UNDERSTANDING PHOSPHORUS IN RURAL AREAS

AGRICULTURAL NON-POINT SOURCES OF PHOSPHORUS

PHOSPHORUS IN SOIL

Soil ecosystems are similar to water systems in that only a small portion of the total phosphorus is easily available to plants.

The soil P system is commonly described as having three pools of P:

- soluble P
- labile P
- stable P.

SOLUBLE PHOSPHORUS

A small fraction of soil P is dissolved in the soil solution in the orthophosphate form – the form that is taken up by plants.

LABILE PHOSPHORUS (ORGANIC AND INORGANIC FORMS)

As plants deplete orthophosphate in the soil solution, dissolved P is replenished from the second major soil P pool called *labile P*. Labile P is held loosely by soil particles and can move easily into solution.

STABLE PHOSPHORUS (ORGANIC AND INORGANIC FORMS)

The third soil P pool, non-labile or *stable P*, is held strongly to soil particles in the form of iron and aluminum phosphates in acid soils, and calcium phosphates in calcareous soils. Some P is part of the molecular structure of soil organic matter. Stable P is unavailable to plants and is converted very slowly to labile and soluble P.

What about P_2O_5 (fertilizer phosphate)?

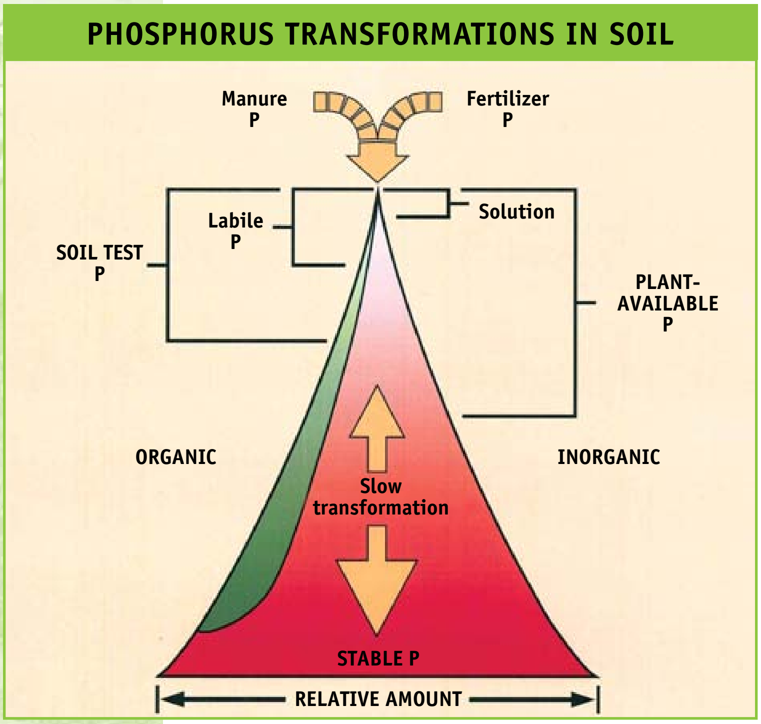
This is a unit of measure used in fertilizer: plants do not absorb phosphorus in this form.

P = phosphorus

PO_4^{3-} = phosphate

For the most part, a discussion of phosphorus is really about phosphates. Phosphate is the form used in the metabolism of plants and animals, and most commonly found in minerals. Chemically, it has four oxygen atoms linked to the central P atom. Its charge and number of hydrogen atoms are a function of pH.

The total P in the top 15 centimetres (6 in.) of soil is equivalent to 3000–5000 kilograms per hectare (2700–4500 lb/ac) of phosphorus. However, less than 1% of the total P is available to crops.

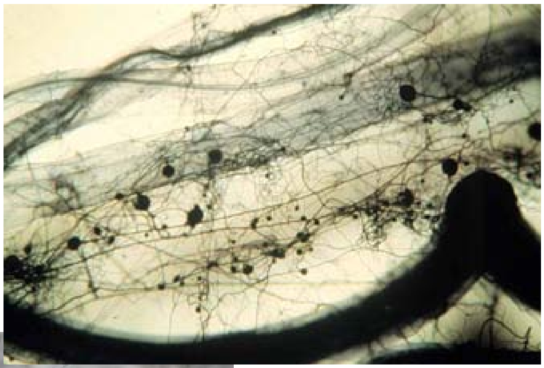


Phosphate reacts with so many different compounds and elements in the soil that only a small amount remains in solution at any time.

Most of the P is tied up in compounds with a range of solubility – as indicated by the *Solution* label in this illustration. When soluble P is added to the soil as fertilizer or manure (see top of illustration), most of it is rapidly converted first to labile forms. (Note: plant-available P is made of P in solution, labile P, and the less stable compound forms.) It then converts to progressively more stable forms, by reacting with iron, aluminum or calcium (see *Inorganic* label), by binding to clay particles or organic matter, or by forming part of the chemical structure of the humus (see *Organic* label).

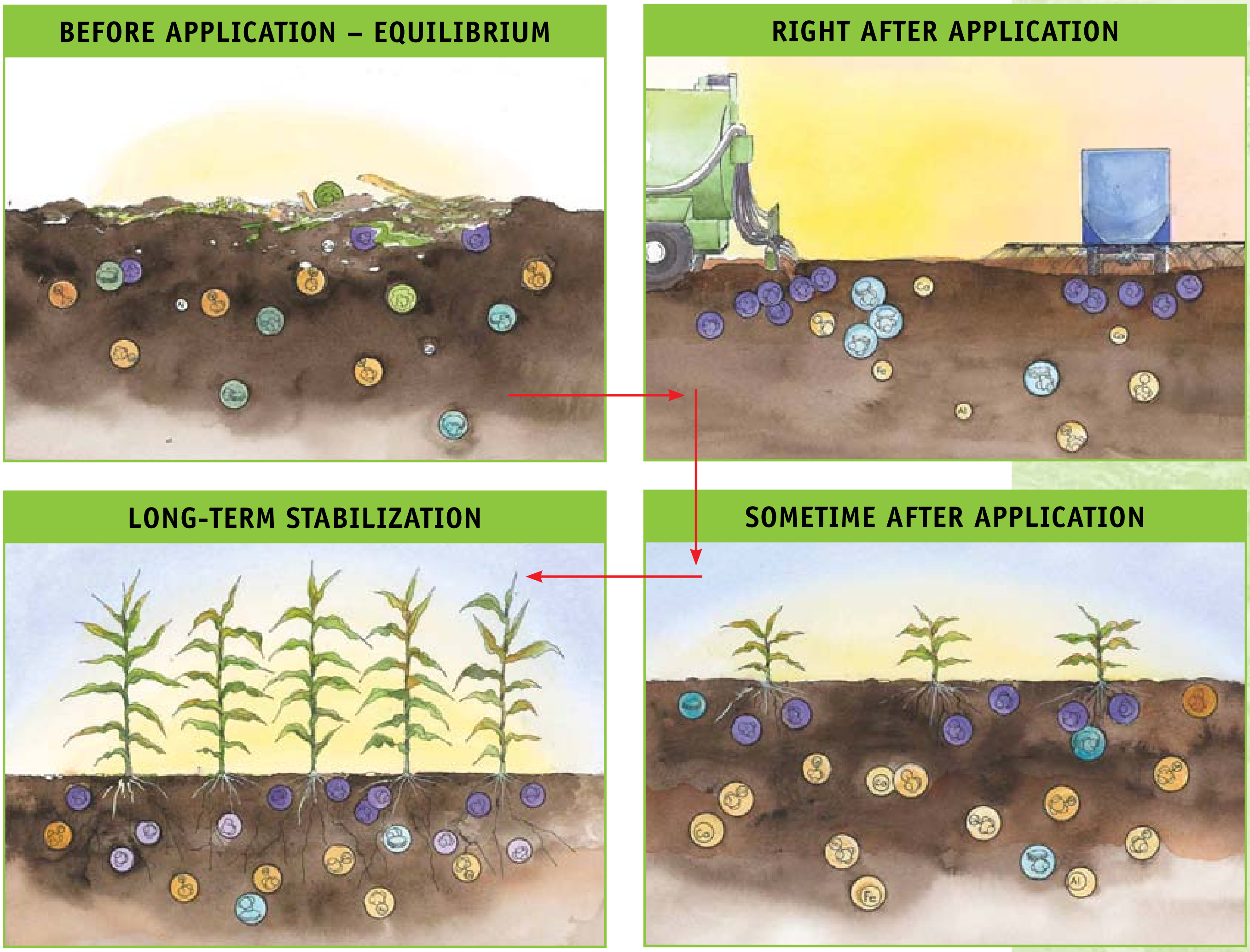
Over time, the P tends to accumulate in the most stable compounds (as represented by the area in the base of the triangle). However, some of the P will also be released into solution to replace the P taken up by plant roots – see arrows showing *Slow transformation* – with proportionally more P becoming stable and smaller amounts slowly released into solution.

Arbuscular mycorrhizae (AM) are fungi that help crops and most other plants increase nutrient and water uptake, especially phosphorus, in exchange for sugars. The very fine roots-like mycelia of the fungi are able to explore a greater volume of soil than the thicker plant roots could. Additionally they can excrete different chemicals to aid nutrient absorption.



The vast majority of phosphorus taken up by plants is due to plant roots, root hairs, and contact with P as they grow through the soil. Because low temperatures slow root growth and nutrient absorption, plants are often unable to obtain sufficient P during cold weather, especially when they are small.

Consequently, it's beneficial to place phosphorus fertilizer where roots can access it and to time fertilizer application to periods of higher use.



Before Application – Equilibrium

P in soil is classed in three groups, although there is a gradation between labile and stable forms of P:

- soluble P: phosphate or PO_4^{3-} (purple spheres)
- labile P: held loosely by soil particles (blue spheres) and the surface of organic matter (green spheres), and
- stable P: phosphorus attached to calcium, iron or aluminum (gold spheres), or chemically bound within complex organic molecules.

Before planting, soil P is in a state of equilibrium with only a fraction of phosphorus in the soluble form.

Right After Application

This illustration shows what happens to this equilibrium when manure or fertilizer P is added before planting. Most P fertilizers are composed of water-soluble P compounds, and most manure P is water-soluble. Application of fertilizer or manure P causes an initial dramatic increase in soluble P in the soil at the point of contact – as indicated by the introduction of dark purple phosphate spheres.

Sometime After Application

Chemical equilibrium is rapidly re-established as much of the added P enters the labile P pool. See the humus (green) and clay attached (blue) P spheres – as well as fewer phosphates in solution (dark purple spheres) in the root zone.

Long-Term Stabilization

Over time, some of the P in the labile pool is converted into more stable organic and mineral forms. (Note the increase in the number of darker gold P spheres.) The immediate effect of P fertilization and manure P applications is to increase the capacity of the labile P pool to replenish solution P. The net long-term effect of P additions on labile and total P in a soil depends on soil properties, P removal by crops, and P loss by other processes (such as erosion and runoff).

PHOSPHORUS IN MANURE

About two-thirds of the phosphorus in manure is found in the feces (not the urine), primarily in the form of organic compounds and also as orthophosphate. The organic compounds are readily degraded in storage or in soil, so that much of the phosphorus in manure becomes available to crops eventually.

The best economic returns from manure generally come from applying rates to meet the nitrogen needs of crops like corn or cereals. However, this usually means that more phosphorus is applied than the crop removes, so phosphorus can accumulate to very high levels in the soil when this management is followed for a number of years.

Soil test results that show high phosphorus levels indicate conditions at risk of phosphorus loss. Runoff and erosion from these areas can contribute high amounts of phosphorus to lakes and rivers.

Manure application often results in increased yield compared to use of fertilizer alone. This is likely due to the additions of organic matter, the proliferation of soil life, and the improvement in soil quality following manure applications.

Nutrient content of manures is highly variable and depends on species, size, age, feed, housing, manure type, and other management factors.

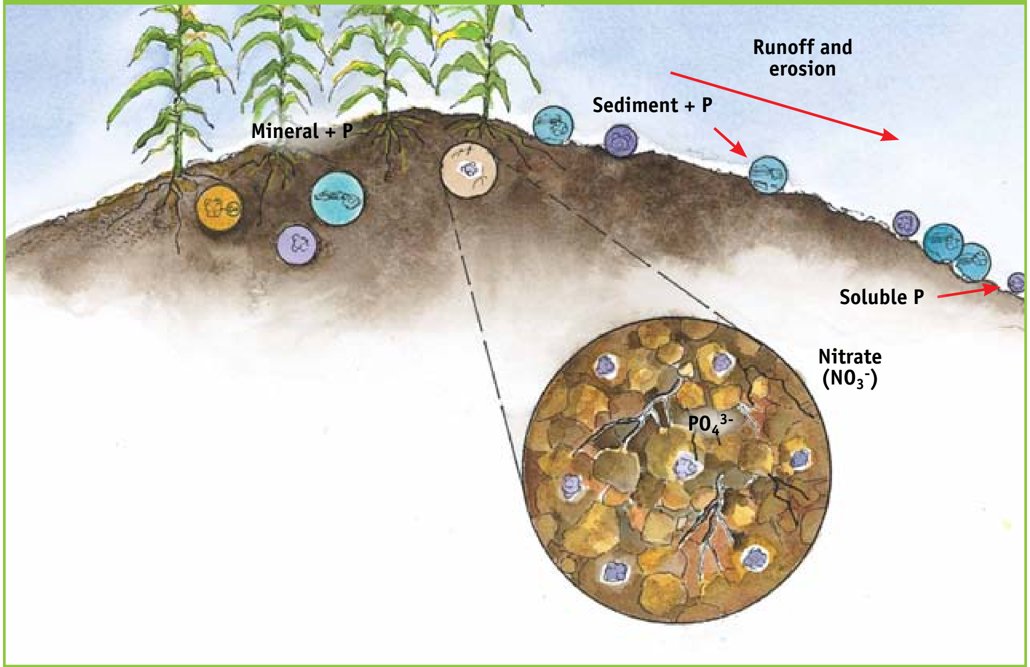
PHOSPHORUS IN FERTILIZERS

Rock phosphate is insoluble in water, and the phosphorus it contains becomes available to plants very slowly – taking 100 years or more.

To make the rock phosphate more available to plants, it is treated with various acids.

Rock phosphate, mined mainly in the southern United States, northern Africa and Russia, is the source of almost all of the phosphorus in fertilizers.

ROOT ZONE AND SOIL PHOSPHORUS



Phosphates in the soil are not easily lost. Most phosphates bind readily to soil particles (labile and stable forms) and are unlikely to leach – depicted by the blue, green and gold spheres positioned below the soil surface in the illustration and the inset.

Phosphorus is lost from the soil surface as surface runoff carries particulate P in eroded sediments and dissolved P – as shown by the sediment-bound and soluble P on the soil surface.

- Phosphate (PO_4^{3-})
- Calcium phosphates ($Ca + PO_4^{3-}$)
  Iron phosphates ($Fe + PO_4^{3-}$)
  Aluminum phosphates ($Al + PO_4^{3-}$)
- Clay + PO_4^{3-}

AGRICULTURAL POINT SOURCES OF PHOSPHORUS

Potential agricultural point sources for phosphorus loadings include:

- storage facilities for manure and other nutrients
- livestock yards
- milking centre washwaters
- faulty septic systems.

Unless properly managed, phosphorus from these sources can reach surface waters from overland flow and subsurface drainpipe (tile) outflow. In these circumstances, the risk of point source pollution is greatest following snowmelt and storm events.

Storm events and snowmelt can carry soil and manure from livestock yards to surface waters such as watercourses and lakes. Soil and manure can contain phosphorus, other nutrients, and bacteria.

Nutrients such as phosphorus in harvested crops are used by livestock and people. Returning their wastes to cropland closes the phosphorus cycle.

PHOSPHORUS TRANSPORT TO SURFACE WATERS

Phosphates from agricultural sources can reach surface waters from point sources and non-point sources. Here are some of the more common pathways for phosphorus transport to surface waters.

POINT SOURCE

Spill

A spill occurs when phosphorus in a stored solution from a concentrated source (e.g., liquid manure, greenhouse solution) is discharged accidentally into the environment.

The spilled materials can run off directly to surface water from the spill source. In most cases, the liquid ponds on the soil or an impermeable surface. The ponded area breaches and forms concentrated flow. The concentrated flow can then move overland and follow the path of least resistance to the nearest body of surface water.

Spills can reach surface water indirectly as well. An adjacent surface inlet, cracked soil, or shallow bedrock formation can serve as direct conduits to subsurface drainage. The subsurface drainage system will outlet to adjacent bodies of surface water.

In the event of a spill, work safely and quickly to stop and contain the spilled material. Then contact the MOE Spills Action Hotline at 1-800-268-6060. Provide the spill details, the action taken, and future intentions.

Leaks

In this context, leaks are the unintentional release of small volumes of contaminated liquids on an ongoing basis. Chronic leaks accumulate in the environment over time. For example, phosphorus can reach surface waters when in solution and suspension with organic sources such as solid manure stacks or livestock yards.

Leaked liquids can pond on the soil surface and follow the path of least resistance to surface waters.

Illegal Connections

There are a few isolated cases where sources of waste liquids are directly connected to subsurface drainage systems for discharge into surface waters. These deliberately bypass the natural treatment functions of soils – and are illegal.

NON-POINT SOURCE

Water Erosion

Particulate P can be eroded from the seedbed and upper layers by water moving over cropland. When a storm event causes soil to reach saturated surface conditions and/or when soils are semi-frozen, soil particles are readily detached. Attached P moves with sediment and runoff waters in sheets, rills and gullies. Eroded materials can be deposited on fields or into adjacent surface waters.

Exposed soil conditions can lead to the transport of particulate P with soil sediment by the erosive forces of wind.

Wind Erosion

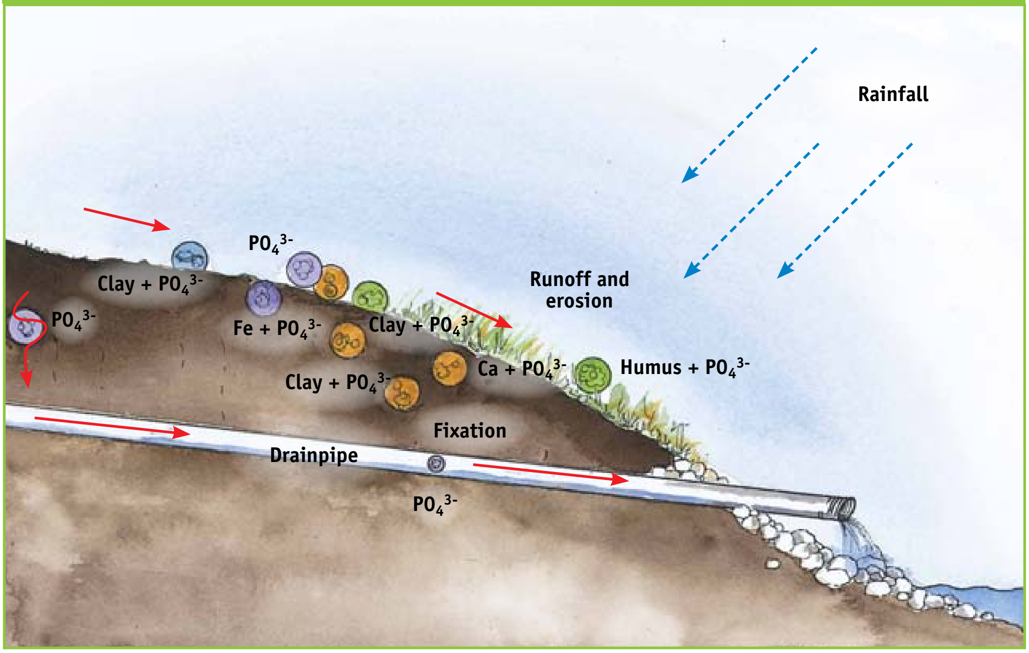
Dry and unprotected, exposed soil conditions can lead to the transport of particulate P with soil sediment by the erosive forces of wind. Most wind-borne particles are deposited on adjacent fields, fencerows or windbreaks. However, some material can reach adjacent surface waters such as lakes and watercourses.

DISSOLVED PHOSPHORUS FORMS

Runoff

Most phosphate in seedbeds and upper layers will remain attached to soil particles. But some will detach from the particles to move with water on the soil surface and be carried off the field with runoff – especially if there are saturated surface conditions and/or semi-frozen soil.

PHOSPHORUS LOSSES FROM A CROPLAND ECOSYSTEM



Phosphate (PO_4^{3-})

Calcium phosphates (Ca + PO_4^{3-}) Iron phosphates (Fe + PO_4^{3-})

Humus + PO_4^{3-}

Clay + PO_4^{3-}

Phosphorus compounds can be lost from cropland root zones in the following ways.

- **Runoff and erosion**. Surface-applied nutrients in organic (e.g., manure) or inorganic (e.g., phosphate fertilizers) forms can run off directly during storm and snowmelt events – see purple P spheres on surface. Soil erosion can lead to the loss of sediment-bound phosphates – see blue and green P spheres on surface. The risk of erosion and runoff increases with slope, low infiltration rates, compacted or frozen soils, low vegetative or crop cover, and intense rainfall and snowmelt.
- **Drainpipe outflow**. Small quantities of phosphates from applied liquid manure or biosolids (see purple P spheres in pipe), or P attached to clay and organic matter can reach drainpipe systems in soils with large cracks and subsurface macropores.
- **Fixation**. Phosphate is very reactive in soil. It combines with calcium, magnesium, iron, manganese or aluminum to form insoluble compounds, or it binds to soil particles – see gold P spheres in soil profile. A small amount remains in solution at any given time. Much of the phosphate remains in a reserve form, and is slowly released into solution to replenish what's been removed by plants.

Subsurface Drainage

Phosphorus can reach subsurface drainage systems when the first condition below is joined by one or more of conditions 2, 3, and 4.

1 – soils with high soil P concentrations due to long-term application of P from organic or inorganic input sources

2 – deep sandy soils

3 – soils with continuous macropores – including cracks and worm burrows

4 – high organic matter soils (e.g., muck soils) with a low capacity to retain phosphorus.

Some of the dissolved P will follow continuous large pores in sandy and gravelly soils out of the root zone (i.e., the soil occupied by plant roots). Most of the gravitational water draining through the root zone above the subsurface drainpipe will reach the subsurface drainage system. However, this water will only carry some of the surface-dissolved P to drainpipes; most of it will be taken up by growing crops or fixed by soil minerals.

Phosphorus fixed to fine particles – such as clay and organic matter – may also follow macropores and enter subsurface drainage systems. In most cases, sediment and P loads are not high in outflow waters. However, there is a risk of higher levels in outfall (outlet) waters if the drained cropland:

- has a low infiltration rate
- is not protected by a crop cover or crop residues, and
- includes surface drainage components such as surface inlets, which connect directly to the subsurface drainage system.

PHOSPHORUS-LOADING RISK INDEX (P INDEX)

The P Index assesses the risk of surface water contamination from a field, and identifies where measures to reduce phosphorus losses are needed.

The risk is highest when a source of phosphorus lies near a pathway to surface water. This means that the areas receiving the highest rates of phosphorus application, or with the highest phosphorus soil tests, will not always be the areas of greatest risk for phosphorus losses.

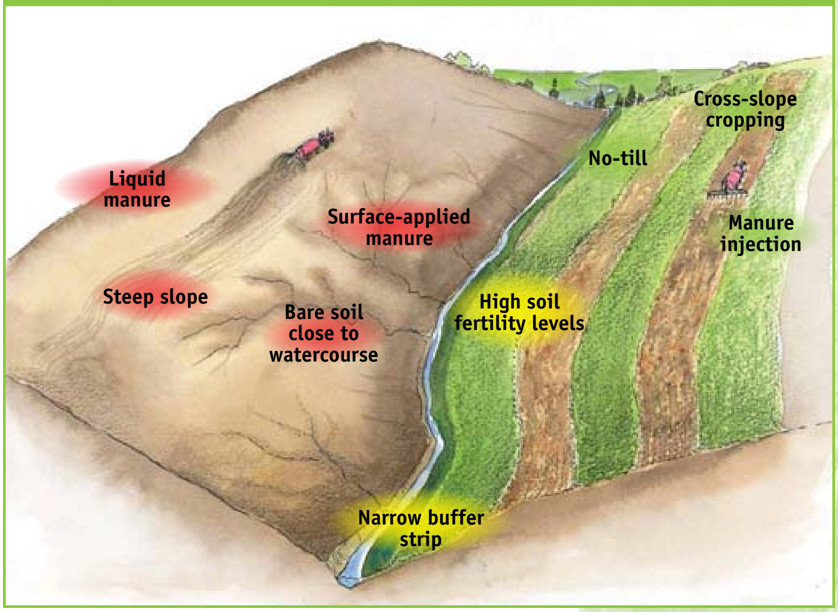
Phosphorus can move off of a field as particulate phosphorus on eroded soil particles, as dissolved phosphorus in surface runoff, or through drainpipe flow. Each of these will have separate source and transport factors, but the sum of each of these components represents the total risk from a particular field. As the risk increases, so do the restrictions on the amount, method and timing of phosphorus applications, to the point where some fields should not be receiving any additional phosphorus.

The following table lists the factors that are considered when assessing the inherent risk for phosphorus losses before the addition of any fertilizer or manure.

INFLUENCING FACTOR		FIELD MEASUREMENT OR INPUT NEEDED TO DETERMINE THE P INDEX
SOURCE	**TRANSPORT**	
PARTICULATE P IN SURFACE RUNOFF – soil erosion potential	– delivery of sediment from field to surface water	• soil texture and surface cover • slope length and gradient • rainfall intensity and duration (average) • distance to watercourse • roughness and cover of flow area
DISSOLVED P IN SURFACE RUNOFF – dissolved P concentration	– runoff potential	• P soil test • field slope • hydrologic soil group
P IN DRAINPIPES – sum of particulate and dissolved P loadings (since most P moves to drainpipes by preferential flow through cracks and worm channels)	– intensity of subsurface drainage network	• drainpipe spacing (systematic or random system) • area included in drainage system

- High P Index = high risk; no P application
- Moderate P Index = limits on rate, timing or method of P application
- Best P Index = low risk

P INDEX FACTORS



This illustration shows the impact of management on the risk of phosphorus losses, even though both fields are close to a stream, have similar slopes, and have highly erodible (silt loam) soils. The field on the left side of the illustration has few soil conservation measures in place, increasing the risk of particulate P losses. A history of high manure application rates has built up the P soil test to very high levels, so there is also a high risk of dissolved P runoff. This field should not be receiving any additional P because the risk of P loss is already so high.

The field on the right side has implemented no-till strip cropping to manage particulate P losses, and has applied phosphorus at much lower rates as guided by soil tests and a nutrient management plan. There is only a narrow strip adjacent to the stream where phosphorus application rates should be restricted, or the phosphorus should be subsurface-banded.

Here are management options where P Index is High.

- ✔ Implement soil conservation measures to reduce soil erosion, thus reducing inherent risk of phosphorus loss.
- ✔ Limit application rates of materials that contain phosphorus (e.g., fertilizer, manure, sewage biosolids).
- ✔ Apply materials containing phosphorus in subsurface bands rather than on the surface, or incorporate immediately.
- ✔ Eliminate phosphorus applications during the late fall and winter.

NON-AGRICULTURAL SOURCES OF PHOSPHORUS

Phosphorus in the form of phosphates was a common component of dishwasher detergents and industrial cleaners. Phosphate in detergent is being phased out of use in Ontario, reducing the P loading in grey water.

Wastewater (sewage) treatment plants discharge treated water into watercourses or lakes. Not all of the phosphate from treated sewage is removed in the process.

Septic systems can also be a source of phosphorus to lakes and rivers. The likelihood of phosphorus reaching surface water increases if a septic system fails, is close to shorelines, or is illegally discharging.

Recreational boats with facilities can be a source of P-rich water. Discharging sewage from boats into Canada's waterways is against the law, and discharging grey water is discouraged. Many marinas have pump-out facilities.

Urban-based phosphorus pollution includes effluent from wastewater (sewage) treatment plants, storm sewers, and industrial sources.