watershed in Pennsylvania (FD-36). The watershed is 30% row crops (corn and soybean), 30% pasture, and 40% wooded, which is typical of land use in this part of the Northeast. In the fall of 1998, soil test P (as Mehlich 3) was determined on a 30-m^2 grid over the watershed. For the managed part of the watershed (excluding the wooded area), it was found that 5% of the land area had soil test P < 50 ppm P, 10% between 50 and 100, 25% between 100 and 200 ppm P, and 60% > 200 ppm P. These groups of soil P are based on agronomic and environmental response because below 50 ppm P, application is recommended. As soil test P increases from 50 to 100 ppm P, there is a decreasing response to applied P, with no yield response to applied P expected when soil P is above 100 ppm P (Beegle 2002). The environmental threshold of 200 ppm P equated to that proposed by several states (Table 34-5).

If P applications to FD-36 were based on an agronomic soil test P of 100 ppm P, P application would not be recommended for crop yield response on 85% of the managed part of the watershed (Figure 34-16a). Based on an environmental soil P threshold of 200 ppm P, 40% of the managed part of the watershed would receive no P (Figure 34-16b). Finally, using the P index to identify those areas at risk for P loss (as shown in Tables 34A-1, -2, -3, and -4; Appendix A; and Table 34-6), 20% of the watershed is ranked at a high and very high risk for P loss in runoff (Figure 34-16c). These areas are where high soil P, manure and fertilizer application, and the risk of surface runoff or erosion coincide. Using the P Index option, P application would not be recommended on only 20% of the managed part of the watershed.

Each of the three P management strategies is intended to reduce the risk of P loss from a watershed. Clearly, there will be different impacts on farm operations depending on which option or strategy is adopted. Although these are hypothetical situations, more research is needed on the actual impacts of the strategies on actual P loss from a watershed as well as farm production. For example, in watershed FD-36, poultry manure from an egg-laying operation and swine slurry from a pig farm are applied to several cropped fields in the watershed. Obviously, selection of the appropriate P management strategy will impact these operations. Research is thus needed on the effect of changing P management, by using these strategies, on actual P loss from the watershed. In other words, would focusing P remedial efforts on the critical high-risk areas in 20% of the area (P Index option) result in as great a reduction in P export as remediating 85% of the watershed?

Remedial Measures

Any approach to controlling P losses from agriculture to water must begin with the long-term objective of increasing P use efficiency by attempting to balance P inputs within a watershed with P outputs, while simultaneously improving management of soil, manure, and mineral fertilizer P at farm, watershed, or regional scales. Reducing P loss in agricultural runoff may be brought about by Best Management Practices (BMPs) that control the source and transport of P, such as those listed in Table 34-7.

...attempt to
(1) balance P inputs within a watershed with P outputs [and]
(2) improve management of soil, manure, and mineral fertilizer P at farm, watershed, or regional scales.

Source management

Source management attempts to minimize P buildup in the soil above levels sufficient for optimum crop growth, by controlling the quantity of P in manure and the amount of P that is applied in a localized area. For more information, see the dietary strategy lessons, Lessons 10, 11, 12, and 13.

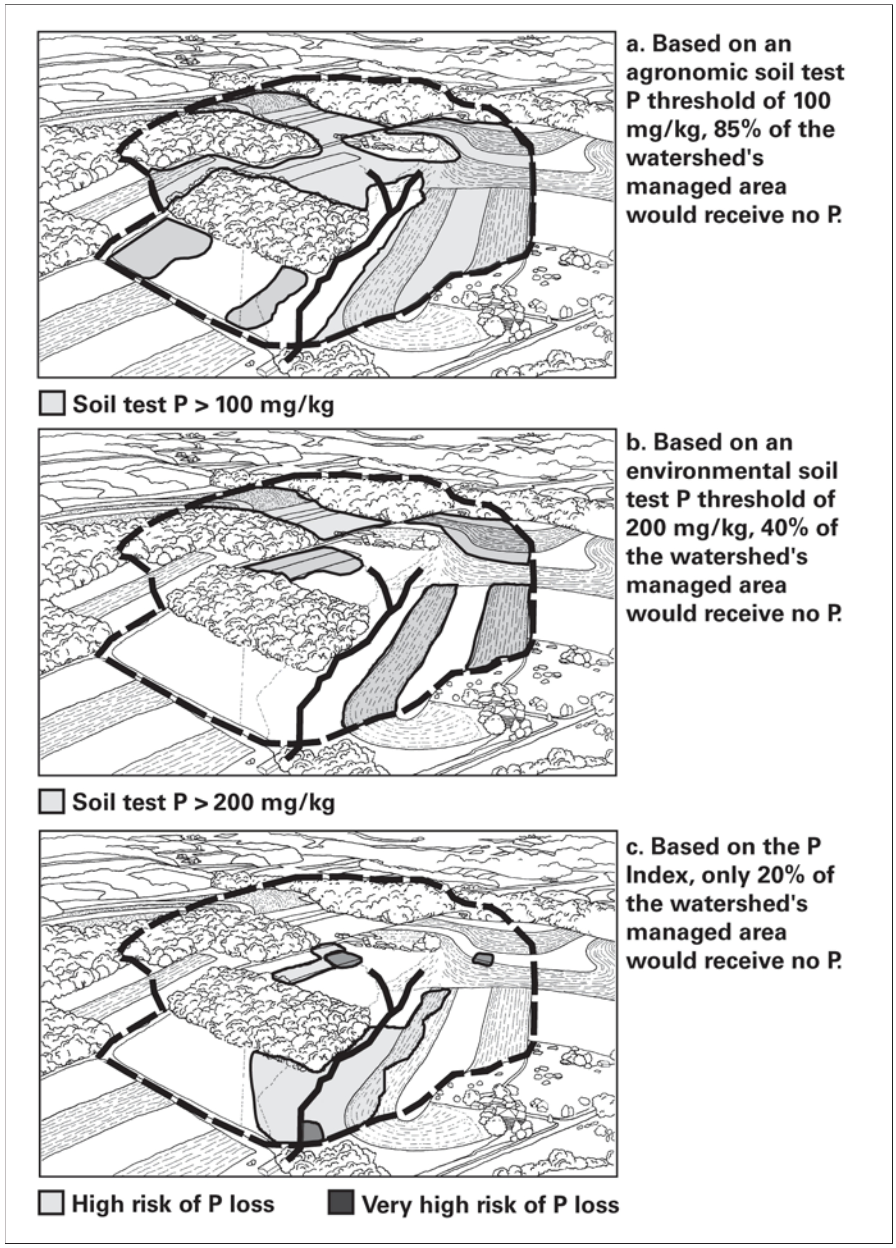

Figure 34-16. Comparison of the three options for P-based management: agronomic soil test P, environmental soil test P, and P indexing of site vulnerability.

Techniques for doing this include

- Manipulating animal intake of dietary P.
- Managing inorganic and protein supplements that contain P.
- Using enzyme additives for animal feed.
- Using corn hybrids with less phytate P.
- Before the land application of manure, determining the P content of both manure and soil.
- Using commercially available manure amendments.
- Physically treating manure to separate solids from liquids.
- Facilitating the movement of manure from surplus to deficit areas.
- Using innovative methods to transport manure.

Table 34-7. Best management practices for the control of NPSs of agricultural P.

Source BMPs: Practices that minimize P loss at the origin

- Balance P inputs with outputs at farm or watershed scale
- Add enzyme to feed to increase nutrient utilization by ani mals
- Minimize P in livestock feed by not overfeeding P
- Feed low phytic acid corn to reduce P in manure
- Test soil and manure to optimize P management
- Physically treat manure to separate solids from liquid
- Chemically treat manure to reduce P solubility, for example, alum, flyash, water treatment residuals
- Biologically treat manure, for example, microbial enhancement
- Calibrate fertilizer and manure application equipment
- Apply proper application rates of P
- Use proper P application method, that is, broadcast, pl owed in, injected, subsurface placement, banding
- Carefully time P application to avoid imminent heavy rainfalls
- Use remedial management of excess P areas (spray fields, disposal sites)
- Compost and/or pelletize manures and waste products to provide alternat e use
- Mine P from high P soils with certain crops and grasses
- Manage urban P use (lawns and gardens)

Transport BMPs: Practices that minimize P transport

- Minimize erosion, runoff, and leaching
- Plant cover crops to protect soil surface from erosion
- Implement terracing, strip cropping, and contour farming to minimize runoff and erosion
- Practice irrigation management and furrow management to minimize runoff and erosion
- Install filter strips, grass waterways, and other conservation buffers to trap eroded P a nd disperse runoff
- Manage riparian zones and wetlands to trap eroded P and disperse runoff
- Practice drainage ditch management and streambank stabilization to minimize erosion
- Build streambank fencing to exclude livestock from water
- Use wellhead protection to minimize by-pass flow to groundwater
- Install and maintain impoundments to trap sediment and P

Source and Transport BMPs: Systems approach to minimize P loss

- Retain crop residues to minimize erosion and runoff
- Consider reduced tillage systems to mini mize erosion and runoff
- Practice grazing (pasture and range) management to minimize erosion and runoff
- Exclude animals from certain sites
- Install and maintain manure-handling systems (houses/lagoons)
- Practice barnyard storm water management
- Install and maintain milkhouse waste filtering systems
- Implement a comprehensive nutrient management plan (CNMP)
- Construct tailwater return flow ponds

Water Body Treatment BMPs: Practices designed to correct problems associated with excess P in the water

- Remove sedim ent from water bodies
- Inactivate sedimentary P with alum or straw
- Stimulate aerobic conditions
- Enhance vegetative growth in littoral zones to decrease water column mixing
- Mine sedimentary P with vegetation
- Harvest aquatic vegetation

- Composting manure.
- Using some manure as “bioenergy” sources.

Manipulating animal intake of dietary P will help balance farm P inputs and outputs in animal operations because feed inputs are often the major cause of P surplus (Table 34-3). Phosphorus intakes above minimum dietary

...matching dietary P inputs to animal requirements can reduce the amount of P that they excrete...

requirements do not seem to confer any growth advantage and are excreted. Thus, carefully matching dietary P inputs to animal requirements can reduce the amount of P that they excrete (Table 34-8). This reduction will have an obvious impact on farm P balance by reducing the potential on-farm accumulation of P and decreasing the land base needed for a balanced P-management plan. For example, a survey of Wisconsin dairy farms by Powell et al. (2002) showed that on farms where manure P exceeds crop P requirements, reducing dietary P to the National Research Council (NRC) recommendation would reduce the number of farms and acreages with an excess P balance by approximately two-thirds.

In addition to inorganic P supplementation of animal feed, some protein supplements can contribute substantial amounts of P to animal diets (NRC 2001). Common protein supplements vary greatly in cost and P content (0.3-4.7% P), and producers often select protein sources based on economics, not P content. For animal operations where an excess P balance exists, protein supplements with lower P concentrations should be selected (Table 34-8).

...enzyme additives in feed can reduce the need for P supplements...

A significant amount of the P in grain is in phytate (phytic acid), an organic form of P that is digested in low proportions by monogastric animals such as pigs and chickens. As a result, feed is commonly supplemented with mineral forms of P that are readily digestible. This supplementation contributes to P enrichment of manure and litter. Enzymes such as phytase, which break down phytate into forms available to monogastric animals, can be added to feed to increase the efficiency of grain P absorption by pigs and poultry. Such enzyme additives in feed can reduce the need for P supplements and potentially reduce the total P content of manure (Table 34-8).

Another approach to better balance farm P inputs and outputs is to increase the quantity of P in corn that is available to hogs and chickens. Corn hybrids are available that contain low amounts of indigestible phytate P. Without the phytase enzyme, hogs and chickens cannot digest this phytate P, which is excreted. Pigs and chickens fed "low-phytic acid" corn grain excreted 10% to 40% less P in manure than those fed conventional corn varieties. This study also showed that P availability to non-ruminants from low-phytate, high available phosphate (HAP) corn is about two to three times higher than that from normal corn (Figure 34-17). Currently, the challenge to plant breeders is to incorporate the low-phytate trait into commercial corn hybrids with other agronomically

Table 34-8. Potential for feed management strategy to affect manure P.

Feeding Strategy	P Loss Reduction, %
Ruminants and Non-Ruminants	
Formulate diet closer to requirement	10-15
Growth promotion	5
Protein/carbohydrate enzymes	5
Use of highly digestible feeds	5
Phase feeding	5-10
Ruminants	
Reduced P in diet	20-30
Non-Ruminants	
Phytase/low-P diet	20-30
Phytase/low-P diet/HAP corn	40-60

Adapted from Ertl et al. 1998, Federation of Animal Sciences Societies 2001, and Baxter et al. 1998.

Figure 34-17. A geneticist examines a new line of corn he developed. The new corn is designed to be lower in phytic acid, a compound suspected of reducing nutrient absorption during human digestion.
Photo by Keith Weller.

desirable traits. Combining use of phytase feed amendments and low-phytate corn resulted in a 60% reduction in P excreted by swine (Table 34-8).

Farm advisors and resource planners are now recommending that the P content of both manure and soil should be determined by soil test laboratories before land application of manure. Without these tests, farmers and their advisors tend to underestimate the fertilizer value of manure.

...the P content of both manure and soil should be determined... [so] the fertilizer value of manure [is not underestimated].

Commercially available manure amendments, such as slaked lime or alum (Figure 34-18), can reduce ammonia (NH_3) volatilization, leading to improved animal health and weight gains. They can also reduce the solubility of P in poultry litter by several orders of magnitude and decrease dissolved P, metal, and hormone concentrations in surface runoff (Moore et al. 2000). Perhaps the most important benefit of manure amendments for both air and water quality is an increase in the N:P ratio of manure, via reduced N loss because of NH_3 volatilization. An increased N:P ratio of manure would more closely match crop N and P requirements.

Separating the solids from the liquids may increase the management options for some types of manure, such as dairy and swine. This process results in some separation of the nutrients as well, leaving a large proportion of the available N in the liquid fraction and a large proportion of the P in the solid fraction. Also, large dairy and swine operations commonly rely on flush-water system for managing their manure. While such systems are very efficient and rank high in overall cleanliness, large volumes of slurry high in solids and soluble nutrients are produced (Figures 34-19 and -20). Coagulant and flocculent techniques commonly used by municipalities are being used to solve such problems. For example, researchers have shown that using a metal coagulant, such as aluminum, in combination with commercial polymers (polyacrylamide) doubles the removal of solids and also dramatically reduces the soluble P in the effluent. While this does not change the total amount of nutrients that must be handled, it enables better targeting of the individual nutrients to locations where they are most needed, reducing the

Chemical and physical treatment of manure can improve air and water quality by decreasing N loss and P solubility as well as increasing the end-use options for manure...

Figure 34-18. A soil scientist looks for signs of dermatitis on a chicken raised in a poultry house with alum-treated litter. Alum reduces dermatitis in chickens, ammonia emissions to the air, and P losses in runoff water.
Photo by Rob Flynn.

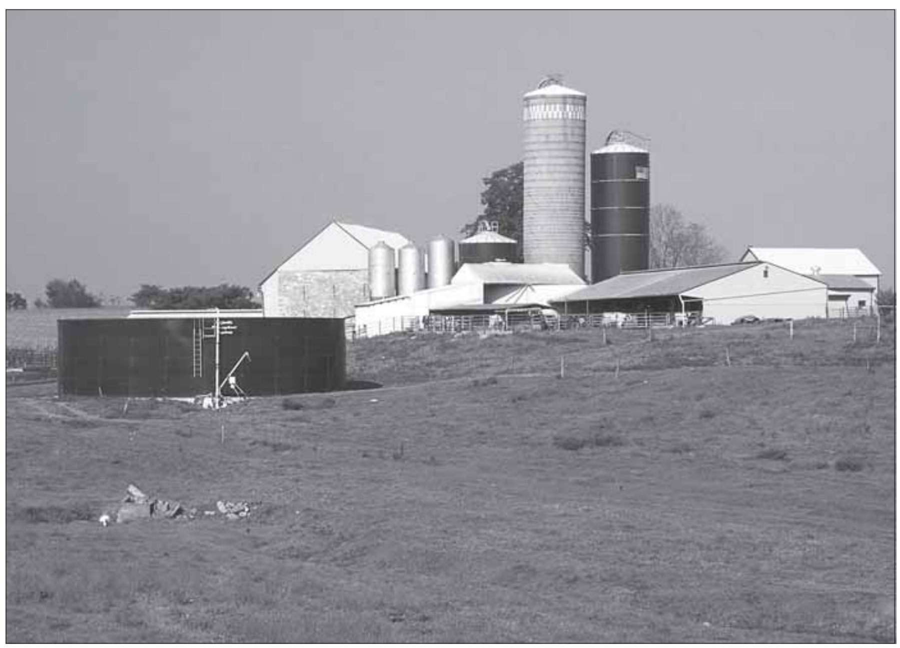

Figure 34-19. This manure storage tank is part of a conservation plan for a dairy farm. Photo courtesy of USDA NRCS.

A program should be established to facilitate movement of manure from surplus to deficit areas.

potential for environmental problems to occur. Also, because the solid fraction is more concentrated, it is more feasible to transport it to remote fields or it can serve as an input for other related biosolid products (Figure 34-21).

Currently, manure is rarely transported more than 10 miles from where it is produced. A program should be established to facilitate movement of manure from surplus to deficit areas. However, mandatory transport of manure from farms with surplus nutrients to neighboring farms where nutrients are needed faces several significant obstacles. First, it must be shown that manure-rich

Figure 34-20. State-of-the-art lagoon manure management system for a hog farm. The facility is completely automated and temperature controlled.
Photo courtesy of USDA NRCS.

Figure 34-21. Poultry litter can be transported from a farm with surplus nutrients and land applied on another farm in lieu of mineral fertilizer.
Photo courtesy of USDA NRCS.

farms are unsuitable for manure application, based on soil properties, crop nutrient requirements, hydrology, actual P movement, and sensitive water bodies. Conversely, it must be shown that the recipient farms are more suitable for manure application. The greatest success with re-distribution of manure nutrients is likely to occur when the general goals of nutrient management set by a national (or state) government are supported by consumers, local governments, farm communities, and the animal industry.

Phosphorus loss via surface runoff and erosion may be reduced by conservation tillage and crop residue management, buffer strips, riparian zones, terracing, contour tillage, cover crops, and impoundments...

Some farmers are already using innovative methods to transport manure. In some states, extension and local trade organizations have established “manure bank” networks that put manure-surplus producers in contact with manure-deficit farmers. To prevent the spread of diseases, however, the biosecurity of any proposed manure transportation network must be ensured.

Composting, another potential tool, may also be considered as a management tool to improve manure distribution (Figure 34-22). Although composting tends to increase the P concentration of manure, the volume is reduced, and thus, transportation costs are reduced.

There is interest in using some manure as sources of “bioenergy.” For example, dried poultry litter can be burned directly or converted by pyrolytic methods into oils suitable for the generation of electric power. Liquid manure can be digested anaerobically to produce methane that can be used for heat and energy.

Transport management

Transport management refers to efforts to control P movement from soils to sensitive locations, such as bodies of fresh water. Phosphorus loss via surface runoff and erosion may be reduced by conservation tillage and crop residue management, buffer strips, riparian zones, terracing, contour tillage, cover crops and impoundments (for example, settling basins). Basically, these practices reduce rainfall impact on the soil surface, reduce runoff volume and velocity, and increase soil resistance to erosion (Figure 34-23). However, none of these measures should be relied on as the sole or primary practice to reduce P losses in agricultural runoff. Conversion from furrow irrigation to sprinkler to drip irrigation significantly reduces irrigation erosion and runoff. Furrow treatments such as straw mulching and use of polyacrylamides will also reduce in-furrow soil movement. Transport management techniques include

- Conservation tillage.
- Cover crops.

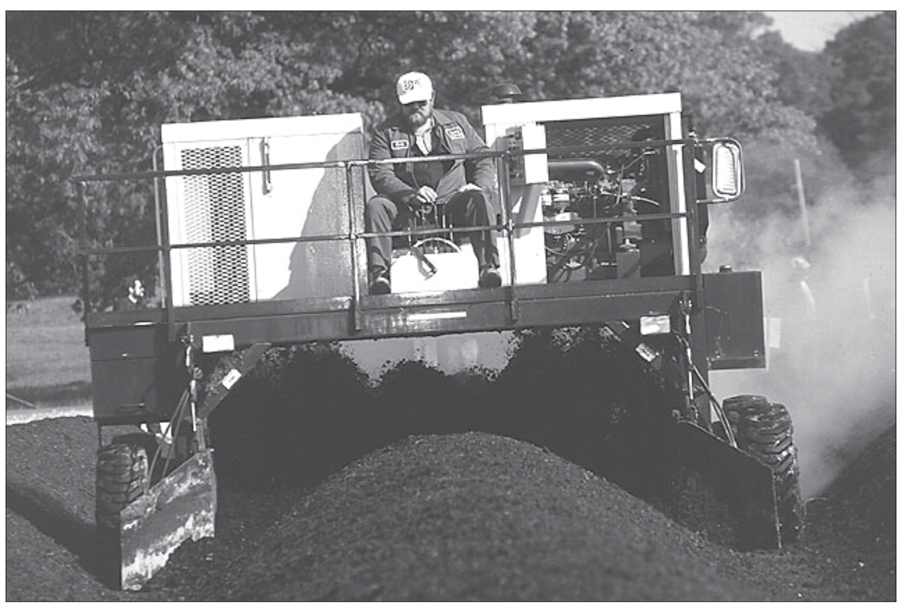

Figure 34-22. A compost site operator turns the windrows to replenish oxygen and mix the organic material for efficient composting.

Photo courtesy of USDA NRCS.

- Grassed waterways.
- Conservation buffers.
- Barnyard runoff management.
- Streambank protection.
- Constructed wetlands and sediment basins.

Conservation tillage practices are designed to reduce runoff and erosion and associated P losses. However, if manure is surface applied to maintain no-till residue compliances, the potential for P loss, particularly in the dissolved form, can be greater than for conventional tillage (Figure 34-24). Thus, the subsurface application of manure by injection, for example, should be considered as part of conservation tillage, particularly no-till, in order to minimize runoff P losses (Figure 34-25).

Cover crops serve to protect the soil surface from raindrop impact, improve infiltration relative to bare soil, and trap eroded particles. In areas where dissolved P transport is the primary concern, cover crops may reduce runoff, and consequently, runoff P load (mass) but are unlikely to impact dissolved P in runoff.

Grassed waterways are designed to trap sediment and reduce channel erosion (Figure 34-26). In some cases, they may be constructed as cross-slope diversions installed to intercept runoff and break up effective slope length. Riparian areas or buffers can reduce erosion and P losses as well as increase wildlife diversity, numbers, and aquatic habitat (Figure 34-27). In addition to acting as physical buffers to sediment-bound nutrients, plant uptake captures P, resulting in a short-term and long-term accumulation of nutrients in biomass. However, the effectiveness of conservation buffer areas as nutrient buffers can vary significantly. For example, the route and depth of subsurface water flow paths though riparian areas can influence nutrient retention. Conservation buffers are most efficient when sheet flow occurs, rather than channelized flow, which often bypasses some of the

Figure 34-23. Controlling erosion is probably still the number one way of minimizing the potential for P loss in runoff.

Photo courtesy of USDA NRCS.

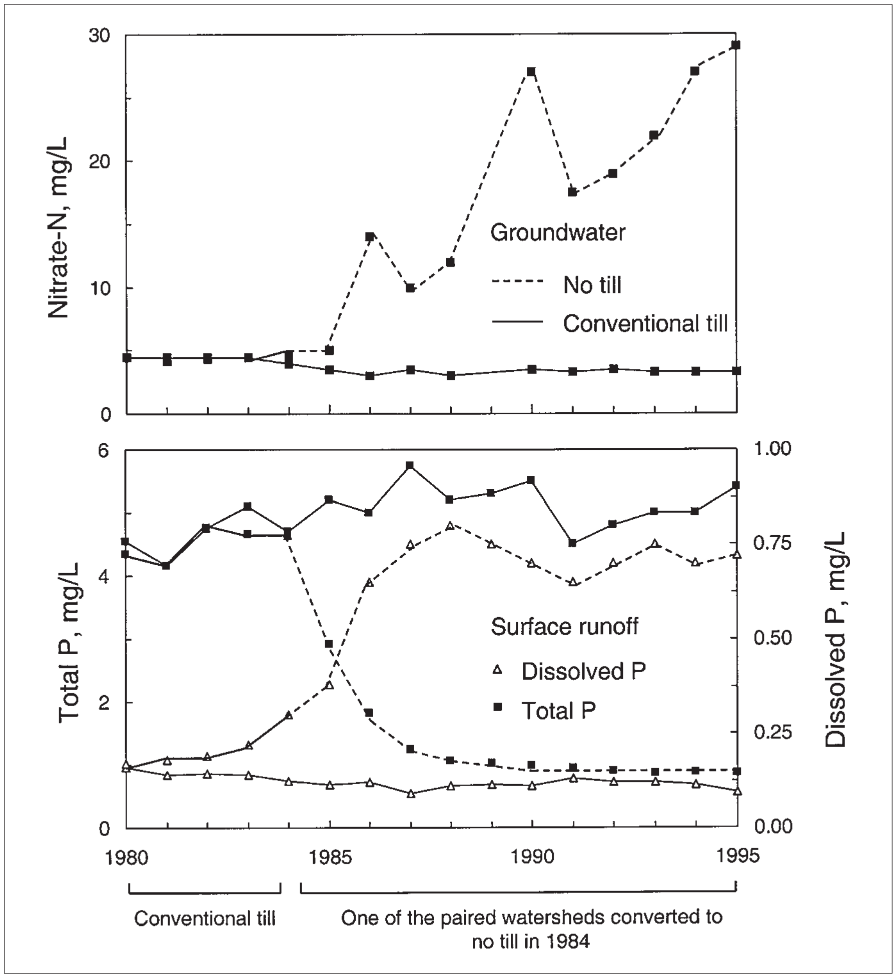

Figure 34-24. Mean annual nitrate-N concentration of groundwater and dissolved and total P concentration of runoff as a function of tillage management of watersheds in Oklahoma.
Adapted from Sharpley and Smith 1994.

retention mechanisms. Thus, these areas must be carefully managed to realize their full retention and filtration capabilities.

A fairly inexpensive transport BMP associated with feedlots or animal loafing areas is the installation of gutter and downspouts on barns and sheds. This BMP is a simple way to divert clean rain water away from these areas and also reduce runoff volumes from the area. Similarly, a berm, constructed around the upslope side of the feedlots or loafing areas, can divert clean water and minimize the potential for P runoff and erosion.

Streambank protection and fencing (for animal exclusion) is another simple BMP that can reduce erosional inputs of P and direct deposition of manure in streams, respectively (Figures 34-28 and -29). However, streambank protection and fencing has not been a popular practice with many farmers, and thus, not widely implemented due to high costs, maintenance needs, and removal of a cheap, readily available drinking water source for animals.

Constructed wetlands and sediment basins both serve to reduce particulate P by intercepting sediment-laden flow and certain wetland plant species (for example, *Phragmites spp.*), substantially improving nutrient removal efficiency (Figures 34-30 and -31).

Figure 34-25. Subsurface injection of manure can decrease losses in runoff and the concentration of P at the soil surface.
Photo courtesy of USDA-ARS.

Figure 34-26. Grassed waterways prevent erosion on cultivated fields.
Photo courtesy of USDA NRCS.

Despite these advantages, any one of these measures should not be relied upon as the sole or primary means of reducing P losses in agricultural runoff. These practices are generally more efficient at reducing sediment P than dissolved P. Also, P stored in stream and lake sediments can provide a long-term source of P in waters even after inputs from agriculture have been reduced.

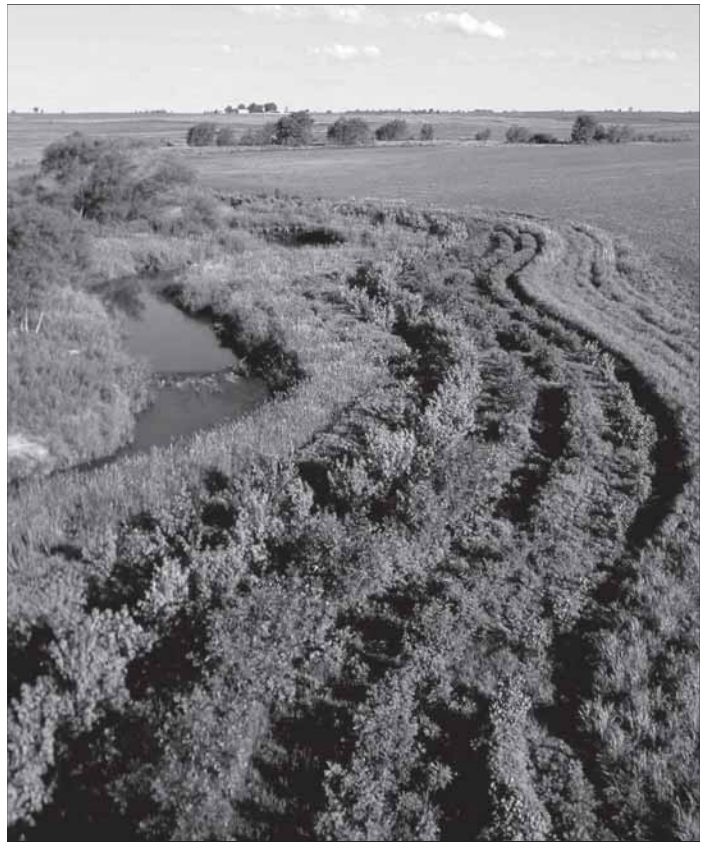

Figure 34-27. A riparian buffer of trees and shrubs along a creek creates shade that lowers the water temperature, improving aquatic habitat. Conservation riparian areas must be carefully managed to ensure that they effectively filter P from runoff. Photo courtesy of USDA NRCS.

Figure 34-28. Cattle crossing on a stream. The crossing keeps the cattle out of the stream except at the time of crossing.
Photo courtesy of USDA NRCS.

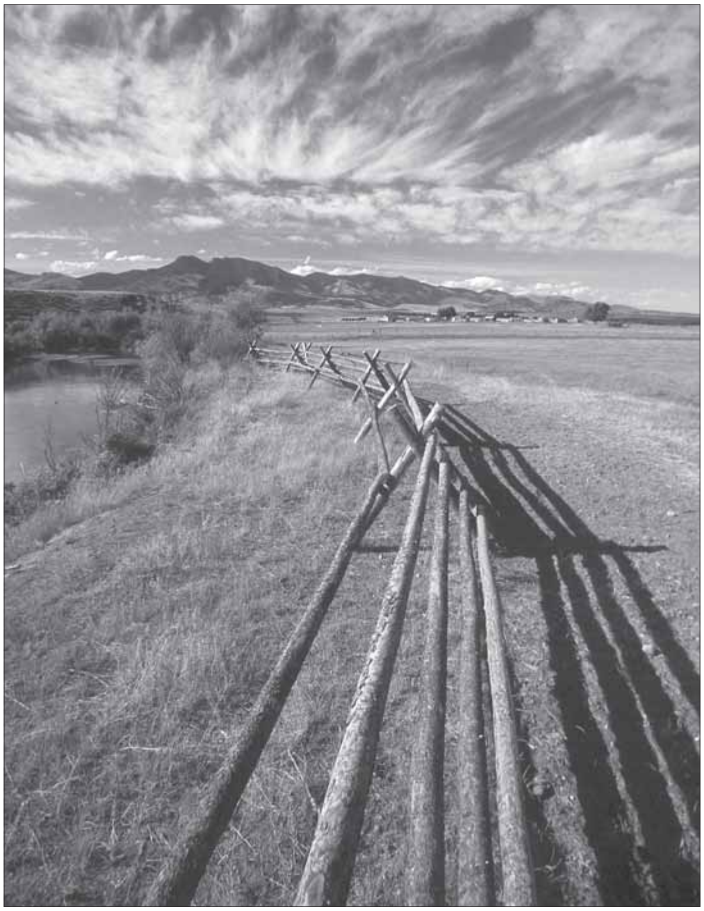

Figure 34-29. Riparian exclusion.
Photo courtesy of USDA NRCS.

Figure 34-30. Restored wetlands can be used to trap P in runoff from cornfields.
Photo courtesy of USDA NRCS.

Figure 34-31. A small dam, terraces, buffer strips, and grass plantings are designed to improve the quality of water entering a lake.
Photo courtesy of USDA NRCS.

Thus, the effect of remedial measures on the contributing watershed will be slow for many cases of poor water quality. Therefore, immediate action may be needed to reduce future problems.

Integrated Nutrient Management

Farm N inputs can usually be more easily balanced with plant uptake than can P inputs, particularly where CAFOs exist. In the past, separate strategies for either N or P have been developed and implemented at farm or watershed scales. Because of different critical sources, pathways, and sinks controlling N and P export from watershed, remedial efforts directed to either N or P can negatively impact the other nutrient. For example, basing manure application on crop N requirements, thus minimizing nitrate leaching to groundwater, can increase soil P and enhance potential surface runoff losses. In contrast, reducing surface runoff losses of P via conservation tillage can enhance N leaching.

These positive and negative impacts of conservation practice on resulting water quality should be considered in the development of sound remedial measures. Clearly, a technically sound framework must be developed that recognizes critical sources of N and P export from agricultural watersheds so optimal strategies can be implemented at farm and watersheds scales to best manage both N and P. An example of this principle can be seen in Figure 34-15d.

...critical sources of N and P export from agricultural watersheds [must be recognized] so optimal strategies can be implemented ... to best manage both N and P.

Summary

The overall goal of efforts to reduce P losses from agriculture should be to balance off-farm P inputs in feed and fertilizer with outputs in products while managing soils in ways that maintain productivity. Source and transport control strategies can provide the basis to increase P use efficiency in agricultural systems.

...all fields do not contribute equally to P export from watersheds.