

Phosphorus Movement from Land to Water

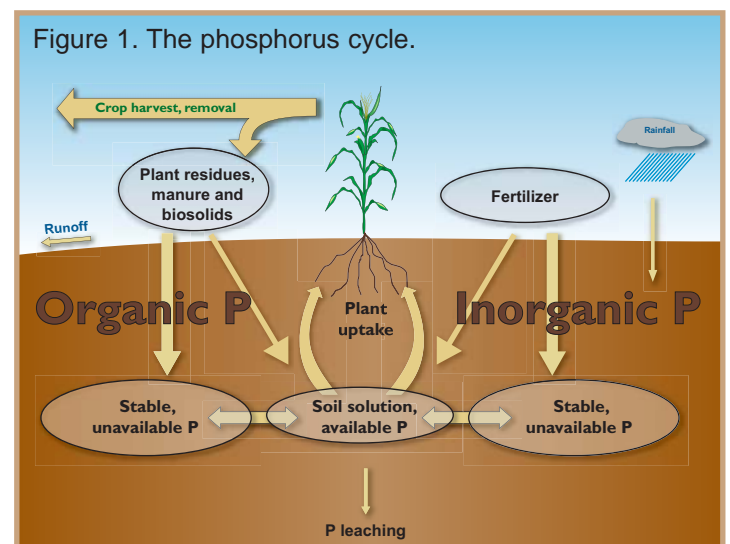
Phosphorus (P) is a naturally occurring element found in soil, water and all living organisms. In soil, P plays a critical role in the health of many crops and is one of 16 essential elements for plant growth. In water, additions of P to lakes and streams can impair water quality by stimulating excessive growth of algae and aquatic vegetation. The result can be a reduction in the recreational value of the water body along with the potential for additional consequences such as fish kills and reduced drinking water quality.

Movement of P across landscapes is a process that requires both a **source** of P and a mechanism for **transport** of P. Soil, vegetation, fertilizer, manure, other soil amendments, and municipal and industrial discharges are all sources of P. Water runoff and soil erosion are forces that transport P from land to water. Understanding the source and transport processes that control P movement is important for the development of sound nutrient management strategies that minimize the impacts of P on water quality.

The Phosphorus Cycle

Phosphorus, like most nutrients, moves through a cycle of interactions from soil to plant to animal (Fig. 1). The P cycle consists of a complex relationship of chemical and biological reactions that control its availability. Soil P originates from the weathering of minerals and from the

additions of P-containing materials previously mentioned. Removal of P from soil occurs by crop uptake and harvest, erosion, runoff, and, occasionally, leaching (water movement through soils). The majority of P is located in the topsoil as a mixture of inorganic (mineral) and organic materials. Both forms of P are important sources for plant growth, but their availabilities are controlled by soil characteristics and environmental conditions. While soils generally contain a significant amount of P, most of it is strongly bound to soil particles by a process known as "fixation", and is unavailable for plant use.



Phosphorus Sources

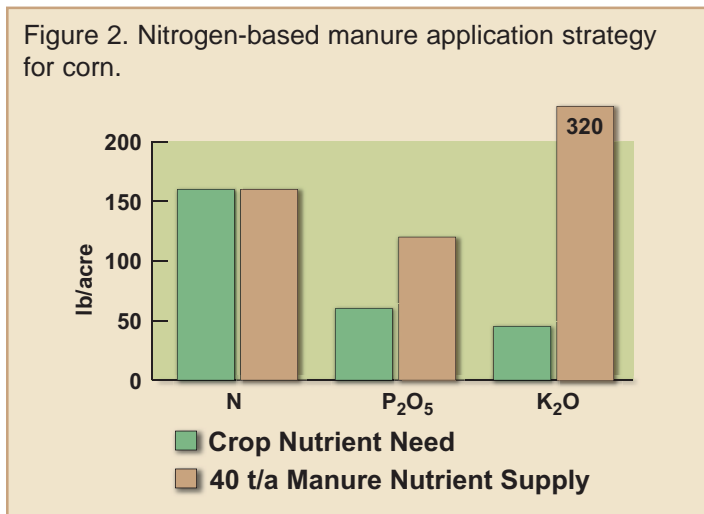
Where is phosphorus coming from?

Soil - Phosphorus occurs naturally in the soil and is often supplemented with various inputs. Supplementation is needed because of the rapid rate at which P is "fixed" to soil particles. Over the course of time, however, P applications in excess of removal will elevate soil P to levels above the range needed for optimum crop growth. In general, soils with excessive levels of P have a higher potential for P losses to surface waters.

Plants - Native and agricultural vegetation can be a source of P. Researchers have found that alfalfa, grasses, crop residues, and forest litter contribute P in spring runoff. Plants release P when tissue is ruptured due to freezing and thawing. During rainfall or thawing events, plant-derived P can be dissolved into runoff water.

Fertilizers - Crop fertilization is the greatest use of P in agriculture. Many native soils were naturally low in P and required supplemental P additions to increase yields. The long-term use of manufactured fertilizers, along with other P inputs, has increased the P content of many soils to levels exceeding those needed for crop growth. In general, as soil P content increases, the potential for P loss in runoff and erosion increases.

Manure - Land application of manure to cropland recycles valuable soil nutrients needed for plant growth. Manure additions also improve many of the physical properties of soil resulting in an improved seedbed for crop growth. Unfortunately, manure applications can also lead to a build-up of soil P. Manure is often applied at rates to meet the nitrogen (N) need of corn. While the crop-available N and P contents of dairy and other animal manures are about equal, the corn need for N is three to five times greater than the P need (Fig. 2). Consequentially, the application of manure at rates to meet the N need of corn results in P applications that exceed crop P removal. The result is a build-up of P in cropland soils. Long-term



manure applications have elevated the P level of many soils above the range necessary for optimum crop growth. This trend is common in areas where concentrated live-stock operations are found.

Livestock Feed - As it relates to manure, livestock feed can be a significant source of P on farms. Farm animals need adequate protein, energy, and nutrients in their feed in order to meet their nutritional needs, but dietary rations often contain excess nutrients, particularly P. Dietary P intake is directly related to the P content of manure. The higher the dietary P levels, the higher the concentration of P in the manure (Table 1). Excess dietary P accelerates the build-up of soil P and increases the potential for P losses from manured fields.

Table 1. Annual phosphorus fed to and excreted by a lactating cow.

Dietary P Level (%)	Supplemental P (lb/cow/year)	Fecal P
0.35*	0	42
0.38*	5.5	47
0.48	23	65
0.55	36	78

*Dietary P levels of 0.35 and 0.38 are within the ranges recommended by the National Research Council (NRC) for dairy cattle feed.

Industrial and Municipal Waste - Water discharged into lakes and streams from industrial and municipal wastewater treatment facilities is an obvious source of pollution, and often a source of P. Storm water runoff from streets, driveways, parking lots, roofs, and lawns is an additional source of P entering surface waters. Biosolids, such as sewage sludge, are produced from the separation of liquid and solid waste at municipal waste water treatment plants. These P-rich solids are applied to nearby agricultural land as a nutrient resource similar to manure. The potential for the build-up of soil P levels to excessively high levels exists with multiple years of biosolid applications to the same fields.

Phosphorus Transport

How does phosphorus move?

Runoff and Erosion - The main transport mechanism for delivery of P to lakes and streams is runoff and erosion from the surrounding land (*see cover illustration*). Runoff and erosion are similar and interrelated processes. Runoff is the movement of water across the land's surface. Erosion occurs when runoff or rainfall dislodges soil particles and moves them with water from their place of origin to be deposited elsewhere. As runoff from rainfall or snowmelt

Point and Nonpoint Source Pollution in Agricultural and Urban Areas

Point Source Pollution: Identifiable pollution discharge sources, such as pipe emissions.

Nonpoint Source (or Runoff) Pollution: Diffuse, hard-to-identify pollution sources transported by runoff and erosion from a widespread land area.

One may be tempted to associate point source pollution with urban and industrial activities and nonpoint sources with agricultural activities. While this is often true, the opposite occurs as well. In urban areas, rainfall and the resulting runoff picks up sediment and pollutants as it travels across construction sites, lawns, parking lots, and streets. This runoff becomes a nonpoint source of pollution. In an agricultural setting, manure, fertilizer, pesticide, etc. spilled into or near a waterway from a storage facility is an example of an agricultural point source of pollution.

Municipal and industrial point source pollution has been greatly reduced over the past decades due to strict regulation, management, and investment in capital improvements by industries and municipalities. The success in reducing point sources of pollution and the substantial costs involved with further reduction of point sources of P is focusing public attention on the reduction of nonpoint (runoff) sources of pollution to further improve water quality.

Urban watersheds are few relative to agricultural watersheds in Wisconsin. Many of the state's watersheds contain both urban and agricultural areas. While the impact of nonpoint source pollution in urban landscapes can be locally significant, it often pales in comparison to agricultural P contributions due to large differences in acreage of the two land uses. As a consequence, the focus of many water quality protection programs has been to reduce nonpoint source pollution from the largest overall land use affecting it – agriculture.

travels along the landscape, the water interacts with the topsoil and any materials on the soil surface. During this process P can be added to the runoff water from soil, plant material, manure, and other soil amendments. Runoff water can contain P in both soluble (dissolved) and particulate (suspended) forms. Particulate-P is bound to the eroded soil and organic particles carried in the runoff. The majority of P lost from agricultural land is in the particulate form. Researchers estimate that particulate-P makes up 60 to 90% total P losses from cropland. The relationship between the soluble-P and particulate-P proportion of the total P contained in runoff varies as a function of erosion rates (Fig. 3). As erosion rates increase, the particulate-P fraction of runoff increases while the soluble-P fraction decreases significantly.

While particulate-P makes up the majority of the P transported in runoff from cropland, P in this form is not immediately available to algae and aquatic weeds in lakes

and streams. However, the soluble-P portion of runoff can immediately stimulate the growth of algae and aquatic vegetation. Eroded sediment that reaches a lake will eventually settle to the bottom where it can act as a reservoir of P - awaiting future release (Fig. 4). The release of P from bottom sediments is a complex process that is dependant upon numerous factors. Biological activity can gradually release soluble-P from bottom sediment and organic matter. This soluble-P may diffuse into the lake water or it may become bound to the surfaces of lake bottom particles before it can reach the overlying water.

It is important to note that even small P additions to lakes and streams can have a big impact on water quality. The amount of P necessary to cause water quality problems is very small compared to the amount of P required for crops or the amounts contained in manure and fertilizer-P applications. Surface water concentrations of P as

Figure 3. Effect of erosion rate on the content of soluble P and particulate P in runoff.

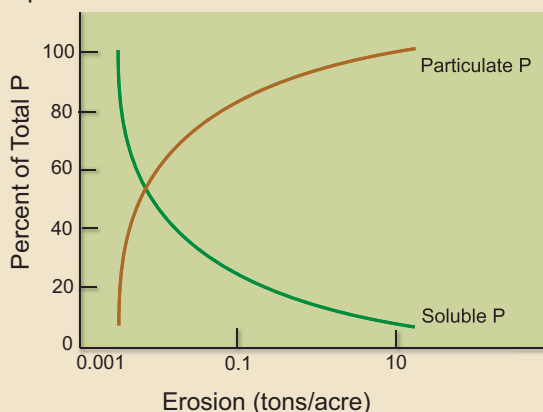
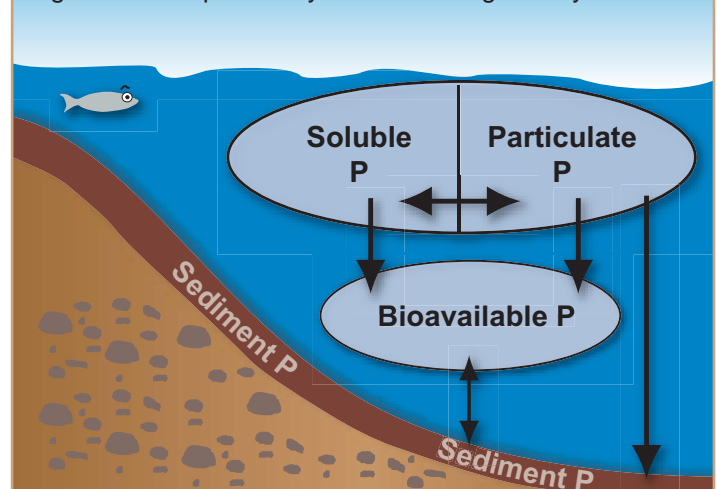


Figure 4. Phosphorus dynamics within a body of water.



low as 0.01 ppm have been shown to impair water quality. These values are ten times lower than the P concentrations required in soil water for plant growth - typically 0.2 to 0.3 ppm. Comparing these concentrations illustrates the importance of limiting any amount of P loss from the land to water.

Leaching - In addition to runoff and erosion, another way P can move is by water infiltration through soil to groundwater, a process called leaching. Groundwater flow has been documented as a P transport mechanism to surface waters, but only under specific and usually rare conditions. *Remember P is tightly bound to soil particles.* Conditions that may result in P leaching include sites with high water tables, soils that are extremely high in P (i.e. P has saturated the soil's adsorption capacity), and/or sandy, highly permeable soils. Groundwater contributions of P are all in the soluble or dissolved form. In Wisconsin, current evidence suggests that P additions to surface waters from groundwater are negligible.

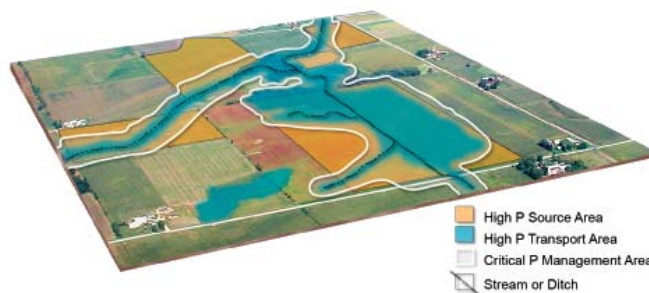
Relationship between Phosphorus Source and Transport

Phosphorus that reaches a lake or stream often originates from small areas within a watershed. One study found that less than 10% of the area within the agricultural watersheds they investigated was responsible for 90% of the P contained in runoff. Source-areas vary in location and magnitude of P contribution due to weather conditions such as the intensity and length of rainfall, as well as land characteristics such as soil moisture, soil erodability, soil water storage capacity, topography, etc. Not all areas that would be obvious P sources have a means to transport P to surface water. On the other hand, not all areas with high potential for P transport have a significant source of P. The many factors influencing P movement from the landscape makes it challenging to identify areas prone to losing P.

The Phosphorus Index

Various landscape assessment tools have been developed over the years to identify sites requiring improved management in order to minimize environmental risk. The Phosphorus Index (PI) is one tool that calculates the risk of P loss from individual fields and provides management recommendations to reduce those losses. The PI evaluates both P source and transport factors in its determination of P loss potential. With the identification of critical areas where both source and transport factors coincide, appropriate management practices can be applied to reduce P losses.

A PI has been developed for Wisconsin and work continues to improve the model. The latest information can be found at <http://wpindex.soils.wisc.edu>.



Summary

In order for P, and other soil nutrients, to be added to lakes and streams, there must be both a **source** of P and a mechanism for **transport** of P to water.

Sources of P include fields with high levels of soil P, or a history of manure, biosolids, or fertilizer applications. Transport of P occurs through runoff, erosion, and, occasionally, leaching.

To minimize P losses, it is critical to identify landscape areas where source and transport factors coincide.

Authors: Angela M. Ebeling, Soil Science Outreach Specialist; Larry G. Bundy, Professor of Soil Science; Scott J. Sturgul, Nutrient Management Specialist. Nutrient and Pest Management (NPM) Program, University of Wisconsin-Madison and University of Wisconsin-Extension. **Publication, production and design:** Roger W. Schmidt, Senior Information Processing Consultant, NPM Program.

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