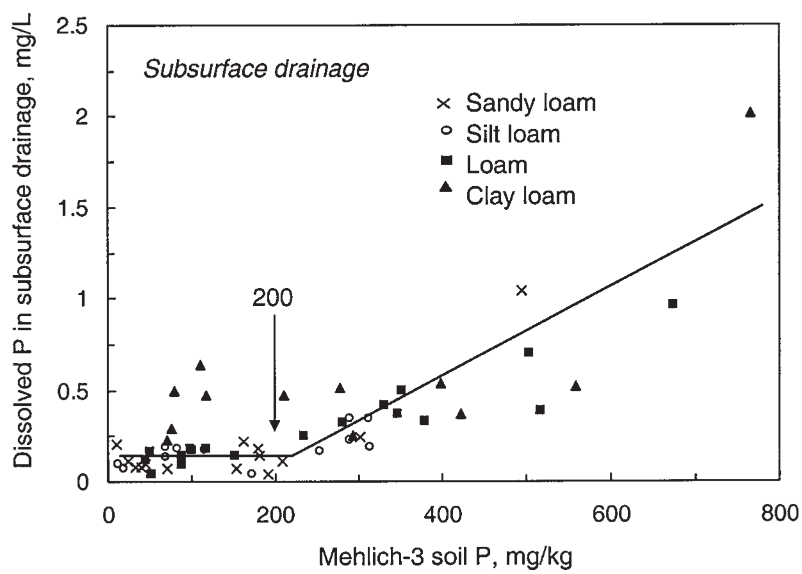

Figure 34-13. Relationship between the concentration of dissolved P in subsurface drainage from 30 cm deep lysimeters and the Mehlich-3 extractable soil P concentration of surface soil (0-2 inch depth) from a central PA watershed.

manure or fertilizer P applications. For example, lake water concentrations of P above 0.02 mg/L generally accelerate eutrophication. These values are an order of magnitude lower than P concentrations in soil solution critical for plant growth (0.2-0.3 mg/L), emphasizing the disparity between critical lake and soil P concentrations. Consequently, this complicates strategies to change farm management, because the loss is too small to show up in most standard practical or economic indicators of crop production efficiency used in farm management.

Environmental Risk Assessment and P Management

The USDA and EPA have developed a Unified Strategy for AFOs to address water quality concerns related to nutrient management (USDA and U.S. EPA 1999). An important part of this strategy is that it spells out how acceptable manure application rates will be determined in these plans. Both N and P must be considered in plans developed under this strategy. The strategy outlines three options for determining appropriate P-based nutrient management plans: agronomic soil test P, environmental soil P thresholds, and P indexing of site vulnerability.

Agronomic soil test P

In this option, manure application rates are based on the recommendations for optimum production of the crop. In other words, if the soil test called for a P addition to grow the crop, manure could be applied only to supply the recommended P. If the soil P test did not recommend any P addition, little or no manure could be applied.

There are several problems with this approach. The most important is that the agronomic soil test sampling, extraction, and interpretations were developed strictly from crop response. In the process of developing the soil test program, no environmental P loss potentials were measured. Therefore, there is no scientific basis for assuming that an agronomic soil test based on crop response will be correlated with environmental impact. Also, this option only measures the plant-available P in the soil that could become an environmental problem. It does not include the probability that this P source will be transported to water and thus have an environmental impact.

Sampling depths can also be problematic. For routine soil fertility evaluation and recommendations, it is generally recommended that soil samples be collected to "plow depth," or the zone of greatest root concentration, which is usually 6 to 8 inches deep. When soil testing is used to estimate soil P loss, however, it is the surface inch or two that comes into direct contact with runoff that is important. One exception is the need to consider the amount of subsoil P in soils with high water tables where shallow lateral flow may be a concern.

...there is no scientific basis for assuming that an agronomic soil test based on crop response will be correlated with environmental impact.

Environmental soil P threshold

Environmental concern has forced many states to consider the development of recommendations for P applications and watershed management based on the potential for P loss in agricultural runoff. A major difficulty is the identification of a threshold soil test P level to estimate when soil P becomes high enough to result in unacceptable P enrichment of agricultural runoff. Table 34-5 gives examples from several states, along with agronomic threshold concentrations for comparison. Environmental threshold levels range from the same as (Maine, Idaho) to almost 5 (Texas) times agronomic thresholds. Determining these thresholds is currently a very contentious and active research area.

The USDA-Agricultural Research Service (ARS) is coordinating a National Phosphorus Research Project in cooperation with EPA, NRCS, and universities to provide a sound scientific basis for establishing threshold soil P levels in areas where accelerated P enrichment of water is known to exist and to define critical sources of P exported from watersheds to better target cost-beneficial remediation (Sharpley et al. 2002). Presently, the project encompasses field-based research to be conducted at over 20 ARS and university locations across the United States. The results of this research will provide defensible nutrient management planning recommendations for utilizing manure and protecting water quality at a watershed scale.

The difference between these first two options is illustrated in Figure 34-14. The critical level for crop response is the point on the dashed line in Figure 34-14 where the yield no longer increases as soil P test levels increase. The environmental critical level (threshold P) is the soil test P level on the solid line where the potential environmental impact becomes unacceptably large. Even if the same soil test extractant is used, it cannot be assumed that there is a direct relationship between the soil test calibration for crop response to P and runoff enrichment potential. What will be crucial in terms of managing P based in part on soil test levels will be the interval between the threshold soil P value for crop yield and runoff P (Figure 34-14). The critical soil test level for P loss may be above or even below the critical level for crop yield.

We do know, however, that threshold soil P levels are too limited to be the sole criterion guiding P management and P applications. For example, adjacent fields having similar soil test P levels but differing susceptibilities

...threshold soil P levels are too limited to be the sole criterion guiding P management and P applications.

Table 34-5. Threshold soil test P values and P management recommendations.

State	Threshold Values , ppm		Soil test P Method	Management Recommendations for Water Quality Protection
	Agronomic[1]	Environmental		
Arkansas	50	150	Mehlich-3	**Above 150 ppm soil P:** Apply no more P, provide buffers next to streams, overseed pastures with legumes to aid P removal, and provide constant soil cover to minimize erosion.
Delaware	50	150	Mehlich-1	**Above 150 ppm soil P:** Develop P-based nutrient management plan (for example, P addition not to exceed crop removal) or use P Index.
Idaho	40	40	Olsen	**Above 40 ppm soil P:** Apply no more P until soil test is < 40 ppm and minimize transport potential.
Kansas	50	200	Bray-1	**Above 200 ppm soil P:** No further P additions.
Maine	20	20	Morgan	**Above 20 ppm soil P:** *Row crops:* Added P not to exceed crop removal in highly erodible soils or soils in P sensitive watershed. *Sod crop:* Added P not to exceed crop removal if soil test P is > 5 times crop removal.
Maryland	25	75	Mehlich-1	**Above 75 ppm soil P:** Use P index. Soils with high index must reduce or eliminate P additions.
Michigan	40	75 and 100	Bray-1	**75 – 150 ppm soil P:** Added P not to exceed crop removal. **Above 150 ppm soil P:** Apply no P until soil test P is < 150 ppm.
Mississippi	40	70	Lancaster	**Above 70 ppm soil P:** No P added
Ohio	40	150	Bray-1	**Above 150 ppm soil P:** Apply no P until soil test P is < 150 ppm.
Oklahoma	30	130 and 200	Mehlich-3	**Non-nutrient limited watershed 130– 200 ppm soil P:** Halve P rate and adopt measures to decrease runoff and erosion. **> 200 ppm soil P** –Added P not to exceed crop removal. **Non-nutrient limited watershed 60-130 ppm soil P:** Halve P rate. **> 130 ppm soil P** – add no P. **Slope – 8%-15%** half P rate: **> 15%** no P.
Pennsylvania	50	200	Mehlich-3	**Above 200 ppm soil P and < 150 ft from stream:** Use P Index.
Texas	44	200	Texas A&M	**Above 200 ppm soil P:** Added P not to exceed crop removal.
Wisconsin	30	50 and 100	Bray-1	**50-100 ppm soil P:** Added P not to exceed crop removal. **Above 150 ppm soil P:** Added P must be < crop removal or use P Index to deter mine if P additions are restricted.

[1]Agronomic threshold concentrations are average values for non -vegetable crops; actual values vary with soil and crop type. Also, vegetables have higher agronomic P requirements.
Adapted from Sharpley et al. 2001.

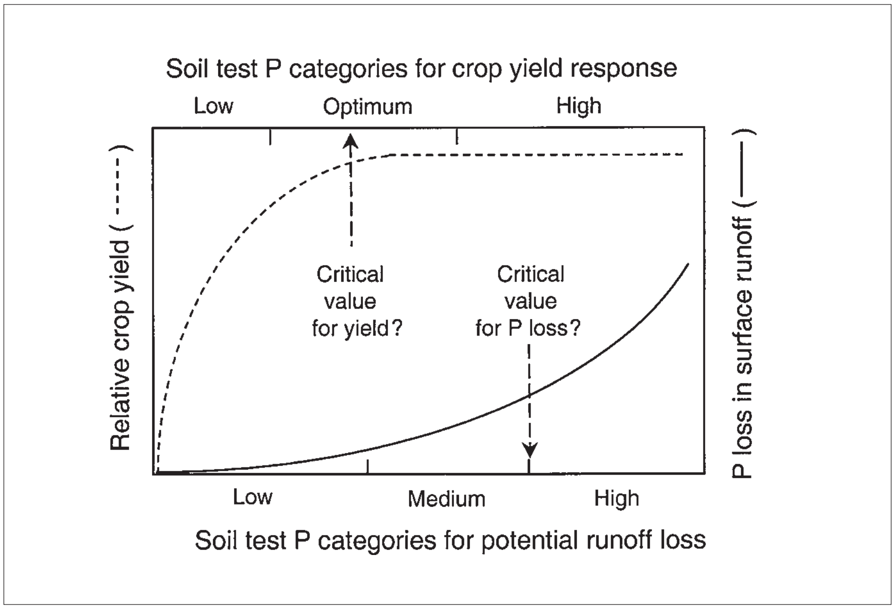

Figure 34-14. As soil P increases, so does crop yield and the potential for P loss in surface runoff. The interval between the critical soil P value for yield and runoff P is important for P management.

to surface runoff and erosion, due to contrasting topography and management, should not have similar restrictions on P use and management. Also, it has been shown that in some agricultural watersheds, 90% of annual algal-available P export from watersheds comes from only 10% of the land area during a few relatively large storms. For example, more than 75% of the annual water discharge from watersheds in Ohio (Edwards and Owens 1991) and Oklahoma (Smith et al. 1991) occurred during one or two severe storms events. These events contributed over 90% of annual total P export (0.2 and 5.6 lb/acre/yr, respectively). Therefore, threshold soil P values will have little meaning unless they are used in conjunction with an estimate of a site's potential for surface runoff and erosion.

The P Index: A risk site assessment tool

To be effective, risk assessment must consider "critical source areas" within a watershed that are most vulnerable to P loss in surface runoff. Critical source areas are dependent on the coincidence of "transport" (surface runoff, erosion, and subsurface flow) and "source" (soil, fertilizer, manure) factors as influenced by site management (Table 34-4, Figure 34-15). Transport factors mobilize P sources, creating pathways of P loss from a field or watershed. Source and site management factors are typically well defined and reflect land use patterns related to soil P status, mineral fertilizer and manure P inputs, and tillage (Table 34-4).

Preventing P loss is now taking on the added dimension of defining risk, then targeting and remediating source areas of P where the risk of P loss is potentially greatest. This approach addresses P management at multi-field or watershed scales and is done using a P Index. In cooperation with several research scientists, USDA-NRCS developed a simple index as a screening tool for use by field staffs, watershed planners, and farmers to rank a field's likelihood of being a source of P loss in surface runoff (Gburek et al. 2000, Lemunyon and Gilbert 1993).

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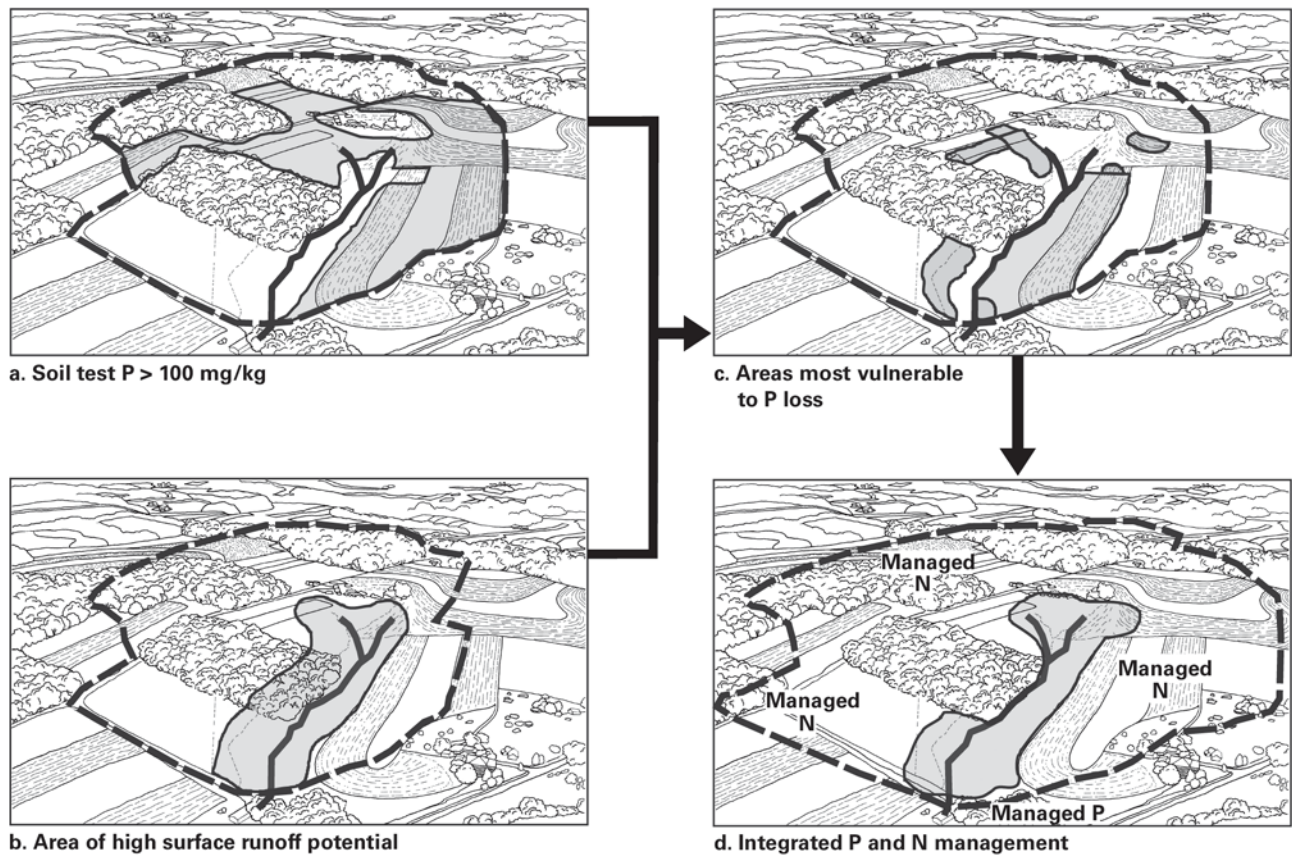

Figure 34-15. The principle of source-area management to more effectively reduce P export in surface runoff from watersheds.

The index accounts for and ranks transport and site management factors controlling P loss in runoff and sites where the risk of P movement is expected to be higher than that of others (Tables 34A-1 and -2, Appendix A). These factors have been chosen because they determine P loss in most cases (Table 34-2). Generally, source management factors include soil test P and applied P source, rate, method, and timing, and transport factors include erosion, surface runoff, subsurface P loss, and distance to receiving water body. While these represent the general categories of parameters, many indices have been selected to include specialized parameters and categories that appropriately represent their unique regional conditions or areas of environmental concern.

The most recent developments of this indexing procedure have been incorporated into the Pennsylvania P Index, which is used as the example for this lesson (Weld et al. 2003). Included as an initial step in the Pennsylvania P Index is a “screening tool” (Table 34A-1, Appendix A). If a field has an STP greater than 200 ppm Mehlich-3 P and is 150 feet or closer to a stream or water body, then a more comprehensive evaluation of the field using the “full” P Index (Tables 34A-2, -3, -4, -5, and -6; Appendix A) is required. The corollary is that if a field has a soil test P less than 200 ppm and is located more than 150 feet from a stream, the full P Index does not need to be run.

In this last situation, the field is assumed to be of a lower risk to contribute P. Thus, time and effort expended in calculating P Index ratings can be directed to those fields that are more likely to be at risk of P loss.

Transport potential for each site is calculated by first summing erosion, surface runoff, leaching potential, and connectivity values (Table 34A-3, Appendix A). To determine a relative transport potential (Table 34A-3, Appendix A), the summed value is then divided by 24, the value corresponding to "high" transport potential (erosion is 6, surface runoff is 8, subsurface drainage is 2, leaching potential is 0, and connectivity is 8). This normalization process assumes that when a site's full transport potential is realized, 100% transport potential is realized. Thus, transport factors < 1 represent a fraction of the maximum potential (Table 34A-3, Appendix A). However, because erosion is open-ended, it is possible to have a transport factor > 1 at high erosion rates.

In the Pennsylvania P Index, site management factors of the P Index, soil test P, fertilizer and manure rate, method, and timing of application (Table 34A-4 and 5, Appendix A) do not all have the same quantitative effect on P loss. In the original P Index, this was addressed with different weighting factors. In the Pennsylvania P Index, a coefficient of 0.2 is used to convert soil test to a value that directly relates to P in manure and mineral fertilizers. This conversion is based on field data that show a fivefold greater concentration of dissolved P in surface runoff with an increase in mineral fertilizer or manure addition compared to an equivalent increase in Mehlich-3 soil test P.

A final P Index value, representing cumulative site vulnerability to P loss, is obtained by multiplying the summed transport and source factors (Table 34A-6, Appendix A). Pennsylvania P Index values are normalized so that the break between "high" and "very high" categories is 100, representing an initiative by Northeastern and Mid-Atlantic states to ensure that P Index output is consistent across state boundaries. Normalization is done by calculating the site P Index value in which all transport and source factors are assumed to be "high." In the Pennsylvania P Index, erosion is set at 6 ton/acre and STP is set at 200 ppm Mehlich-3 P. Breaks between "medium" and "high" and between "low" and "medium" are calculated using the same method, with STP set at 50 and 30 ppm Mehlich-3 P, respectively. These Mehlich-3 P levels correspond to crop response and fertilizer recommendations for Pennsylvania, where > 50 ppm is sufficient for production and no P addition is recommended, 30 to 50 ppm where no crop response is expected but maintenance P is recommended, and < 30 ppm is low and will respond to added P.

The P Index is a tool that helps farmers, consultants, extension agents, and animal producers identify and rank (1) agricultural areas or practices at greatest risk of P loss and (2) management options that give land users flexibility in developing remedial strategies. Determination of the P Index for soils adjacent to sensitive waters is the first step to prioritize the efforts needed to reduce P losses. Then management options appropriate for soils with different P Index ratings can be implemented. Some general recommendations are given in Table 34-6; however, P management is very site specific and requires a well-planned, coordinated effort among farmers, extension agronomists, and soil conservation specialists.

The P Index... helps... identify and rank
(1) agricultural areas or practices at greatest risk of P loss and
(2) management options that give land users flexibility in developing remedial strategies.

Comparing P management strategies

The three options for developing a P-based nutrient management plan described earlier—agronomic soil test P, environmental soil P thresholds, and P indexing of site vulnerability—were evaluated and compared on a 40-ha

Table 34-6. Management options to minimize nonpoint source (NPS) pollution of surface waters by soil P based on the P Index ranking of site vulnerability to P loss.

Phosphorus Index	Management Options
Low	• **Soil testing:** Have soils tested for P at least every three years to monitor buildup or decline in soil P. • **Soil conservation:** Follow good soil conservation practices. Consider effects of changes in tillage practices or land use on potential for increased P transport from site. • **Nutrient management:** Consider effects of any major changes in agricultural practices on P losses *before* implementing them. Examples include increasing the number of animal units on a farm or changing to crops with a high demand for fertilizer P.
Medium	• **Soil testing:** Have soils tested for P at least every three years to monitor buildup or decline in soil P. Conduct a more comprehensive soil-testing program in areas that have been identified by the P Index as being most sensitive to P loss by surface runoff, subsurface flow, and erosion. • **Soil conservation:** Implement practices to reduce P losses by surface runoff, subsurface flow, and erosion in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management). • **Nutrient management:** Any changes in agricultural practices may affect P loss; carefully consider the sensitivity of fields to P loss before implementing any activity that will increase soil P. Avoid broadcast applications of P fertilizers and apply manures only to fields with lower P index values.
High	• **Soil testing:** A comprehensive soil-testing program should be conducted on the entire farm to determine fields that are most suitable for further P additions. For use in the long-range planning of fields that have excessive P, develop estimates of the time required to deplete soil P to optimum levels. • **Soil conservation:** Implement practices to reduce P losses by surface runoff, subsurface flow, and erosion in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management). Consider using crops with high P removal capacities in fields with high P index values. • **Nutrient management:** In most situations, fertilizer P, other than a small amount used in starter fertilizers, will not be needed. Manure may be in excess on the farm and should only be applied to fields with lower P index values. A long-term P management plan should be considered.
Very High	• **Soil testing:** A comprehensive soil-testing program must be conducted on the entire farm to determine fields that are most suitable for further additions of P. • **Soil conservation:** Implement practices to reduce P losses by surface runoff, subsurface flow, and erosion in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management). Consider using crops with high P removal capacities in fields with high P index values. • **Nutrient management:** Fertilizer and manure P should not be applied for at least three years and perhaps longer. A comprehensive, long-term P management plan must be developed and implemented.

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.