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Site-Specific Use of the Environmental Phosphorus Index Concept

Summary

Phosphorus (P) loss to surface water can have negative impacts on the environment. The risk of such loss depends on both source (added fertilizer and manure, soil P) and transport factors (erosion and surface runoff). Fields at risk are those where areas of high P application or soil P coincide with zones of active surface runoff or erosion. A P index has been developed to rank field vulnerability to P loss so that high risk fields may be identified for site-specific management. The index provides a framework that can be regionally adapted to prevailing topography, geology, and climatic conditions and requires only readily available data. This fact sheet describes the technical basis of the index and shows its application to a watershed in Pennsylvania.

Impacts of Phosphorus Loss on the Environment

Phosphorus is essential for all terrestrial plant and animal growth and for the health and functioning of all aquatic ecosystems. However, problems can occur in ecosystems when nutrients become imbalanced.

State water quality authorities have reported that nutrient…nitrogen (N) and phosphorus (P)…over-enrichment is the greatest source of impairment of the nation’s rivers, streams, lakes, and estuaries. The 1996 USEPA National Water Quality Inventory report stated that 40 percent of the rivers, 51 percent of the lakes, and 57 percent of the estuaries surveyed were impaired by nutrient over-enrichment. While these surveys targeted problem areas and are thus not representative of all waters, the proportion affected by nutrients is substantial.

Excessive amounts of P in shallow surface waters can accelerate freshwater eutrophication: algal blooms, seasonally-low oxygen status, and reduced clarity. Hypoxia, dissolved oxygen levels less than 2 parts per million (ppm), in the northern Gulf of Mexico and *Pfiesteria* issues in the Chesapeake Bay and North Carolina have drawn considerable public concern to nutrient enrichment in surface waters of the U.S. Although no direct link of these impacts to increased P inputs has been shown, public concern has led to revision of nutrient management planning in several states. In response, many groups and individuals have proposed the use of a site-specific assessment of the potential and risk for P loss to identify areas at risk for targeted remedial measures.

Factors That Control Phosphorus Loss

Phosphorus can leave land surfaces as dissolved P and particulate P, which is attached to eroding soil. When runoff enters streams or lakes, bioavailable P in the water may increase or decrease, depending on whether P is adsorbed or released by sediments. Sediment with a high P concentration that enters surface water can contribute bioavailable P by desorption for a prolonged period of time.

Phosphorus, applied to the soil as fertilizer or in animal wastes, typically moves very slowly because of its sorption to soil particles. Under the majority of conditions, annual runoff losses of P from farm fields are less than 1 to about 3 lb/A/year when best management practices (BMPs) have been used. When significant soil erosion occurs, loss of P increases dramatically because large amounts of P can be attached to soil particles. Surface runoff can also move large amounts of P, but mainly when concentrations of soluble P at the soil surface are very high. Runoff loss of P can occur, for example, within a few days after broadcast application of fertilizer or manure P. Also, surface-applied manures can be floated from the soil in heavy runoff events. The shorter the time between application and runoff-producing rainfall, the greater the risk of runoff loss…the longer the time, the less risk of loss. When soil P levels are very high due to repeated manure applications, runoff losses of P may also increase.

In certain circumstances, soluble P may leach through the soil profile. For this to occur, the P sorption capacity of the surface horizons must first be saturated. Generally, the concentration of P in water percolating through the soil profile is small due to fixation of P by P-deficient subsoils. Exceptions occur in sandy, acid organic, or peat soils, with low P fixation or holding capacities and in soils where flow of water can occur rapidly through macropores, root channels, and earthworm holes.

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Soil Testing: Agronomic and Environmental

Routine soil testing methods for P have been developed over decades to estimate the availability of soil P for plant growth. Various methods for P extraction (e.g. Bray 1, Olsen, Mehlich 3, etc.) are used in different areas of the country based on the predominant soil, crops grown, and supporting calibration data.

As soil tests for P were developed for agronomic purposes, their environmental interpretation and application may not be valid. Direct linear relationships have been shown between the concentration of dissolved P in surface runoff and soil test P levels. This relationship varies with soil type, depth of soil sampled, soil test extractant method, crop grown, soil management, rainfall amount, intensity and duration, soil slope, water infiltration rate, ground cover, and other factors. Relationships between soil test P levels and the total quantity of P lost in runoff may be more complex and are not fully understood at this time.

Some states have proposed guidelines for soil test P values (**threshold P levels** measured by routine soil testing procedures) above which the risk of P enrichment outweighs any agronomic benefit.

Other soil P tests (degree of P saturation, iron oxide strip, water-soluble, bioavailable, etc.) have been studied and are under consideration as potential diagnostic aids to assess the risk of environmental P loss from soils. These methods have not yet been developed for routine laboratory use. In some instances, they have shown improved efficacy for both agronomic and environmental purposes.

The Phosphorus Index

Determining the risk of P loss is a function of both source and transport factors. Not all watersheds, fields, nor portions of fields contribute P to surface waters at significant concentrations or quantities that are of environmental concern. With the diversity in landscapes, soils, and crops, it appears to be unreasonable to develop

Table 1. Example of a *P Index* being developed in the northeast US.

		Phosphorus loss rating (value)				
Transport characteristics	**Weight**	**None (0.6)**	**Low (0.7)**	**Medium (0.8)**	**High (0.9)**	**Very High (1.0)**
Soil erosion	1.0	Not applicable	<5 tons/A	5-10 tons/A	10-15 tons/A	>15 tons/A
Runoff class	1.0	Negligible	Very low or low	Medium	High	Very high
Return period rating Frequency of runoff Distance to watercourse	1.0	**None (0.2)** >10 years >500 feet	**Low (0.4)** 6-10 years 500-400 feet	**Medium (0.6)** 3-5 years 400-250 feet	**High (0.8)** 1-2 years 250-100 feet	**Very High (1.0)** <1 year <100 feet
Source Characteristics	**Weight**	**None (0)**	**Low (1)**	**Medium (2)**	**High (4)**	**Very High (8)**
0-2 inch depth Mehlich-3 soil test P	1.0	<10 ppm	10-30 ppm	30-100 ppm	100-200 ppm	>200 ppm
Fertilizer P rate applied	0.75	None applied	< 15 lb/A P (35 lb/A P_2O_5)	16-40 lb/A P (36-92 lb/A P_2O_5)	41-65 lb/A P (93-149 lb/A P_2O_5)	>65 lb/A P ≥150 lb/A P_2O_5
Fertilizer P application method	0.5	None applied	Placed with planter deeper than 2 inches	Incorporated immediately before the crop	Incorporated >3 months or surface applied<3 months	Surface applied > 3 months before the crop
Organic P rate (manure, biosolid, etc.)	1.0	None applied	< 15 lb/A P (35 lb/A P_2O_5)	16-40 lb/A P (36-92 lb/A P_2O_5)	41-65 lb/A P (93-149 lb/A P_2O_5)	>65 lb/A P ≥150 lb/A P_2O_5
Organic P application method	1.0	None	Injected deeper than 2 inches	Incorporated immediately before the crop	Incorporated >3 months or surface applied <3 months before the crop	Surface applied >3 months before the crop

P Index Calculation
PI= (erosion rating x runoff rating x frequency of runoff rating[1]) x (Sum of [source characteristic rating x weight])

[1] Note that ratings for return period are different than those for erosion and runoff characteristics

P index	**Site P loss vulnerability**
<5	Low
5-9	Medium
9-22	High
>22	Very high

and impose uniform guidelines or standards such as the **threshold P** across all agricultural regions in order to reduce P loadings to surface waters. As a consequence, a ***P Index* approach**, which incorporates P management and erosion and runoff potential, is being developed to provide a useful assessment of the potential for P transport to nearby surface waters.

A national group of scientists within the USDA-ARS, USDA-NRCS, land grant universities, and the Cooperative Extension Service are currently building on the **P Index** concept to improve the accuracy of predicting potential for P loss, through integration of factors affecting P loss. Factors identified to date are: soil erosion, irrigation erosion, runoff class, return period/contribution distance to surface waters, soil test P, and P application source, rate, and method. These factors are assigned weighting coefficients at the present time, based on professional judgement of the scientists who developed the approach. Originally, an additive effect of the factors and weighting was used to calculate a loss vulnerability rating for a field. More recently, Drs. Sharpley and Gburek of the USDA-ARS at University Park, Pennsylvania, modified the index to better represent actual site vulnerability to loss. They proposed a multiplicative consideration of transport factors, in conjunction with the additive effects of the source factors. The multiplicative transport approach and rating scheme are used in the example of a ***P Index*** illustrated in **Table 1**. The final form of the P Index will likely vary considerably from region to region because of differences in agriculture, soils, and climate.

The higher the P loss rating, the greater the need to manage the soil, crop, and nutrient applications to minimize the risk of P loss due to runoff.

Application of the P Index— A watershed case study example

A study was conducted by Drs. Sharpley and Gburek of the USDA-ARS on a 98-acre subwatershed (FD-36) of Mahantago Creek, a tributary to the Susquehanna River in Pennsylvania, which ultimately drains to the Chesapeake Bay (**Figure 1**). The watershed has mixed use for soybean, wheat, or corn (50 percent), pasture (20 percent) and woodland (30 percent) production. Based on a 100-foot sampling grid, Sharpley and Gburek found that 0 to 2-inch Mehlich 3 soil P levels ranged from 7 to 788 ppm. Fifty-two percent of the samples had P levels above the optimum range (30 to 100 ppm P), thus no P would be recommended (**Figure 2**). Based strictly on a soil test interpretation alone (i.e. threshold P), P application in 63 percent of the crop land in FD-36 would be restricted or limited.

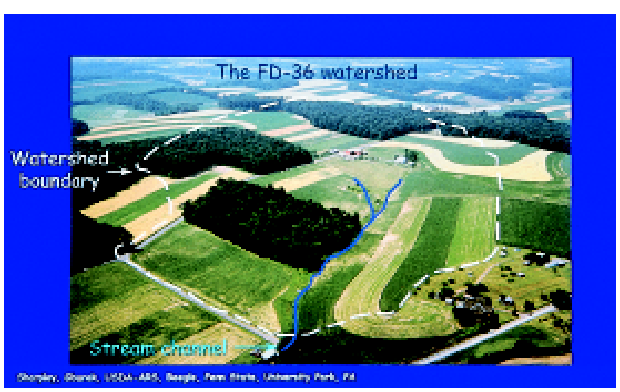

Figure 1. Assessing site vulnerability. Shows the aerial photo with the watershed boundary and the stream channels outlined.

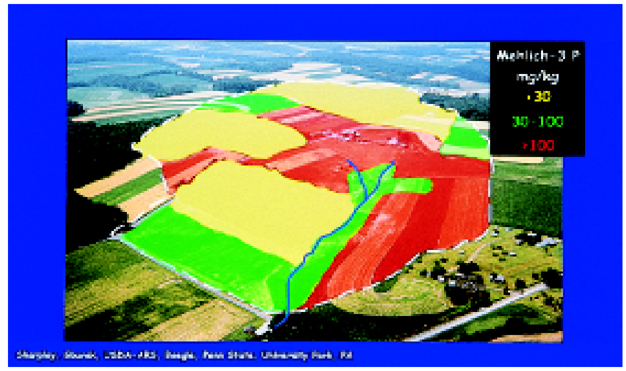

Figure 2. Soil test P distribution. Shows three classes (less than 30, 30 to 100, and greater than 100 ppm) of 0 to 2-inch soil test P overlaid on the watershed.

To account for the probability of significant runoff loss to the stream at likely rainfall intensity/durations, Sharpley and Gburek included distance from the stream and hydrologic analysis in the multiplicative P Index for each 270-ft^2 cell in the FD-36 watershed. Erosion and surface runoff classes (**Figure 3**) for each soil map unit in the watershed and grid area were taken from the USDA Soil Survey. Mehlich 3 soil P results (0 to 2 inch) were used to calculate P loss vulnerability ratings according to criteria shown in **Table 1**.

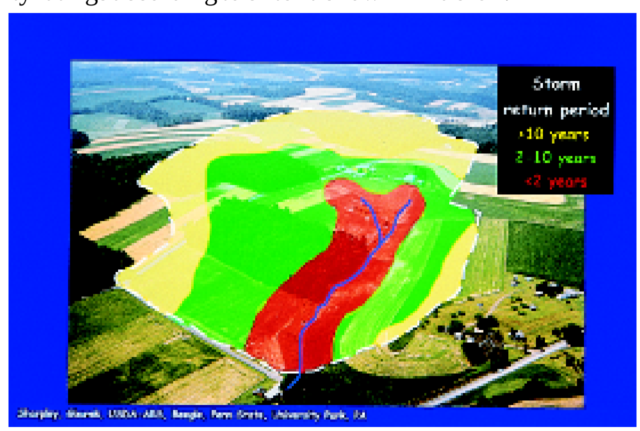

Figure 3. Surface runoff potential. Shows return periods of less than 2, 2 to 10 and greater than 10 years overlaid on the watershed.

The results shown in **Figure 4** illustrate that much less of the watershed is at risk for P transport losses to the stream, compared to estimates based on soil test P levels or runoff potential alone (compare **Figure 4** with **Figures 2 and 3**). From this, Sharpley and Gburek identified specific "critical source" areas in the watershed for P management considerations to minimize the potential for loss...15 percent of the watershed was classified as "high risk". For example, Arkansas scientists McKimmey and Scott incorporated the use of digital spatial data, the Universal Soil Loss Equation (USLE) and the **P Index** model in a geographic information system (GIS).

Results from this Arkansas study showed that a small portion of a large sub-basin with a long history of poultry litter application, was at significant risk of P loss. At the highest manure P application (> 90 lb P_2O_5/A) and fertilizer P application (> 150 lb P_2O_5/A), only 2.1 percent and 0.1 percent of the land area was rated very highly vulnerable to P loss.

Figure 4. Ranking site vulnerability to P loss. Shows low, medium, and high ratings overlaid on the watershed.

Site-Specific Application of the Phosphorus Index

Interpretation of the **P Index** will depend on the region under consideration and the degree to which the local watershed is sensitive to P losses. The sensitivity depends on the designated beneficial uses of the water bodies in the watershed. Thus, application of the **P Index** will be region-specific on the large scale.

Within fields, components of the **P Index** such as slope, runoff potential, and distance to watercourse vary greatly. Thus, there will be an advantage to site-specific mapping of the P Index, to a resolution as small as field equipment can manage. This could be useful in terms of avoiding manure or nutrient applications in sensitive areas of the field and applying variable rates based on soil and crop capacity to absorb and retain nutrients in other areas of the field. However, it must be kept in mind that the P Index is only designed as a crude estimator to rank sites on the relative risk of loss of P to surface water. Therefore, while the site-specific microscale approach can have advantages, it may not be seen to have value by all landholders. For some, a field level application of the P Index may be more appropriate.

Conclusions

Use of the **P Index** as a tool to rate the potential for off-site losses of P through runoff is encouraged, especially for those sites near lakes, reservoirs, and streams. Much work remains to validate its accuracy in ranking site vulnerability for P losses to surface water. The weighting coefficients, P loss categories, and the multiplicative transport factor calculation are all based on best professional judgement rather than observed quantitative relationships and need validation.

The **P Index** is an approximation of risk rather than a model of process. It was developed to rank relative risks, and its level should not be interpreted as an assurance of low P loss. Nevertheless, its use should direct conservation efforts and limits on nutrient budgets to hydrologically active zones. This should result in more rational, lower cost efforts to minimize the impact of intensive agriculture on water quality. The **P Index** can also provide a suite of management options available to a farmer to reduce the risk of P loss. The **P Index** may also be useful in identifying sites which do not have elevated soil test P, but which may also be prone to loss of surface P applications during intense rainfall events.

A host of options are presently available to farmers to reduce the risk of P loss. These include:

- matching mineral P supplements in feed to animal requirements
- genetically engineered feed crops which reduce P in animal waste
- nutrient management planning
- appropriate timing of nutrient additions to avoid runoff-producing rainfall events
- variable rate fertilizer application
- conservation tillage
- grassed waterways, vegetative and riparian buffers
- incorporation or subsurface nutrient placement
- treatment of animal manure with alum or gypsum to buffer soluble P

Further research is required in three main areas. The first is to calibrate weighting factors and validate the P Index for the area or region where it will be used, as previously discussed. Another research area is to develop tests that identify soils capable of sorbing large amounts of P. Some soils can sorb up to 17,000 lb of P_2O_5/A . Calcareous soils have very high P-retention capacity. Research is also needed to identify acceptable loading rates for accumulation of P in these soils. ■

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