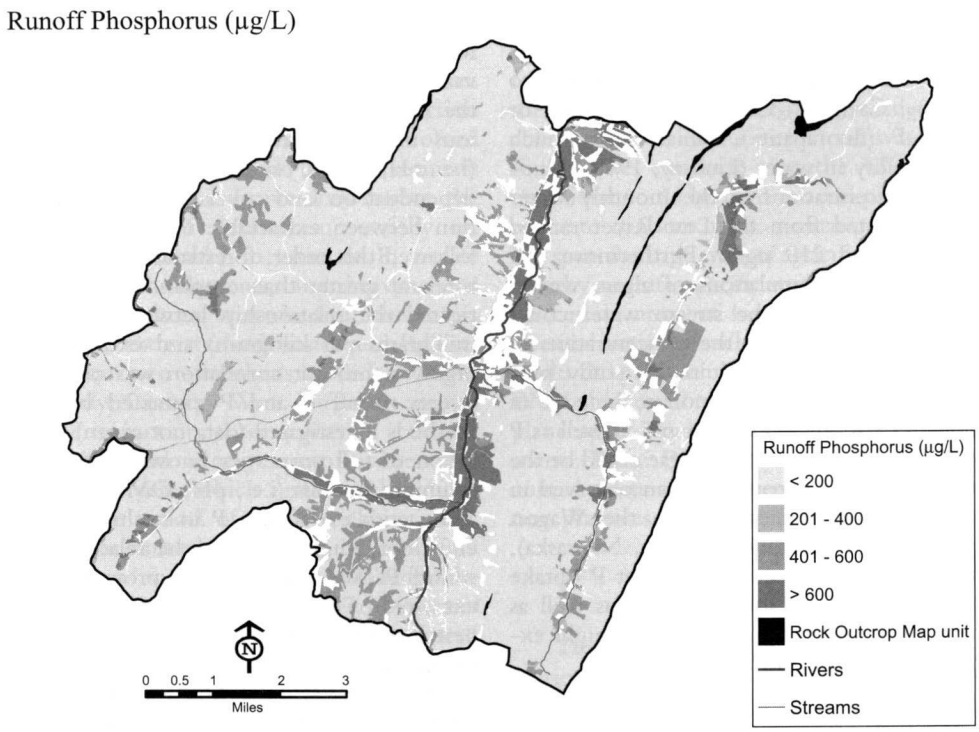

Fig. 3. Predicted P concentration in runoff water (in micrograms per liter) generated from 15 major soils under various land covers in CR/UCR watersheds, Hardy County, West Virginia.

the Lost River watersheds. In long-term studies on the water quality in Lost and North river watersheds, West Virginia (Cacapon Institute, 2002), the authors listed a median P concentration of 10 µg/L for 147 samples collected from the CR watershed. Two water sampling sites were investigated in the UCR watershed. A median P concentration of 10 µg/L was measured for the first site (113 samples), whereas a slightly higher P concentration was determined for the second site (149 samples). Furthermore, the median pH value was 7.4 for stream water samples collected from the CR watershed, whereas it was slightly higher at 8.1 and 8.4 for the two sites in the UCR watershed (Cacapon Institute, 2002).

In this study, the pH values in the water extract for the forest soils were strongly acidic, fluctuating between 3.99 and 4.74 with an average of 4.22 (Table 1). For soils under pasture, pH values were slightly higher and ranging between 5.10 and 5.73, with an average of 5.42. Meanwhile, relatively higher pH values than those obtained for both forest and pasture soils (but still in the acidic range) were measured for the cropped soils. The pH values ranged from 5.88 to 6.40, with an average of 6.15. When compared with forest soils, the relatively high pH values for both pasture and cropped soils could be attributed to lime application.

Monocalcium phosphate [$Ca(H_2PO_4)_2$] is the major form of phosphate fertilizer usually

TABLE 8

Best three-variable regression models relating runoff P to extractable P and selected properties for 15 major soils under various land covers in CR/UCR watersheds, Hardy County, West Virginia

Land cover	Best three-variable model	R^2
Forest	Runoff P (mg/kg) = 9.21 + 0.06 (AER-1h-P) + 0.07 (OM%) − 1.11 (pH)	0.288†
Pasture	Runoff P (mg/kg) = 9.14 + 0.04 (Mehlich3-P) + 0.43 (Clay%) − 0.49 (OM%)	0.449†
Crop	Runoff P (mg/kg) = 4.94 + 0.48 (AER-1h-P) + 1.44 (Clay%) − 2.02 (CEC)	0.754†

†Indicates 0.1% significant level of correlation.

added to these soils. Changing pH of the runoff water from acidic to the alkaline range in the Lost River could transform the $Ca(H_2PO_4)_2$ to $Ca_3(PO_4)_2$, $Ca_5(PO_4)_3OH$ (hydroxyapatite), or $Ca_5(PO_4)_3F$ (fluorapatite), which have much lower solubility in water (Lindsay, 1979). Fluoride ion concentrations in the monthly water samples collected from the Lost River ranged between 30 and 210 μg/L. Furthermore, the presence of large populations of algae, weeds, and aquatic plants in the stream water could assimilate P and decrease the concentration in water. The technique used in this study predicted P concentrations in runoff at the edge of the 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. In their study on the Wagon Train watershed (Lancaster County, Nebraska), Elrashidi et al. (2005) concluded that P uptake by algae, weeds, and aquatic plants, as well as high pH in the reservoir and streams, might explain the low P concentration in waters.

Relationship With Soil Phosphorus

Phosphorus extracted (in milligrams per kilograms) by five methods (i.e., water, AER–1 h, AER–24 h, Bray1, and Mehlich3) for 15 major soils under forest, pasture, and crop in the CR/UCR watersheds is given in Table 1. For soils, irrespective of land cover, the amount of P extracted by various methods followed this order: water less than AER–1 h less than AER–24 h less than Bray1 less than Mehlich3.

In this study, the land cover seemed to have a significant effect on P extracted by various methods. In general, P extracted from cropped soils was greater than pasture soils, whereas it was the least for forest soils. For cropped soils, the average P extracted was 1.39, 76.5, 216, 246, and 362 mg/kg for water, AER–1 h, AER–24 h, Bray1, and Mehlich3, respectively. For pasture soils, the average P extracted was 0.73, 39.6, 108, 174, and 220 mg/kg for water, AER–1 h, AER–24 h, Bray1, and Mehlich3, respectively. The corresponding values were much smaller for forestland than for both cropland and pastureland, where the average P extracted was 0.21, 11.4, 26.7, 14.4, and 25.9 mg/kg, respectively. These P values might reflect the amount of P fertilizer and/or poultry litter applied on these soils. In comparison to both cropland and pastureland, forestland usually receives very small amounts of P fertilizer.

Generally, significant correlations were found among P extracted from soils by the various methods (data not given). Furthermore, the relationship between P determined by various methods and soil properties investigated (i.e., pH, OM%, clay%, and CEC) seemed to be dependent on land cover. The level of correlation between extractable P and soil properties followed this order: forestland greater than pastureland greater than cropland. We also investigated the relationship between runoff P (in milligrams per kilogram) and extractable P. A highly significant correlation was observed between runoff P and P extracted by the five methods investigated (data not given). Incorporation of soil properties known to influence P solubility in soils (i.e., pH, OM%, and clay%), along with extractable P in multiple regression equations, might improve the relationship with runoff P. We included soil properties with P extracted by the five methods to determine the best three-variable regression models to predict the runoff P (Table 8).

For cropped soils in CR/UCR watersheds, we found that including clay% and CEC along with P determined by AER after 1-h extraction period (AER-1h-P) gave the best three-variable model to predict runoff P. The model could account for 75.4% of variations in the value of runoff P generated from cropland in the watersheds. Meanwhile, including clay% and OM% with P extracted by Mehlich3 method as independent variables produced the best three-variable model that can predict runoff P from soils under pasture in CR/UCR watersheds. A model that included both clay% and OM% with Mehlich3-P could predict 44.9% of variations in the value of runoff P. We found that including pH and OM% with AER-1h-P as independent variables in multiple regression equations gave the best three-variable model to predict P in runoff generated from forestland in the two watersheds. The model, however, could account only for 28.8% of variations in the value of runoff P.

SUMMARY AND CONCLUSIONS

Nutrients and other water-soluble chemicals can be transported from agricultural land by surface runoff to 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 elements by runoff from agricultural land. The technique applies a runoff model to estimate water loss from agricultural watersheds. The interaction between both runoff waters and dissolved elements in root-zone soil is used to estimate element losses from soil. In previous studies, the technique has been applied successfully on watersheds in Nebraska to estimate P, nitrate N, alkaline earth elements, and heavy metal losses from agricultural watersheds. In this study, it was used to estimate both water and P losses by runoff from two watersheds in the Lost River basin (Hardy County, West Virginia) and to predict the impact on water quality.

The predicted average runoff water was 4374 m^3/h per year, which agreed with the observed average runoff of 4267 m^3/h per year. This gives an annual water loss by runoff of 74.6 million m^3 for CR/UCR watersheds. The average P loss by runoff was 0.57, 1.98, and 5.51 kg/ha per year from soils under forest, pasture, and crop, respectively. The high P loss by runoff from cropland was probably associated with application of P fertilizer or poultry manure to these soils. The total annual loss of P from soils by runoff was estimated at 16,435 kg for the two watersheds. Phosphorus is an essential nutrient for crop production, and the significant loss from soils by runoff should emphasize the need for periodic applications of P fertilizers to agricultural land.

The predicted P concentration varied widely in runoff water generated from different soils and land covers. The average P concentration in runoff water was 133, 432, and 1146 μg/L for forestland, pastureland, and cropland, respectively. The predicted average P concentration in runoff was 224 μg/L for CR/UCR watersheds. Including soil properties with extractable P in a multiple regression model was used to predict runoff P from soils under various land covers in CR/UCR watersheds. The observed P concentration was very low (1.3–13.3 μg/L) in the monthly samples collected from the Lost River, where the pH ranged between 7.6 and 8.4. The average pH in soils was 4.22, 5.42, and 6.15 for forestland, pastureland, and cropland, respectively. Changing the pH of runoff water from acidic (soils) to the alkaline range in the Lost River could precipitate calcium phosphates and decrease P concentration in water.

We need to emphasize that the predicted element concentration was calculated for runoff water generated at field sites and not in stream water. When we consider factors (i.e., biological processes and chemical precipitations) affecting P concentration in runoff after leaving the field, the technique could provide a reasonable estimation of the impact on water quality. Finally, we conclude that the USDA-NRCS technique 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. With respect to essential nutrients such as P and N, the technique could also provide useful information for nutrient BMP that can be applied to increase nutrient plant uptake and reduce losses to the environment. These BMP may include fertilizers and animal waste management plans, soil conservation practices, and mitigation technologies.

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