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Guidance for Federal Land Management in the Chesapeake Bay Watershed

Chapter 2. Agriculture

Nonpoint Source Pollution
Office of Wetlands, Oceans, and Watersheds
U.S. Environmental Protection Agency

Chapter 2. Agriculture

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1 Purpose and Overview

1.1 Need for an Agricultural Chapter

1.1.1 Purpose

Approximately 87,000 farm operations and 8.5 million acres of cropland, or nearly a quarter of the watershed, in the Chesapeake Bay watershed provide food and fiber, as well as significant natural areas and aesthetic and environmental benefits. Farms in the Chesapeake Bay watershed are very diverse. They vary greatly in size and produce a wide variety of products. Today, according to the U.S. Department of Agriculture (USDA), more than 50 commodities are produced in this region. The area's primary crops include corn, soybeans, wheat, hay, pasture, vegetables, and fruits. The eastern part of the region is also home to a rapidly expanding nursery and greenhouse industry.

On federal lands in the Chesapeake Bay watershed, approximately 30,396 acres are managed for agricultural production. Specifically

- National Park Service: 14,669 acres
- USDA: 7,000 acres[1]
- Department of Defense: 5,588 acres
- Fish and Wildlife Service: 1,259 acres

The purpose of this document is to present an overview of the practices and information resources available for federal land managers and others to achieve water quality goals in the most cost-effective and potentially successful manner, with the overall objective of improving water quality, habitat, and the environmental and economic resources of the Chesapeake Bay and its tributaries.

This chapter provides a host of practices and actions that can be employed to reduce the loadings of nitrogen (N), phosphorus (P), and sediment from agricultural activities to local waters and the Chesapeake Bay. This chapter focuses on nutrient management on cropland and the prevention of soil erosion from cropland, and on nutrient management in the production

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[1] USDA manages a number of large facilities in the Chesapeake Bay watershed. The Beltsville Agricultural Research Center in Maryland is a leader in agricultural research and, at approximately 7,000 acres, serves as a laboratory for state-of-the-art conservation practices. The National Arboretum in Washington, DC, managed by USDA's Agricultural Research Service, sits on more than 440 acres and is intensively managed for horticultural purposes. USDA manages additional smaller sites around the watershed and provides technical assistance for agricultural practices on small acreages of federal lands managed by other agencies.

area of animal feeding operations (AFOs). It is important to note that planning and implementing successful conservation or control measures depends on site-specific considerations and information. Consequently, the practices and actions presented here are a general guide to inform development of a more detailed plan or approach tailored to a specific facility, activity, or location.

This chapter does not address the management of agricultural lands to protect and restore water quality by reducing impacts from pesticides and from irrigation; for information on those subjects, see the chapters devoted to those activities in the *National Management Measures for the Control of Nonpoint Pollution from Agriculture* (USEPA 2003). This chapter does not thoroughly cover losses of N to air, but it does provide some information on volatilization controls. Finally, while recognizing the need to create new markets and alternative manure uses, this chapter does not cover the emerging technologies and financial mechanisms that are being developed to address those needs.

1.1.2 Intended Audience

The primary audience for this document is land managers in federal agencies who are responsible for meeting water quality goals and implementing water quality programs on agricultural land. In addition, state and local agencies may use this guidance in developing Watershed Implementation Plans to meet water quality goals. Others who can benefit from the information in this document include conservation districts; the agricultural services community; farm owners, operators, and managers; local public officials responsible for land use and water quality decision making; environmental and community organizations; and the business community.

1.1.3 Water Quality Significance of Agricultural Runoff in the Chesapeake Bay Watershed

Agriculture is the single largest source of nutrients and sediments to the Chesapeake Bay, and according to the Chesapeake Bay model, it is responsible for approximately 43 percent of the N, approximately 45 percent of the P, and approximately 60 percent of the sediment loads. Much of that load is delivered from Pennsylvania (Susquehanna River), Virginia (Shenandoah and Potomac rivers), and the Delmarva Peninsula of Maryland, Delaware, and Virginia. Chemical fertilizer accounts for 17 percent of the N and 19 percent of the P load, and manure accounts for 19 percent of the N and 26 percent of the P load. Seven percent of the total nitrogen (TN) load comes from air deposition from livestock and soil emissions from agriculture.

Implementing agricultural management practices might not provide nutrient load reductions to the Chesapeake Bay as quickly as implementing actions by other sectors; however, reductions in agricultural loads are the most cost-effective means to restore the Bay over time. Excess N from cropland is transported to the Bay via groundwater with a lag time of years or decades, depending on the location in the watershed. Additionally, reductions in P loads from agricultural lands might not be seen immediately after implementing P-control practices because of current P saturation in cropland soils in areas with high animal densities. Protecting the Bay and its watershed is costly and will require a variety of cost-share and economic support measures as the next generation of tools and practices are expanded.

Historical Context of Agricultural Land in the Chesapeake Bay Watershed

Since European settlement, agriculture has played an important role in sustaining the people of the Chesapeake Bay watershed. In the 1650s, the land was first broadly cleared for timber and agriculture. The land was able to support the growing population and in the 1700s, as agriculture expanded, the first signs of environmental degradation were noted. By the 1750s, 20 to 30 percent of the forested areas were stripped for settlement, and the shipping ports began to fill with eroded sediment. By the 1800s, plows were used widely in agriculture, beginning the widespread use of tillage, preventing reforestation and encouraging soil erosion. In the first half of the 1800s, the Chesapeake and Delaware canal project encouraged even broader expansion of agriculture. Half of the forests were cleared for agriculture and settlement, wetlands were drained, and the first imported fertilizers (bird guano) were introduced from the Caribbean and from nitrate (NO_3) deposits on the northern Chilean coast.

Agriculture in the Chesapeake Bay Watershed Today

Immediately following World War II, chemical fertilizer use became widespread, and as suburban expansion began in the 1950s, wetlands continued to be drained and filled. In the 1980s, nutrient management efforts began to take hold in agriculture, and in the 1990s, Chesapeake Bay tributary strategies were put in place, setting goals for reductions of nutrient and sediment loadings to the Bay. Today, for assessment purposes, the Bay and its tidal tributaries are broken into 92 segments. The states have identified those segments as being impaired because they do not meet water quality standards, and a total maximum daily load (TMDL) will be prepared for each of the segments, collectively adding up to the Chesapeake TMDL. A TMDL is a calculation of the maximum amount of a pollutant that the Bay can receive and still safely meet water quality standards.

Approximately 25 percent of the land in the Chesapeake Bay watershed is used for agriculture. Some practices used to maximize crop yields can cause deterioration in the quality of the Bay and its watershed. Improperly applied fertilizers and pesticides can flow off the land and deliver excess N, P, and chemicals to the Bay. The nutrients and bacteria in animal manure, which is used for fertilizer, can seep into groundwater and run into waterways if managed improperly on site at an AFO or off-site on cropland or elsewhere. Poor tilling and irrigation practices can promote erosion and can lead to additional sediment loads being delivered to waterbodies. The outflow of the tile or the edge of drain creates a high potential for loss of streamside vegetation and sediment scouring (see Chapters 5 and 7). Those practices can be improved, enhanced, or modified as appropriate to reduce pollutant loads from agriculture throughout the Chesapeake Bay watershed. Also, an imbalance of nutrients in the Chesapeake Bay watershed must be addressed through agriculture.

1.1.4 Managing Agricultural Runoff to Reduce Nutrient and Sediment Loss

Recommended Water Pollution Control Strategy: Implement Next Generation of Tools and Actions

To reach the Bay goals, the Chesapeake Bay Executive Order calls for implementation of the *next generation* of tools and actions (Chesapeake Bay Program Office 2010). While nutrient management planning (NMP) has been a part of farm operations since the 1980s because of state program requirements, this document presents a description of the next generation of NMP based on state-of-the-art science and understanding of the farm landscape today. The NMPs will provide a strong link between production, nutrient management on the land, and water quality. The NMPs described in this document will enable producers to achieve their expected yields and reduce waste of the valuable, finite resources of nutrients and sediments, while reducing the losses of the nutrients and sediments to surface water that eventually enters the Chesapeake Bay.

Although agriculture is a key part of the solution to the Chesapeake Bay restoration given the magnitude of loads and the relative cost-effectiveness of practices, we must overcome significant barriers to reach broad-scale implementation in agriculture. While the draft Executive Order section 203 Federal Strategy notes that restoration of the Chesapeake Bay or its watershed is not expected for many years, restoration will require a renewed commitment and therefore actions taken throughout the agricultural landscape will need to become more strategic, coordinated, and goal-oriented to meet the Bay goals (Federal Leadership Committee 2009).

The most significant improvement in agricultural production needed to restore the Chesapeake Bay is to change how excess manure nutrients are handled. Therefore, the major focus of this chapter is on nutrient management, accompanied by practices and actions for AFO production areas as well as sediment and erosion control on cropland. The practices, taken together, can greatly reduce the introduction of nutrients to the Chesapeake Bay.

The most effective practices to reduce pollution inputs of nutrients to the Chesapeake Bay focus around controlling the rate, timing, method and form of nutrient application. This guidance presents the implementation measures component of NMPs that would maximize reductions by agriculture. The current practices in the Chesapeake Bay watershed being reported by states should be expanded. The Chesapeake Bay Program Office has compiled a great deal of information on the effectiveness of those practices, http://www.chesapeakebay.net/marylandbmp.aspx?menuitem=34449.

Achieving Multiple Benefits

The benefits and services provided by well-managed agriculture in the Chesapeake Bay watershed are numerous and include sustained crop yields; restored waterbodies for drinking water, recreational, and other beneficial uses; habitat benefits; a functioning ecosystem; reduced vulnerability to invasive species; and a continued healthy and productive agricultural economy in the Chesapeake Bay watershed. When effective land cover from agriculture occurs year-round, those systems can store carbon and minimize soil erosion that fills local waters and the Bay. A healthy agricultural network in the Bay watershed will provide for key connections across the landscape for animals and birds, as well as reduce the watershed's vulnerability to flooding and the effects of climate change.

Readers of this chapter should also see Chapters 4 and 5 regarding Forestry and Riparian Buffers. While this chapter focuses on source control and treatment options for cropland and animal production areas in agriculture, it is essential that a holistic restoration of the Chesapeake Bay watershed also achieve the benefits that can be reaped when all these systems are operating together to serve the watershed.

1.2 Overview of the Agriculture Chapter

This chapter provides recommendations in the form of implementation measures for the suite of practices that can be implemented on agricultural lands. While these recommendations are made from state-of-the-art literature, the chapter expands on the *National Management Measures to Control Nonpoint Pollution from Agriculture* (USEPA 2003).

Information on the effectiveness of practices included in this chapter is largely taken from literature published after 2000 to build on the earlier literature that was used in developing the *National Management Measures to Control Nonpoint Pollution from Agriculture* (USEPA 2003). For some practices, however, the literature search went back further in time. This includes, for example, drainage water management, a practice not addressed to a significant extent in EPA's 2003 guidance. The bulk of literature used in this chapter comes from professional journal publications (e.g., *Journal of Environmental Quality*), but information is also derived from government documents and resources (e.g., USDA conservation practice standards), books, Cooperative Extension publications, proceedings from professional meetings, and online publications by professional groups and industry. Most literature was found through keyword searches of sources such as the National Agricultural Library Catalog and specific professional journals. Literature specific to the Chesapeake Bay watershed states was given top priority, but relevant literature from across the United States and from other countries was included to provide as complete coverage as possible on each of the topics addressed in this chapter.

Practice cost data taken from the literature and other sources were converted to 2010 dollars using the conversion factors provided by the U.S. Inflation Calculator (2010). Exceptions are that cost data provided for fiscal year 2010 by states were not changed, and aggregate cost data expressed over a range of years were not converted to 2010 dollars. Unless specified, the year of publication was used as the initial year for conversion of dollars.

1.2.1 Management Practices and Management Practice Systems

To best plan and implement practices that will benefit water quality, producers should have in place a conservation plan. A conservation plan based on an evaluation of the soil, water, air, plant, and animal resources should present the practices, tools, and actions that will be used on the agricultural land to benefit water quality. This plan outlines the management practices to be implemented and maintained.

Management practices are implemented on agricultural lands for a variety of purposes, including protecting water resources, human health, terrestrial or aquatic wildlife habitat, and land from degradation by wind, salt, and toxic levels of metals. The primary focus of this guidance is on agricultural management practices that reduce the delivery of pollutants into water resources by reducing pollutant generation or by remediating or intercepting pollutants before they enter water resources. This guidance generally refers to the term management practice, and this encompasses all agricultural practices, including structural, cultural, and traditional management practices.

The Natural Resources Conservation Service (NRCS) maintains a continuously updated *National Handbook of Conservation Practices* (USDA-NRCS 2010d), which details nationally accepted management practices. Those practices are on the USDA-NRCS Web site at http://www.nrcs.usda.gov/technical/Standards/nhcp.html. Each state adopts and tailors those standards to meet state and local conditions and criteria, and the state-adopted standards could be more restrictive than the national criteria referenced in this guidance. In addition to the NRCS standards, many states use locally determined management practices that are not reflected in the NRCS handbook. Note that while a wide variety of practices are available, all require regular inspection and maintenance to ensure continued performance at expected levels. Readers interested in obtaining information on management practices used in their area should contact their local Soil and Water Conservation District or local USDA office. Two very helpful handbooks are *60 Ways Farmers Can Protect Surface Water* (Hirschi et al. 1997), and *50 Ways Farmers Can Protect their Ground Water* (Hirschi et al. 1993).

Management practices are used to control a pollutant type from specific land uses. For example, conservation tillage is used to control erosion from irrigated or non-irrigated cropland. Management practices can also provide secondary benefits by controlling other pollutants, depending on how the pollutants are generated or transported. For example, practices that reduce erosion and sediment delivery often reduce P losses because P is strongly adsorbed to silt and clay particles. Thus, conservation tillage reduces erosion and reduces transport of particulate P.

In some cases, a management practice can provide environmental benefits beyond those linked to water quality. For example, riparian buffers, which reduce P and sediment delivery to waterbodies, can also serve as habitat for many species of birds and plants where the design and width provide for this use.

Sometimes, however, management practices used to control one pollutant might inadvertently increase the generation, transport, or delivery of another pollutant; management practices should be implemented through a systems approach to ensure balance. Conservation tillage, because it creates increased soil porosity (i.e., large pore spaces), can increase water transport through the soil. Without crop growth and the associated root system that would take up available N, increased water transport through the soil can also lead to increased N leaching particularly where fertilizer N is applied not as part of the management plan that accounts for the timing and amount of crop N needs. Tile drains, used to reduce surface runoff and increase soil drainage, can also have the undesirable effect of concentrating and delivering N directly to streams (Hirschi et al. 1997). To reduce the N pollution caused by tile drains, other management practices, such as nutrient management for source reduction, cover crops and biofilters that treat the outflow of the tile drains, might be needed. On the other hand, practices that reduce runoff might contribute to reduced in-stream flows, which have the potential to adversely affect habitat. Therefore, management practices should be chosen only in the context of a holistic evaluation of both the benefits and potential adverse effects of the suite of practices, or management system, to be implemented at a site.

Some management practice systems include both repetitive treatment by the same practice at different places in a field as well as diversification of practices to enhance all the benefits of each. An example of such a system is an animal waste management system in which some components are included to help others function. For example, diversions and subsurface drains might be necessary to convey runoff and wastes to a waste treatment lagoon for treatment. While the diversions and subsurface drains might not provide any measurable pollution control of their own, they are essential to the overall performance of the animal waste management system. Other components, such as lagoons and waste utilization plans, are added to provide repetitive treatment.

Note on Practice Effectiveness: The effectiveness of any management practice is a function of a variety of factors including the characteristics of the baseline condition (e.g., influent water quality, soil nutrient levels, and current management practices), slope, soil type, climate, crops, and weather conditions during the study. Further, the monitoring and assessment approach used in a study imparts significant limitations to interpreting the findings. For example, inflow-outflow studies can be used to assess pollutant removal but only if the outflow and inflow measurements pertain to the same parcel of water. Load and concentration reductions have different meanings and utility, and it is particularly important to have full understanding of the comparison or benchmark against which the reduction is measured. This chapter's summary of literature findings on the effectiveness of agricultural management practices and systems must be interpreted carefully, and EPA strongly recommends that the reader review full reports before applying the findings to any specific situation, because the information presented represents general examples applicable to the site and situation studied and the effects of conservation tools and approaches applied depends on a number of variables site specific to the farm operation.

This chapter is divided into three sections regarding specific control options. Three types of practices are necessary in agricultural production to control nutrients and sediments; through these types of practices, the path of nutrients and sediment can be controlled. These three types avoid, control, and trap pollutants (ACT), and practices that suit each should be implemented in agricultural production.

- Section 2: Nutrient and sediment source control and avoidance from cropland and animal production areas
- Section 3: Cropland in-field controls
- Section 4: Cropland edge-of-field trapping and treatment

This guidance separately discusses source control and avoidance practices for the two critical topics of cropland agriculture and animal agriculture. However, the link between ensuring adequate storage and developing appropriate land application practices is one of the most critical considerations in successfully developing and implementing a site-specific nutrient management plan for manure, litter and process wastewater on animal agriculture operations that rely on cropland agriculture. Therefore, while the specific management practices are separately discussed in this guidance, it should be understood that those two aspects of agriculture are intricately linked and must be implemented through a systems approach to ensure a reduction in nutrient delivery to the Bay watershed.

Controlling the sources of nutrients and sediment entering the Chesapeake Bay through a variety of approaches at the field or production area, farm, and watershed scale will minimize the pollutants available throughout the agricultural operation. Source control and avoidance pertains to a crop's ability to use the nutrients available throughout the growing season, cropping cycles, feed management, manure management, and chemical fertilizer management. Source control approaches for cropland carefully evaluate the proper rate, timing, method, and form of nutrient application.

The cropland in-field controls focus on nutrient and sediment controls throughout the field itself. In-field practices will impede the transport or delivery (or both) of pollutants, either by reducing water transported, and thus the amount of the pollutant transported, or by transforming the pollutant into less harmful forms into the soil or atmosphere.

Wetlands, drainage water management, and buffers and setbacks are examples of important edge-of-field or end-of-pipe measures to prevent nutrient loads to the Chesapeake Bay.

This chapter presents a set of implementation measures that are organized by the pathway in which nutrient and sediment controls can be implemented. While the implementation measures are discussed independently from one other, they are intended to be implemented together as a comprehensive management system. The implementation measures are organized into the three components of source control and avoidance, in-field control, and edge-of-field trapping and treatment. The specific set of practices to be chosen by an agricultural producer to achieve pollutant reductions will necessarily be tailored as appropriate on the basis of a variety of factors related to the landscape, agricultural operation, and other similar factors; the practices chosen should link controls at the source, in the field, and at the edge of the field.

1.2.2 Implementation Measures for Agriculture in the Chesapeake Bay Watershed to Control Nonpoint Source Nutrient and Sediment Pollution

Source Control and Avoidance

Cropland Agriculture

Implementation Measures:

A-1. Base P application on P saturation in soils as follows:

- If the soil P saturation percentage is above 20 percent, do not apply manure or commercial fertilizer that contains P to cropland, grazing or pasture land.
- When soil P saturation percentage allows for application (i.e., is below 20 percent saturation), apply up to an N-based rate.
- Also, implement a soil P monitoring plan to ensure that soil-P levels are staying steady over time.
- If soil P saturation percentage is increasing, adjust manure applications to P-based rate and use commercial N fertilizer to make up the difference; if levels exceed 20 percent P saturation, no longer apply P.

A-2. Maximize N fertilizer use efficiency to maximize the net benefit from the lowest-needed amount of manure, biosolids, or commercial N fertilizer entering the cropland system. Whenever N fertilizer is applied where manure has already been applied, reduce N fertilizer rates according to the N credit of the manure that was applied. That N credit will vary depending on the amount, timing, type, and method of manure that was applied.

A-3. Replace high nutrient loading crops in high-risk areas for water quality effects with sound alternatives.

A-4. (1) Retire highly erodible lands (HELs) from cropland and replace the crop with perennial native vegetation, or (2) develop and implement a soil conservation plan to reduce sheet and rill erosion to the Soil Loss Tolerance Level (T) as well as a nutrient management plan.

A-5. When using commercial fertilizer, give credit for manure nutrients. When commercial fertilizer is used, provide for the proper storage, calibration, and operation of chemical fertilizer nutrient application equipment.

Animal Agriculture

Implementation Measures:

A-6. Formulate animal feeds to reduce nutrient concentration in manure, improve the manure N:P ratio in relation to crop needs, and/or eliminate toxic substances such as arsenic in manure used as fertilizer. Align the N:P ratio of the manure to be equal to (or greater than) the N:P ratio of the crop need.

A-7. Safely and strategically apply (with properly calibrated equipment), store, and transport manure.

- Liquid manure storage systems including tanks, ponds, and lagoons (e.g., NRCS Practice Code 313 Waste Storage Facility) should be designed and operated to safely store the entire quantity and contents of animal manure and wastewater generated, contaminated runoff from the facility, and the direct precipitation from events in the geographic area, including chronic rain.
- Dry manure (i.e., stackable, greater than or equal to 20 percent dry matter), such as that produced in poultry and certain cattle operations, should be stored in production buildings, storage facilities, or otherwise covered to prevent precipitation from coming into direct contact with the manure and to prevent the occurrence of contaminated runoff. When necessary, temporary field storage of dry manure (e.g., poultry litter) may be possible under protective guidelines (e.g., NRCS Practice Code 633 Waste Utilization).
- For manure and litter storage, the AFO should maintain sufficient storage capacity for minimum critical storage period consistent with planned utilization rates or utilization practices and schedule.

A-8. Exclude livestock from streams and streambanks and provide alternative watering facilities and stream crossings to reduce nutrient inputs, streambank erosion, and sediment inputs and to improve animal health.

A-9. Process/treat through physical, chemical, and biological processes facility wastewater and animal wastes to reduce as much as practicable the volume of manure and loss of nutrients.

Cropland In-Field Control

Implementation Measures:

A-10. Manage nutrient applications to cropland to minimize nutrients available for runoff. In doing so

- Apply manure and chemical fertilizer during the growing season only
- Do not apply any manure or fertilizer to saturated, snow-covered, or frozen ground
- Inject or otherwise incorporate manure or organic fertilizer to minimize the available dissolved P and volatilized N
- Apply nutrients to HELs only as directed by the nutrient management plan, while at the same time implementing all aspects of the soil conservation plan

A-11. Use soil amendments such as alum, gypsum, or water treatment residuals (WTR) to increase P adsorption capacity of soils, reduce desorption of water-soluble P, and decrease P concentration in runoff.

A-12. Use conservation tillage or continuous no-till on cropland to reduce soil erosion and sediment loads except on those lands that have no erosion or sediment loss.

A-13. Use the most suitable cover crops to scavenge excess nutrients and prevent erosion at the site on acres that have received any manure or chemical fertilizer application. Cover crops should be used during a non-growing season (including winters) or when there is bare soil in a field.

A-14. Minimize nutrient and soil loss from pasture land by maintaining uniform livestock distribution, keeping livestock away from riparian areas, and managing stocking rates and vegetation to prevent pollutant losses through erosion and runoff.

A-15. Where drainage is added to an agricultural field, design the system to minimize the discharge of N.

Cropland Edge-of-Field Trapping and Treatment

Implementation Measures:

A-16. Establish manure and chemical fertilizer application buffers or minimum setbacks from in-field ditches, intermittent streams, tributaries, surface waters, open tile line intake structures, sinkholes, agricultural well heads, or other conduits to surface waters.

A-17. Treat buffer or riparian soils with alum, WTR, gypsum, or other materials to adsorb P before field runoff enters receiving waters.

A-18. Restore wetlands and riparian areas from adverse effects. Maintain nonpoint source abatement function while protecting other existing functions of the wetlands and riparian areas such as vegetative composition and cover, hydrology of surface water and groundwater, geochemistry of the substrate, and species composition.

A-19. For both new and existing surface (ditch) and subsurface (pipe) drainage systems, use controlled drainage, ditch management, and bioreactors as necessary to minimize off-farm transport of nutrients.

A-20. Manage runoff from livestock production areas under grazing and pasture to minimize off-farm transport of nutrients and sediment.

2 Implementation Measures and Practices for Source Control and Avoidance

2.1 Cropland Agriculture

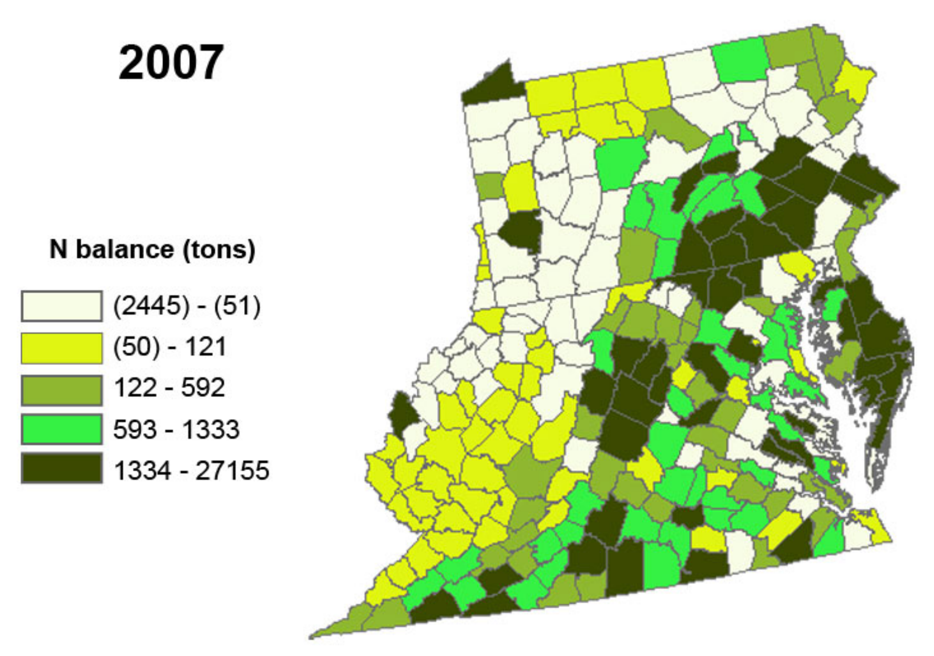
2.1.1 Nutrient Imbalance in the Chesapeake Bay Watershed

In the Chesapeake Bay watershed, the overall delivery of agriculture-based nutrients to the Bay needs to decrease significantly to protect the quality of the Chesapeake Bay. Unfortunately, a significant nutrient imbalance exists in the Bay watershed. More P is produced and imported into the watershed than is needed to fertilize crops, resulting in the imbalance and excess N and P available for delivery to the Bay through surface and ground waters. Nationwide, 1997 USDA estimates show that most U.S. counties (78 percent) need to move manure P from at least some animal operations to avoid P accumulation. Also, 1997 USDA estimates show that poultry operations account for two-thirds of N on farms and half of the excess P because generally, poultry litter has a high P-content, and poultry operations have less land than other operations for application. Dairy and hog operations also contribute to excess on-farm P. While manure as fertilizer does provide benefits to the soil in the form of amendments and carbon, the controlled use of manure is imperative to protecting water quality in the Bay watershed.

The Mid-Atlantic Water Program (MAWP), a consortium of land grant universities in the Chesapeake Bay watershed, developed nutrient budgets and balances by county and state for 2007 (MAWP 2007). Nutrient budgets are, “a summary of the major nutrient inputs and outputs to the cropland in a geographic region.” Nutrient balances are defined as “the difference between nutrient inputs and outputs.” When the nutrient balance is close to zero, nutrients applied from manure and commercial fertilizer are closely matched to crop use. When the nutrient balance is positive, nutrient inputs exceed outputs and excess nutrients are available that can reach the Bay. When the nutrient balance is negative, nutrient outputs exceed inputs.

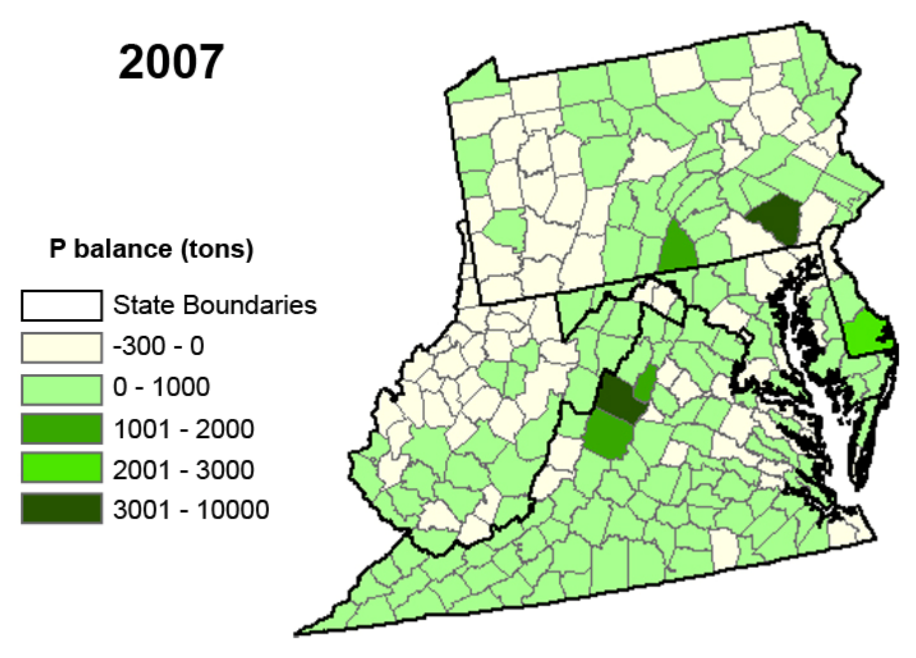
The MAWP also developed maps, in which nutrient input equals the amount of manure and fertilizer nutrient available for application, and nutrient output is determined by the amount of nutrient taken up by the crop, measured in the plant biomass harvested. The maps do not account for the level of nutrients that are already in the soil before application of additional nutrient inputs and also do not account for the N and P chemical fertilizers that are applied to crops annually; however, in places where there is a zero balance and it might seem that nutrients are being appropriately managed, high soil nutrients are available in those areas that could lead to nutrient loss to the Bay because P-saturation is not part of the consideration. The analysis identifies three such *hotspots* in the Chesapeake Bay watershed: the Shenandoah

River Valley in Virginia, the Eastern Shore of Maryland, and Lancaster County and surrounding areas in Pennsylvania (Figures 2-1 and 2-2).



Source: MAWP 2007, Note: The darkest color indicates counties with the highest N balances.

Figure 2-1. The map shows the N balance for cropland in mid-Atlantic counties in 2007.



Source: MAWP 2007, Note: The darkest color indicates counties with the highest P balances.

Figure 2-2. The map shows the P balance for cropland in mid-Atlantic counties in 2007.

Realistic production goals should guide nutrient rate reductions in agriculture and are critical for reducing N and P export from agricultural lands and moving toward a nutrient-balanced Chesapeake Bay watershed. The current model for nutrient use maximizes plant uptake by saturating nutrients through application, especially for N; this should be adjusted to account for non-optimum weather patterns. Because optimum weather conditions occur on average once every 5 to 7 years, an excess of N and P is in the fields in most years (those with non-optimum weather).

The following section details practices and actions that can minimize excess nutrients from entering the agricultural production system and achieve a nutrient balance.

2.1.2 Nutrient Management

The management tools and practices in widespread use in the Chesapeake Bay watershed for both organic (manure, sludge, and such) and inorganic (commercial fertilizer) nutrient application are insufficient to prevent over-application and the resulting nutrient loading to the Chesapeake Bay. However, NMP in line with those implementation measures, if broadly applied in the watershed, will significantly reduce nutrients available as runoff into local waters and the Chesapeake Bay. Controlling the rate of nutrient application is the first defense to limiting the amount of nutrients that might be able to leave the land throughout the production process.

The goals of NMP are to apply nutrients at rates necessary to achieve realistic crop yields, improve the timing of nutrient application, employ appropriate tools to determine application rate, method and form (manure or inorganic), and to reduce the risks of nutrients moving from the land and production area to local waters. When manure is the source of fertilizer, both the nutrient value and the rate of availability of the nutrients should be determined. With commercial fertilizer, that information is on the label. Where legume crops (e.g., soybeans) are planted, the N contribution of the crop should be determined and credited to the following crop.

NMP is implemented to increase the efficiency with which crops use applied nutrients, thereby reducing the amount available to be transported to both surface and ground waters. Controlling nutrient inputs (source) by practicing effective nutrient management is imperative, and reducing the nutrient inputs to the agricultural system will effectively minimize nutrient losses from cropland occurring at the edge-of-field by runoff and by leaching from the root zone. Once N, P, or other nutrients are applied to the soil, their movement is largely controlled by the movement of soil and water and must therefore be managed through other control systems such as erosion control and water management. That is usually achieved by developing a nutrient budget for the crop, applying nutrients at the proper time with proper methods, applying only the types and amounts of nutrients necessary to produce a crop, and considering the environmental hazards of the site. In cases where manure is used as a nutrient source, manure storage will be needed to provide capability to apply manure at optimal times. Even with proper nutrient management, rain can cause nutrients to move into waterways if the rain is heavy, frequent, or comes soon after nutrient applications. Therefore, nutrient management needs to be supplemented with in-field and edge-of-field controls.

In many instances, NMP results in using lower application rates of commercial fertilizer because of the availability of manure nutrients and, therefore, a reduction in production costs. However, the agriculture system in the watershed has a general imbalance of nutrients due to excess manure generated annually by the combination of all AFOs in the watershed. Thus, for any cropland where there has not been a balanced use of nutrients in the past, NMP should incorporate the options for source control presented in this section—the reduction of nutrients for input into the agricultural production system—to reduce the possibility of excess nutrients being applied out of need to reduce capacity of manure.

Nutrient management planning should consider all aspects of the rate, timing, method, and form of nutrients, consistently using the host of data available through effective use of nutrient use tools. Nutrient management plans typically focus on N and P, the nutrients of greatest concern for water quality, and it is important to consider all sources of those nutrients as input to the agricultural system. The major sources of nutrients include the following:

- Commercial fertilizers
- Manures, sludges, and other organic materials
- Crop residues and legumes in rotation
- Irrigation water
- Atmospheric deposition of N
- Soil reserves

Good and strategic NMP can significantly reduce costs. For example, when manure is used, the total cost of a nutrient management system are those costs associated with manure nutrient application, plus the disposal of alternative use cost for manure that cannot be applied within a reasonable local transport area, less the savings incurred by reduced commercial fertilizer. Maximizing the nutrient use efficiency (NUE), the measure of how much crop is produced per unit of nutrient supplied, should always be a part of NMP. A greater NUE of a crop leaves less N and P available for transport to waterbodies. NUE consists of two main components:

- Crop removal efficiency or the removal of nutrient in a harvested crop as a percent of nutrient applied to the crop (Mosier et al. 2004)
- The increase in residual nutrients available to the crop from the soil (Ladha et al. 2005)

Because N and P behave very differently, basic understanding of how N and P are cycled in the soil-crop system is an important foundation for effective nutrient management. The *National Management Measures to Control Nonpoint Pollution from Agriculture* (USEPA 2003) is an excellent source describing the technical details of each of the nutrient sources and cycles in agriculture. Figures 2-3 and 2-4 depict the N and P cycles, respectively.

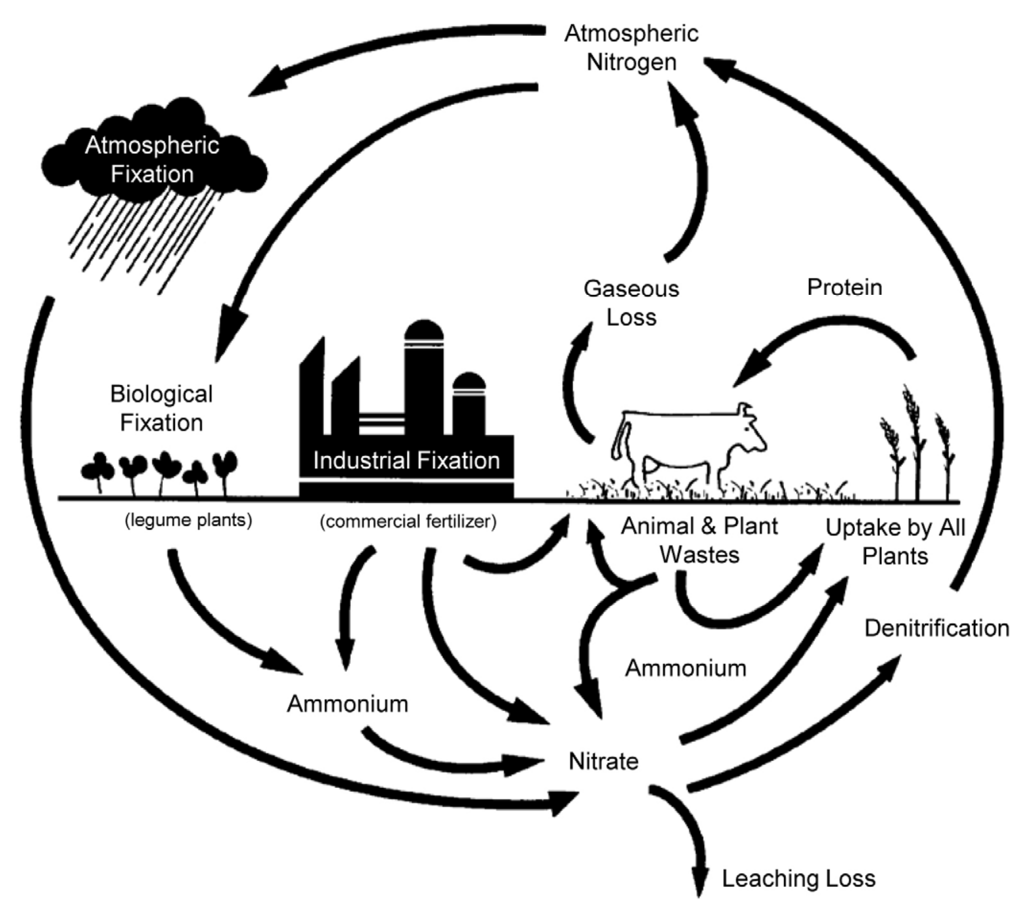


Figure 2-3. The N cycle.

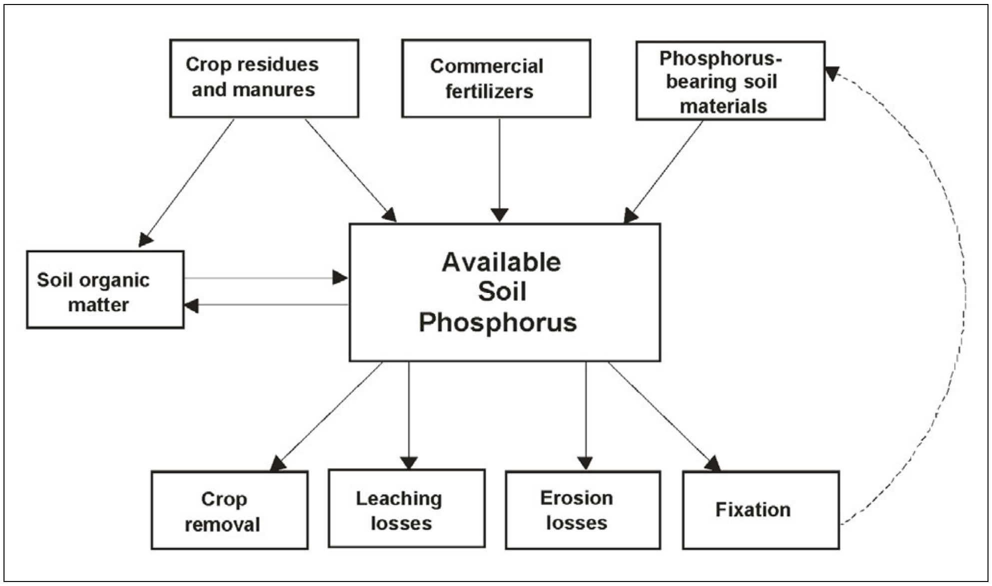


Figure 2-4. The P cycle.

N is continually cycled among plants, soil organisms, soil organic matter, water, and the atmosphere in a complex series of biochemical transformations. Some N forms are highly mobile, while others are not. At any time, most of the N in the soil is held in soil organic matter (decayed plant and animal tissue) and the soil humus. *Regeneration* processes slowly transform the N in soil organic matter by microbial decomposition to ammonium ions (NH_4+), releasing them into the soil where they can be strongly adsorbed and kept relatively immobile. Plants can use the ammonium, however, and it can be moved with sediment or suspended matter. *Nitrification* by soil microorganisms transforms ammonium ions (either mineralized from soil organic matter or added in fertilizer) to nitrite (NO_2-) and then quickly to nitrate (NO_3-), which is easily taken up by plant roots. NO_3, the form of N most often associated with water quality problems, is soluble and mobile in water. *Plant uptake* includes processes by which ammonium and NO_3 ions are converted to organic-N, through uptake by plants or microorganisms, and by binding with the soil. *Denitrification* converts NO_3 into nitrite (NO_2) and then to nitrous oxide (N_2O) and gaseous N through microbial action in an anaerobic environment. *Volatilization* is the loss of ammonia gas (NH_3) to the atmosphere.

An N atom can pass through the cycle many times in the same field. The processes in the N cycle can occur simultaneously and are controlled by soil organisms, temperature, and availability of oxygen and carbon in the soil. The balance among the processes determines how much N is available for plant growth and how much will be lost to groundwater, surface water, or the atmosphere.

P lacks an atmospheric connection (although it can be transported via airborne soil particles) and is much less subject to biological transformation, rendering the P cycle considerably simpler. Most of the P in soil occurs as a mixture of mineral and organic materials, and P exists largely in a single valence state, unlike N. A large amount of P (50–75 percent) is held in soil organic matter, which is slowly broken down by soil microorganisms. Some of the organic P is released into soil solution as phosphate that is immediately available to plants. The phosphate released by decomposition or added in fertilizers is strongly adsorbed to soil particles and is rapidly converted into forms that are unavailable to plants. The equilibrium level of dissolved P in the soil solution is controlled by the chemical environment of the soil (e.g., pH, oxidation-reduction, iron and aluminum concentration) and by the P content of the soil. Plant-available P is measured by varying methods, and this guidance references P measurements made with the following extractable solutions: Mehlich 1, Mehlich 3, Bray 1, and modified Morgan.

Throughout the Chesapeake Bay watershed, those cycling processes are constantly occurring throughout agricultural lands. To effectively plan, design, and implement controls, it is imperative to understand these basic nutrient cycles.

Practice Costs

An analysis of the more than $3.5 billion spent toward nutrient controls in the Chesapeake Bay watershed between 1985 and 1996 found that nutrient management (e.g., USDA-NRCS Conservation Practice Code 590) was the least costly practice for nutrient control (Butt and Brown 2000). The estimated average unit cost in fiscal year (FY) 2010 for development and record keeping for a comprehensive nutrient management plan in Virginia is $1,190 (USDA-NRCS 2010).

Phosphorus

Implementation Measure A-1:

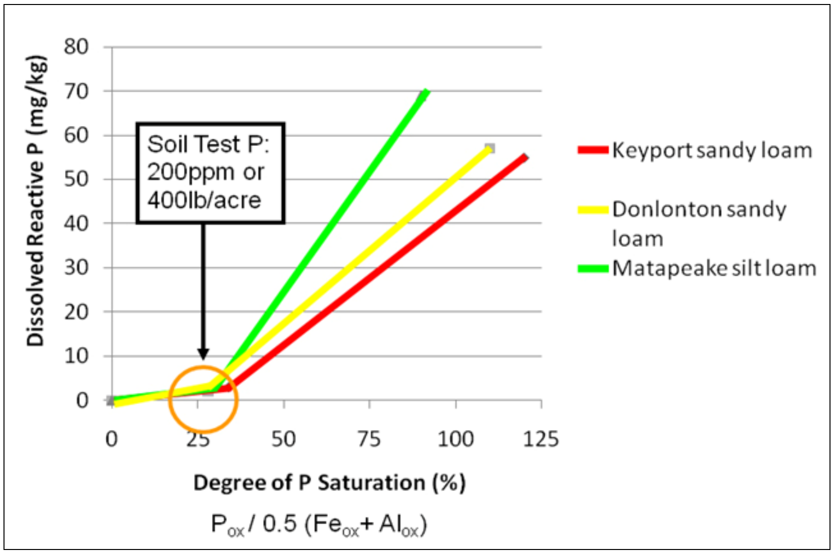
Base P application on P saturation in soils as follows:

- If the soil P saturation percentage is above 20 percent, do not apply manure or commercial fertilizer that contains P to cropland, grazing or pasture land.
- When soil P saturation percentage allows for application (i.e., is below 20 percent saturation), apply up to an N-based rate.
- Also, implement a soil P monitoring plan to ensure that soil-P levels are staying steady over time.
- If soil P saturation percentage is increasing, adjust manure applications to P-based rate and use commercial N fertilizer to make up the difference; if levels exceed 20 percent P saturation, no longer apply P.

In the Chesapeake Bay watershed, where animal manure is a dominant and available source of fertilizer, an overabundance of P exists, as described in Section 2.1.1.

Because P attaches to soil particles, P levels can build up in the soil, and the P saturation (P-sat) percentage increases. (P-sat is a tool that can estimate the degree to which P sorbing sites are saturated with P.) Thus, P fertilizer application is dependent on the existing soil P-sat percentage. When P is attached to the soil, it poses a risk to water quality if soil erosion is not controlled appropriately, because it will move off-site with the soil. For an environmental risk to exist from P transport to surface waters, P must be in a form that can be released to water. The P-sat percentage does not measure directly the risk for P loss in runoff; the P-sat percentage indicates the amount of P that is desorbed and moved into solution *when the soil comes into contact with water* (Kovzelove et al. 2010). This is only one mechanism by which P will be released from a soil mineral. While P will cease to sorb to mineral surfaces if binding sites are saturated, P can also be released if the sorbing complexes solubilize. Various environmental conditions control the solubility of such complexes. For example, iron, when oxidized, forms strong insoluble complexes with P, but if iron becomes reduced, the complex will solubilize and release P. When P bound to soil sediments via iron complexes are eroded to surface waters, the iron will become reduced and release P. While this is one pathway for P to move into the water solution if there are no more places for P to bind to on the mineral, there are other pathways for loss as well.

Butler and Coale (2005) describe how the amount of P released from soil when in contact with water increases exponentially once the P-sat percentage is between 20–30 percent (Figure 2-5).



Source: adapted from Butler and Coale 2005

Figure 2-5. The chart shows the relationship between P-saturation and dissolved P release to water.

EPA recommends that P fertilizer not be applied to soils that are above 20 percent where P desorption and loss as runoff can occur. In addition, it is important for the nutrient management plan to address the slope and movement patterns for water as runoff in a field by implementing cropland in-field controls (as described below in Section 3 of this chapter), because P-sat percentage does not dictate the probability of P in runoff to move to a ditch or local waterbody.

Tools can be used to plan for the applicable rate, timing, form, and method of P fertilizer application. Understanding P-sat percentages in soils throughout the field is necessary to ensure that the farmer is not applying P that is above the level needed for the crop and dually affecting water quality. When testing for soil P, depth of measurement below the surface is an important consideration, to account for buildup on the surface when manure is applied (but not incorporated); a host of soil P of testing options are available, including Mehlich 1, Mehlich 3, Bray 1, and modified Morgan, all of which must be fully understood because they are not immediately exchangeable. P-sat percentage calculations can be implemented with the assistance of USDA-NRCS staff, extension agents, Technical Service Providers (TSPs), or other private industry consultants and researchers.

Beck et al. (2004) have calculated for three major physiographic regions of Virginia the degree of P-sat as a function of Mehlich 1 extractable P for soils. That calculation provides a useful model that can be adopted throughout the Chesapeake Bay watershed. Future research should include calculation of the degree of P-sat in major soil types, starting in the areas of the Bay watershed where there is a significant P imbalance (Figure 2-2).

Nitrogen

Implementation Measure A-2:

Maximize N fertilizer use efficiency to maximize the net benefit from the lowest-needed amount of manure, biosolids, or commercial N fertilizer entering the cropland system. Whenever N fertilizer is applied where manure has already been applied, reduce N fertilizer rates according to the N credit of the manure that was applied. That N credit will vary depending on the amount, timing, type, and method of manure that was applied.

The NUE should be maximized to the extent practicable, and the expected NUE based on the tests described here should be incorporated into the NMP. A host of tools can assist nutrient management planners in developing the N application rate on the basis of in-field variability. By using tools to increase crop NUE, N loss is minimized through reductions in leaching, surface flow, ammonia volatilization, nitrification and denitrification, and soil erosion by calibrating the N input to the yield potential and crop needs. NUE is maximized to reduce N loss when the crop-removal efficiency (the efficiency of the crop to take in all N made available to it) works in tandem with the increase in residual nutrients available from the soil during the time the crop is growing.

Use of N use efficiency tools reduces over-applied N from leaving the production field and entering local waterways. Good N use efficiency is critical because higher use efficiency reduces the level of excess N available to create potential environmental problems, especially after the fall crop harvest during groundwater recharge events.

Improving the N application rate of a nutrient management plan for any cropland should use NUE tools as a guide through a series of steps to determine the rate, realistic production goals, and precision/decision agriculture systems and tools to efficiently apply N through improved materials, timing, placement, and use. A variety of in-field tests can be used to adjust inputs to meet the optimum yield of the plant in a manner in which N loss to the environment is minimized.

Maryland and Delaware have determined a suite of tools that make up a decision agriculture program, and other states in the Chesapeake Bay watershed are actively considering similar approaches; a broad range of effective tools can be used where applicable. The tools have varying degrees of technical needs and can all be implemented with the assistance of NRCS, extension agents, TSPs, or other private industry consultants and researchers. Many of the tools can be implemented at a scale broader than the field level, so it can be financially beneficial if neighboring smaller farms collaborate in implementation. Those include the following decision agriculture tools (additional tools and references are in Appendix 2):

- **Stalk nitrate tests** for field corn production is one of the most accurate methods to estimate N application rate for subsequent years when used over time to make better and more confident N management decisions. The test is done at the end-of-season and provides field specific data to know if the N available for crop uptake was deficient, marginal, optimal, or in excess for the plant to produce the optimum yield. The results of the test can be used to improve the NUE practice, and the NUE effectiveness is enhanced when the results are shared among localized area farmers with comparable cropland production conditions (Blackmer and Mallarino 1996).
- **Crop testing** is a broader approach for a wider diversity of crops than the stalk NO_3 test. Crop testing is used generally to detect the relative plant available N by sight with a leaf color chart or chlorophyll meter, measuring plant available soil N with the Pre-Sidedress Nitrate Test (PSNT) or employing real time chlorophyll measurement for variable rate application in the field.

- **Fertilizer prescription rate maps** can be a very useful NUE tool; they are developed using strategic soil testing (e.g., PSNT) and global positioning system (GPS) crop yield monitoring data. Soil tests are conducted throughout a field and GPS crop yield data maps are joined, to chart the field variability of N availability, to determine realistic crop production levels, and to help determine the subsequent season's appropriate nutrient prescriptive application rates.

- To maintain existing soil fertility levels, **crop nutrient removal** can be used to measure the difference between the application rate and the plant uptake rate. Simple charts can be devised to employ this tool, or software programs are available to ease the calculations.

- **Aerial imagery and strip trials** are effective individual tools, but when coupled at the end of a season, can provide an effective means to understand the spatial variability of a field remotely. This can also help identify field areas where there are signs of planter or applicator skips, diseased or pest-damaged areas, weed infestations and other non-uniform areas, which can decrease the amount of plant available N required to meet crop needs. While strip trials are conducted throughout the season, aerial imagery is generally done during the growth phase of the crop (as opposed to when the crop is mature).

- **Nutrient source integration** is used generally with organic fertilizer (manure), as a part of developing a manure management plan. This tool provides multiple benefits and is used to determine subsequent season's manure needs and can simplify manure application records.

- A tool being developed for the future is **environmental risk assessment**. It considers the location of the field and its potential to impair local or far-field areas using known transport factors.

2.1.3 Alternative Crops

Implementation Measure A-3:

Replace high nutrient loading crops in high-risk areas for water quality effects with sound alternatives.

High-risk areas exist in places where there is intense animal agriculture because of the resulting imbalance in nutrients (see Section 2.1.1). High nutrient loading crops, such as corn and soybean, should be replaced with alternatives in environmentally sensitive areas such as those in close proximity to local waters or in areas where there is a recorded nutrient imbalance for N or P. High-risk areas include such agricultural lands as sandy soils, which allow for easy N transport. When shifting high-nutrient loading crops out of the sensitive areas, the viability and market for the replacement crops will play an important role in deciding on which crops to grow.

Local agricultural contacts such as extension agents, conservation district staff, and TSPs can provide the best assistance in choosing alternative crops while meeting production goals. In Maryland, the document *Alternative Agriculture in Maryland: A Guide to Evaluate Farm-Based Enterprises* (Musser et al. 1999) provides a workbook with 78 separate decision worksheets. The USDA National Agricultural Library document *Alternative Crops & Enterprises for Small Farm Diversification* (Gold and Thompson 2009) provides a broad range of information on alternative crops.

2.1.4 Land Retirement

Implementation Measure A-4:

(1) Retire highly erodible lands (HELs) from cropland and replace the crop with perennial native vegetation, or (2) Develop and implement a soil conservation plan to reduce sheet and rill erosion to the Soil Loss Tolerance Level (T) as well as a nutrient management plan.

Highly erodible land (HEL) is defined by the Sodbuster, Conservation Reserve, and Conservation Compliance parts of the Food Security Act of 1985 and the Food, Agriculture, Conservation, and Trade Act of 1990 (USDA-NRCS 2010b). A soil map unit with an erodibility index (EI) of 8 or greater is HEL. The EI for a soil map unit is determined by dividing the potential erodibility for the soil map unit by the soil loss tolerance (T) (USDA-NRCS 2010c) T is an integer value from 1 through 5 tons/acre/year. T of 1 ton/acre/year is for shallow or otherwise fragile soils, and 5 tons/acre/year is for deep soils that are least subject to damage by erosion. The classes of T are 1, 2, 3, 4, and 5. A field is considered HEL if either one-third or more of the field has an EI value of 8 or greater or if the HEL in the field totals 50 acres or more (USDA-NRCS 2010a).

Sheet and Rill Equation

$$\frac{R \times K \times LS = EI}{T}$$

where

T = soil loss tolerance, or the maximum rate of annual soil erosion that will permit crop productivity to be sustained economically and indefinitely (tons/acre/year)

R = rainfall/runoff factor, quantifying the effect of raindrop impact and the amount and rate of runoff associated with the rain, based on long term rainfall record

K = soil erodibility factor based on the combined effects of soil properties influencing erosion rates

LS = slope length factor, a combination of slope gradient and continuous extent

The methodology used in implementing the Farm Bill Conservation Reserve Program has encouraged the retirement of HELs from cropland and replacing the crop with perennial vegetation.

When the lands are retired through the federal program, a suite of environmental benefit indicators are considered:

- Water quality benefits from reduced erosion, runoff, and leaching
- Wildlife habitat benefits resulting from covers on contract acreage
- On-farm benefits from reduced erosion
- Benefits that will likely endure
- Air quality benefits from reduced wind erosion
- Cost

Those indicators can be used to assess environmentally sensitive areas as well as USDA-identified HELs to determine where they are in the Chesapeake Bay watershed. Nutrients should not be applied to HELs, even if the lands are in continuous cropland production.

For HELs adjacent to stream channels, employ the recommendations from Chapters 5 and 7 (Riparian and Hydromodification) as the perennial vegetation. For information on federal programs that can assist landowners through the process of land retirement, see Chapter 5. Emerging and alternative markets can be used in conjunction with this recommendation to make this viable for the producer.

When the retirement of HEL will significantly affect the sustainability of the farm and after all native vegetation markets are considered, a conservation plan to reduce sheet and rill erosion to T as well as a nutrient management plan should be implemented.

2.1.5 Commercial Fertilizer Use

Implementation Measure A-5:

When using commercial fertilizer, give credit for manure nutrients. When commercial fertilizer is used, provide for the proper storage, calibration, and operation of chemical fertilizer nutrient application equipment.

Commercial fertilizers represent the largest single source of N and P applied to most cropland in the United States. In the Chesapeake Bay watershed, commercial fertilizers are used when manure is not readily available or undesirable, and are an important source of inorganic nutrient. Commercial fertilizers can be a tool used to abate the nutrient imbalance in the Chesapeake Bay watershed; where soils have a high range of P-sat percentage, but are below 20 percent, commercial N fertilizer can be applied so that manure can be applied at the P rate.

Major commercial fertilizer N sources include anhydrous ammonia, urea, ammonium nitrate (NH_4NO_3), and ammonium sulfate [$(NH_4)_2SO_4$]. Major commercial P fertilizer sources include monoammonium phosphate, diammonium phosphate, triple superphosphate, ammonium phosphate sulfate, and liquids. Descriptions of common commercial fertilizer materials are given in Table 2-1.

Also, where soils have a high range of P-sat below 20 percent, apply commercial N fertilizer to apply manure at the P rate.

Commercial fertilizers offer the advantage of allowing exact formulation and delivery of nutrient quantities specifically tailored to the site, crop, and time of application in concentrated, readily available forms. The use of any particular material or blend is governed by the characteristics of the formulation (such as volatilization potential and availability rate), suitability for the particular crop, crop needs, existing soil test levels, economics, application timing and equipment, and handling preferences of the producer.

Table 2-1. Common commercial fertilizer minerals

Common name chemical formula	Analysis (%)		
	N	P_2O_5	K_2O
N materials			
Ammonium nitrate NH_4NO_3	34%	0%	0%
Ammonium sulfate $(NH_4)_2SO_4$	21%	0%	0%
Ammonium nitrate-urea NH_4NO_3+$(NH_2)_2CO$	32%	0%	0%
Anhydrous ammonia NH_3	82%	0%	0%
Aqua ammonia NH_4OH	20%	0%	0%
Urea $(NH_2)_2CO$	46%	0%	0%
Phosphate materials			
Superphosphate $Ca(H_2PO_4)_2$	0%	20%–46%	0%
Ammoniated superphosphate $Ca(NH_4H_2PO_4)_2$	5%	40%	0%
Monoammonium phosphate NH_4H2PO_4	13%	52%	0%
Diammonium phosphate $(NH_4)_2HPO_4$	18%	46%	0%
Urea-ammonium phosphate $(NH_2)_2CO$+$(NH_4)_2HPO_4$	28%	28%	0%
Potassium materials			
Muriate of potash KCl	0%	0%	60%
Monopotassium phosphate KH_2PO_4	0%	50%	40%
Potassium hydroxide KOH	0%	0%	70%
Potassium nitrate KNO_3	13%	0%	45%
Potassium sulfate K_2SO_4	0%	0%	50%

Note: Adapted from Pennsylvania State University (1997) and Cornell Cooperative Extension (1997)

However, because of the nutrient imbalance from the amount of livestock manure produced in the Chesapeake Bay watershed, EPA recommends that use of commercial fertilizer be minimized by applying it only to the extent that manure nutrients are not available to be used. EPA also recommends that provisions be in place for storing fertilizer, as well as regularly calibrating and properly operating commercial fertilizer application equipment. That recommendation encourages considering manure as the first-choice source of nutrients. While there could be an upfront equipment cost, the benefits previously mentioned that manure can bring to the soil should be considered. Moreover, such an approach will help reduce the imbalance of nutrients that exists in significant portions of the Chesapeake Bay watershed that has resulted from the existing excess supply of manure in the watershed.

2.2 Animal Agriculture

In the Chesapeake Bay watershed, because of the intensity of animal agriculture and manure generation, it is imperative to control all nutrient sources in the livestock production area. All AFOs should provide the capacity to properly store for the minimum critical storage period (dictated by the size of the storage facility) (1) all manure generated, (2) all contaminated runoff generated, and (3) for open liquid manure storage structures, the direct precipitation from events in the geographic area, including chronic rain. Proper storage of dry manure, such as that produced at poultry operations, means covered storage, e.g., in production buildings or storage sheds. All AFO personnel should also ensure no runoff of pollutants is occurring from the production area or discharged through conveyances to local waters, including any precipitation-related water that comes into contact with the animals, animal by-products, litter, or feed. Proximity to waterbodies, floodplains, HELs, and other environmentally sensitive areas is a critical consideration in siting manure storage systems.

Strategies for source control associated with animal agriculture focus on containing and treating feed, manure, and facility wastewater and preventing their movement to surface waters. Four general principles can help control sources of nutrients and other pollutants from animal agriculture: animal feed management, manure storage and transport, treatment or processing of wastes, and management of grazing livestock. NRCS Practice Standards exist for those four general principles and are referenced throughout this section.

2.2.1 Animal Feed Management

Important feeding strategies for livestock production focus on adjustment of feed additives, formulations, phase feeding (matching feed to growth stage), or feeding methods to reduce the nutrient content, change the form of nutrient excreted in manure, and feed as close to animal requirements as possible (NRCS Practice Code 592). Decreasing the P and N content of manure through diet modification is a powerful, effective approach to reducing the nutrient balance and nutrient losses from livestock farms (Knowlton et al. 2004; Maguire et al. 2007; Swink et al. 2009). Reduction of P and N overfeeding, use of feed additives to enhance dietary P and N utilization, and development of grains in which a high proportion of the P is available (high-available P, or HAP, grains) have all been shown to decrease P and N excretion without impairing animal performance (Maguire et al. 2005). Phytase, a feed additive generally used in poultry or swine feed, is an enzyme that breaks down the form of phosphorus (phytate) that is found in grains so that the phosphorus can be digested and used by the animal. The phytase enzyme is regularly produced and is present naturally in ruminants (e.g., dairy and beef cattle).

The ratio of N to P in manure applied to the land is a critical issue. Manures used as fertilizers on fields commonly contain N:P ratios of approximately 3:1, whereas most major crops require

N:P ratios of approximately 8:1. Application of manure to meet N requirements consequently tends to apply excess P. Two major factors contributing to the low N:P ratio in manure are the loss of N through ammonia volatilization and the presence of excess P in the diets of farm animals. In addition to reducing the P content of manure through feed management, the combination of reducing N volatilization losses and immobilization of P through manure or litter amendment can significantly increase the final N:P ratio of land applied manure (Lefcourt and Meisinger 2001).

Finally, some feed additives that pass through the animal and reside in the manure can be problematic in the environment. For example, most of the arsenic used as an antibiotic in commercial broiler production remains in the litter. As a result, higher levels of arsenic tend to be found in soils that receive poultry litter compared to areas where litter is not applied. Reducing or eliminating arsenic in poultry feed can reduce this problem.

Implementation Measure A-6:

Formulate animal feeds to reduce nutrient concentration in manure, improve the manure N:P ratio in relation to crop needs, or eliminate toxic substances such as arsenic in manure used as fertilizer. Align the N:P ratio of the manure to be equal to (or greater than) the N:P ratio of the crop need.

Practice Effectiveness

Several studies have shown that reducing the nutrients in feed has a significant effect on the manure nutrient content.

Arriaga et al. (2009) estimated that dietary manipulation in Spain could decrease dairy herd N excretion by 11 percent per hectare, whereas P would be decreased by 17 percent. On two New York dairy farms, Cerosaletti et al. (2004) reported that fecal P concentrations decreased 33 percent following dietary adjustments; milk production was not adversely affected. In a modeling study of the same New York farms, precision feed management reduced the P imbalance on each farm and reduced the soluble P lost to the environment by 18 percent (Ghebremichael et al. 2007). Ebeling et al. (2002) applied dairy manure from two dietary P levels to corn land in Wisconsin and reported that at equivalent manure rates, dissolved P concentration in runoff from the high P diet manure was 10 times higher (2.84 versus 0.30 mg/L) than the low P diet manure, and four times higher (1.18 versus 0.30 mg/L) when applied at equivalent P rates.

In a review, Graham et al. (2003) reported that including xylanase or phytase in poultry feeds can reduce manure volume by up to 14 percent and N and P outputs by up to 13 percent and 70 percent, respectively. A review by Powers and Angel (2008) reported that for each one percent reduction in dietary crude protein, estimated NH_3 losses are decreased by 10 percent, creating the potential for a 20–40 percent reduction in NH_3 emissions from poultry houses. For P, under commercial conditions, broiler litter P was decreased by 30 percent when diet P was decreased by 10 percent. In North Carolina, Leytem et al. (2008) reported that inclusion of phytase in poultry diets at the expense of inorganic P or reductions in dietary available P decreased litter total phosphorus (TP) by 28 to 43 percent. Litter water-soluble P decreased by up to 73 percent with an increasing dietary Ca/available P ratio, irrespective of phytase addition. Nahm (2009) found that phytase addition to simple gastric animal diets in South Korea can decrease the litter water-soluble P concentration by 30–35 percent. In Arkansas, Smith et al. (2004) showed that phytase and HAP corn diets reduced litter-dissolved P content in broiler litter by 10 and 35 percent, respectively, compared with the normal diet (789 mg P/kg). P concentrations in runoff water were highest from plots receiving poultry litter from the normal diet, whereas plots receiving poultry litter from phytase and HAP corn diets had reduced P concentrations.

In Canada, Emiola et al. (2009) showed that complete removal of inorganic P from growing pig diets coupled with phytase supplementation improves digestibility and retention of P and N, thus reducing manure P excretion without any negative effect on pig performance. In another Canadian study, Grandhi (2001) reported that replacing inorganic P with phytase and lowering the dietary protein level while supplementing amino acids in swine diets can decrease the excretion of P up to 44 percent and N up to 28 percent in manure with no adverse effect on performance of pigs. In a Danish study, replacing inorganic phosphates with phytase in pig feed reduced the concentration of P in slurry by 35 percent (Sommer et al. 2008). In Europe, Aarnink and Verstegen (2007) found that a combination of lowering crude protein intake and increasing fermentable carbohydrates, and other modifications to feeding strategies could reduce ammonia emission from growing-finishing pigs by 70 percent.

Despite ample research evidence that phytase addition, use of HAP feeds, and other approaches can significantly reduce N and P content in manure, marketing and adoption of such feeds has been slow. Recent survey data in Delaware suggest that poultry producers with high soil P levels are willing to adopt HAP corn, despite increased costs and yield loss (Bernard and Pesek 2007). It is possible that the lack of economic return for sales of HAP seed has inhibited production and marketing of modified seed by suppliers. There is an apparent need for additional work in this area to determine how to effectively get this promising technology into wider production and use.

Dao (1999) reported that treatment of cattle manure with alum and other amendments can increase the effective N:P ratio in manure, bringing it into a range suitable for using manure as a balanced source of nutrients for crop production. Alum addition to stockpiled and composted cattle manure reduced water-extractable P (WEP) in the manure by 85–93 percent. Worley and Das (2000) reported that separation of solids from flushed swine manure and subsequent amendment with alum removed 75 percent of P and only small amounts of N from the manure. As a result, the N:P ratio of the effluent entering the lagoon improved from 3.6 without separation to 8 with separation and to 16.7 with separation and alum amendment.

Table 2-2. Summary of reported practice effects resulting from changes in animal feeding strategies

Location	Study type	Practice	Practice effects	Source
Spain	Farms	Dairy feed formulation	11% reduction in N excretion; 17% reduction in P excretion	Arriaga et al. 2009
New York	Farm	Dairy dietary management	33% reduction in manure P concentration	Cerosaletti et al. 2004
New York	Model	Dairy precision feeding	18% reduction in soluble P lost from farm	Ghebremichael et al. 2007
Wisconsin	Field	Dairy dietary management	75% reduction in dissolved P in runoff from land applied manure[a]	Ebeling et al. 2002
Many	Review	Phytase in poultry feed	14% reduction in manure volume; 13% reduction in litter N, 70% reduction in litter P	Graham et al. 2003
Many	Review	Poultry feed formulation	10% reduction in NH3 losses per 1% decrease in dietary crude protein; 30% reduction in litter P with 10% reduction in dietary P	Powers and Angel 2008
North Carolina	Animal trials	Phytase in poultry feed	28%–43% decrease in litter TP; Up to 73% reduction in litter water-soluble P[b]	Leytem et al. 2008
S Korea	Review	Phytase in poultry feed	30%–35% reduction in litter water-soluble P	Nahm 2009
Arkansas	Farm/ Plot	Phytase and high available P corn in poultry feed	10% reduction in litter dissolved P with phytase; 35% reduction with high available P corn[c]	Smith et al. 2004
Canada	Animal trials	Swine diet	Removal of inorganic P from diet plus phytase supplementation improved digestibility and retention of P and N, reduced manure P excretion without negative effects on growth	Emiola et al. 2009
Canada	Animal trials	Swine diet	44% reduction in P excretion, 28% reduction in N excretion from replacing inorganic P with phytase and lowering dietary protein	Grandhi 2001
Denmark	Farm	Phytase in swine diet	35% reduction in P in slurry	Sommer et al. 2008
Europe	Review	Swine feeding strategies[d]	70% reduction in ammonia emissions from growing-finishing operations	Aarnink and Verstegen 2007

Notes:

a. High-P diet manure and low-P diet manure applied at equivalent P rates

b. With increasing Ca/available P in feed, irrespective of phytase

c. Study also reported that P concentrations in plot runoff were reduced where litter from modified diets was applied

d. Feeding changes included lowering crude protein intake, increasing fermentable carbohydrates, and addition of acidifying salts

Practice Costs

In an experiment in India, Khose et al. (2003) reported that the cost of broiler production per kg live weight was lowest in the group fed the diet with a 50 percent reduction in feed dicalcium phosphate supplemented with phytase. Osei et al. (2008) used an integrated economic and environmental modeling system to evaluate effects of N- and P-based manure application rates in Texas. Results of the study indicate that edge-of-field TP losses can be reduced by about 0.8 kg/ha/year or 14 percent when manure applications are calibrated to supply all the recommended crop P requirements from manure TP sources only versus manure applications at the recommended crop N agronomic rate. Corresponding economic effects are projected to average $4,852 (2010 dollars) annual cost increase per farm.

2.2.2 Manure Storage and Transport

Implementation Measure A-7:

Safely and strategically apply (with properly calibrated equipment), store, and transport manure.

- Liquid manure storage systems including tanks, ponds, and lagoons (e.g., NRCS Practice Code 313 Waste Storage Facility) should be designed and operated to safely store the entire quantity and contents of animal manure and wastewater generated, contaminated runoff from the facility, and the direct precipitation from events in the geographic area, including chronic rain.
- Dry manure (i.e., stackable, greater than or equal to 20 percent dry matter), such as that produced in poultry and certain cattle operations, should be stored in production buildings, storage facilities, or otherwise covered to prevent precipitation from coming into direct contact with the manure and to prevent the occurrence of contaminated runoff. When necessary, temporary field storage of dry manure (e.g., poultry litter) may be possible under protective guidelines (e.g., NRCS Practice Code 633 Waste Utilization).
- For manure and litter storage, the AFO should maintain sufficient storage capacity for minimum critical storage period consistent with planned utilization rates or utilization practices and schedule.

The manure and other wastes generated by livestock production should be contained and management should prevent runoff losses from the facility. Key measures and some component practices (including some as USDA-NRCS National Practice Codes) include the following:

- Ensure that the farm has sufficient storage for all manure.
  - **Waste storage facility (NRCS Practice Code 313)**: A waste impoundment made by constructing an embankment, excavating a pit or dugout, or by fabricating a structure.
  - **Waste treatment lagoon (NRCS Practice Code 359)**: An impoundment made by excavation or earth fill for biological treatment of animal or other agricultural wastes.
- Ensure that manure and litter are stockpiled safely.
  - **Waste Utilization (NRCS Practice Code 633[2])**: Using agricultural wastes, such as manure and wastewater, or other organic residues (including temporary field storage).
- Minimize the need for temporary storage by scheduling clean-outs as close to utilization as possible.
- Locate storage on level ground not subject to flooding and away from surface waters and wells.
- Stack manure on an impermeable pad or in areas with adequate separation from the groundwater table.
- Rotate temporary storage areas to avoid buildup of salts and nutrients in a single location.
- Cover stockpiles when practical. Although data on the benefits of covering poultry litter is mixed (Poultry Litter Experts Science Forum 2008), there is evidence that dry broiler litter should be covered to protect litter quality and to prevent extensive nutrient runoff (Mitchell et al. 2007). Most Extension recommendations call for covering field stockpiles of poultry litter and other solid manure (e.g., Carter and Poore 1998, Arkansas Cooperative Extension Service 2006, Ogejo 2009).
- Minimize stockpile footprint and provide grass filter strip to protect downslope areas.
  - Set total (whole-house) clean-out schedules that ensure no poultry litter stockpiling during times of the year with the greatest environmental losses (e.g., winter).

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[2] NRCS Practice Code 633 is being revised at the national level. If the practice cannot be isolated as a unique technology different from the technology delivered by NRCS Code 590, it may be abandoned or redefined. Interested parties should be advised that the 590 is under revision and that 633 practice will be redefined or abandoned.

  - Divert clean water away from waste storage areas.
  - **Diversion (NRCS Practice Code 362)**: A channel constructed across the slope with a supporting ridge on the lower side.
  - **Roof runoff management (NRCS Practice Code 558)**: A facility for controlling and disposing of runoff water from roofs.
- Ensure that any recipient of manure generated has planned effectively to meet, at a minimum, the same performance goals as those of the sourced manure.
  - Areas receiving manure should be managed in accordance with meeting the goals for erosion and sediment control, irrigation, and grazing management applicable, including practices such as crop and grazing management practices to minimize movement of applied nutrient and organic materials, and buffers or other practices to trap, store, and *process* materials that might move during precipitation events.
  - **Waste utilization (NRCS Practice Code 633)**: Using agricultural wastes or other wastes on land in an environmentally acceptable manner while maintaining or improving soil and plant resources.

Measures for manure storage protect the wastes from precipitation and runoff and provide opportunities for further treatment (see Section 2.2.4) or for subsequent manure management according to a nutrient management plan (see Section 2.1.1). Thus, little recent literature exists quantifying the effectiveness of waste storage alone. General pollutant reductions associated with containment structures were reported (TP 60 percent, TN 65 percent, sediment 70 percent, and fecal coliform 90 percent) in *National Management Measures to Control Nonpoint Pollution from Agriculture* (USEPA 2003) based on information published by Pennsylvania State University (PSU 1992). Mitchell et al. (2007) reported high nutrient losses in runoff from uncovered poultry litter. Habersack (2002) studied runoff from uncovered and covered poultry manure stockpiles and concluded that even protecting litter piles with the common 95 percent plastic coverage technique was unsuccessful in reducing environmental pollution. It was recommended that poultry litter be stored in a litter shed that prevents all contact from precipitation and runoff. Reductions of fecal coliform bacteria numbers of two to three orders of magnitude have been reported with manure storage for 2 to 6 months (Patni et al. 1985; Moore et al. 1988).

Practice Costs

Concrete pits for storing wet animal waste can cost from \$42.50/yd^3 for pits larger than 1,000 yd^3 to \$159/yd^3 for pits smaller than 370 yd^3, with typical total costs ranging from \$42,800 for smaller pits to over \$200,000 for larger pits (USDA-NRCS 2010). The cost of earthen ponds ranges from \$9.92/yd^3 for ponds larger than 1,000 yd^3 to \$13.65/yd^3 for smaller ponds. A typical small, earthen pond costs about $12,500, while a larger pond could cost just under $17,000. Earthen floor storage for dry waste costs from $41.50 to $55.90/yd^3, with typical small (less than or equal to 1,000 yd^3) structures costing just over $37,000 and larger structures costing nearly $50,000. Storage of dry wastes costs more with concrete floors ($70.90 to $106/yd^3); structures with a capacity of less than or equal to 500 yd^3 typically cost around $50,000, whereas larger structures cost nearly $70,000. Loose housing for dry waste storage costs about $207/yd^3, and typical structures holding 1,150/yd^3 cost about $240,000. Waste field storage consisting of fabric and gravel with a tarp costs $1.62/ft^2 while a concrete slab and tarp goes for $3.67/ft^2 in Virginia, with typical total costs of $11,310 and $14,665, respectively (USDA-NRCS 2010).

Waste treatment lagoons with earthen bottoms cost about $13/yd^3, and lagoons typically cost about $21,440 (USDA-NRCS 2010). Pond sealing or lining with flexible membrane ($1.38/ft^2), soil dispersant ($1.52/ft^2), or bentonite clay ($1.52/ft^2) are improvement options in Virginia for which total costs are typically in the range of $6,700 to $7,500. Sealing with compacted clay costs about $6.91 or $16.63/yd^3 of earth moved for on-site and off-site clay sources, respectively. Typical total costs for compacted clay liners are about $2,300 for on-site clay and $5,500 for off-site clay.

Earthen diversions cost about $2.70 per linear foot. Roof runoff structure costs range from $1.84/gallon for underground cisterns with hookup, to $4.54/ft for downspouts and drain lines, to $6.00/ft for 6-inch gutters. Dry poultry spreading generally costs about $33.90/ac, whereas spreading of liquid dairy waste costs about $12.50/ac. Waste utilization via lagoons and irrigation systems cost about $377/ac, with typical systems running about $66,000.

2.2.3 Livestock Exclusion from Streams

Implementation Measure A-8:

Exclude livestock from streams and streambanks to reduce nutrient inputs, streambank erosion, and sediment inputs and to improve animal health.

Grazing livestock should be excluded from streams and riparian areas to reduce direct nutrient and pathogen inputs, prevent streambank damage and resulting sediment inputs, and improve animal health (NRCS Practice Code 472). Fencing is the most reliable way to protect streams and riparian areas from the effects of livestock, and can be woven wire or electric (NRCS Practice Code 382). Cost-share programs might require permanent fencing, rather than temporary or movable fence. Management intensive or rotational grazing could, however, involve using movable fences to create temporary paddocks to direct livestock away from a water course. If complete fencing is not possible, the most sensitive streambank areas should be fenced, while providing an alternate watering source (NRCS Practice Code 614) for access to drinking water for grazing animals. Some trials have documented success in keeping livestock out of streams without continuous fencing by providing drinking water and/or shade away from the stream to encourage livestock to congregate away from riparian areas.

Practice Effectiveness

Livestock exclusion fencing

Line et al. (2000) documented 33, 78, 76, and 82 percent reductions in weekly nitrate + nitrite, total Kjeldahl nitrogen (TKN), TP, and sediment loads, respectively, resulting from fencing dairy cows from a 10- to 16-m wide riparian corridor along a small North Carolina stream. In the same system, Line (2003) showed that fecal coliform and enterococci levels decreased 65.9 percent and 57.0 percent, respectively, after livestock exclusion.

In Vermont streams draining dairy pastures, Meals (2002) reported 20–50 percent reductions in nutrient and suspended solids loads and 40–60 percent reductions in fecal bacteria counts following livestock exclusion and riparian restoration with bioengineering techniques.

James et al. (2007) estimated 32 percent reduction of in-stream deposition of fecal P by grazing dairy cattle in New York following livestock exclusion under the CREP.

In central Pennsylvania, Carline and Walsh (2007) reported that following riparian treatments, consisting of fencing, 3- to 4-m buffer strips, stream bank stabilization, and rock-lined stream crossings, stream bank vegetation increased from 50 percent or less to 100 percent in formerly grazed riparian buffers, suspended sediments during base flow and storm flow decreased 47–87 percent, and macroinvertebrate densities increased in two treated streams.

However, Agouridis et al. (2005) reported that incorporation of an alternate water source or fenced riparian area along a central Kentucky stream did not significantly alter stream cross-sectional area where the measures were applied. The authors suggested that riparian recovery within the exclosures from pretreatment grazing practices might require decades, or greater intervention (i.e., stream restoration), before a substantial reduction in streambank erosion is noted.

Table 2-3. Summary of reported practice effects resulting from livestock exclusion

Location	Study type	Practice	Practice effects	Source
North Carolina	Small watershed	Fencing dairy cattle	Load reductions: 33% NO_2+NO_3-N, 78% TKN, 76% TP, and 82% sediment	Line et al. 2000
North Carolina	Small watershed	Fencing dairy cattle	Reductions: 66% fecal coliform, 57% enterococci	Line 2003
Vermont	Small watersheds	Fencing dairy cattle; riparian restoration	Load reductions: 20–50% TP, TKN, TSS Reductions: 40–60% fecal coliform, fecal strep., and *E. coli*	Meals 2002
New York	Stream	Fencing dairy cattle[a]	32% reduction in deposition of fecal P in stream	James et al. 2007
Pennsyl-vania	Small watersheds	Fencing, buffer strips, stream bank stabilization, rock-lined stream crossings	Streambank vegetation increase from ≤ 50%–100%; 47–87% reduction in SS concentrations; increase in macroinvertebrate densities	Carline and Walsh 2007
Georgia	Stream	Off-stream water supply	63% decrease time cattle spent in riparian zones	Franklin et al. 2009
North Carolina	Stream	Off-stream water supply	No significant changes in physical water quality parameters or bacteria counts	Line 2003

Note:

a. Livestock exclusion under Conservation Reserve Enhancement Program (CREP)

Alternative water supply

In Georgia, Franklin et al. (2009) found that when the temperature and humidity index ranged between 62 and 72, providing cattle with water troughs outside of riparian zones tended to decrease time cattle spent in riparian zones by 63 percent. The study suggests that water troughs placed away from unfenced streams can improve water quality by reducing the amount of time cattle spend in riparian zones.

However, Line (2003) reported that levels of most measured physical parameters and bacteria were not significantly different following the installation of alternate water supply in a North Carolina pasture.

Practice Costs

Fence costs range from $0.49/ft for 1-strand, stainless steel electric poly wire used as temporary fencing, to $8.77/ft for 4-foot chain-link fence with one strand of barbed wire (USDA-NRCS 2010). Most fencing falls within the range of about $2/ft to $3/ft, with typical total costs of about $3,000 to $4,000. Watering facilities cost about $812 each for converted heavy truck tires to as much as $1,700 for 4-hole, freeze-proof troughs including gravel and a concrete pad. Portable shade structures for livestock cost \$4.85/ft^2 for a typical total cost of $1,940. Graded stream crossings made of gravel and fabric cost under \$2.50/ft^2, while stream crossings with concrete access or culverts cost about \$4.10/ft^2 and \$4.90/ft^2, respectively (USDA-NRCS 2010). Typical total costs for graded stream crossings range from $1,700 to $2,900 for gravel and fabric, to $4,300 with concrete access, to just over $5,100 for culverts.

2.2.4 Wastewater and Animal Wastes

Implementation Measure A-9:

Process/treat through physical, chemical, and biological processes facility wastewater and animal wastes to reduce as much as practicable the volume of manure and loss of nutrients.

Manure and wastewater stored on farms has a significant pollution potential even after wastes are collected and stored appropriately. Researchers have recommended a variety of practices to manage the effects of animal wastes, focusing on treating waste to change its physical, chemical, or biological properties; remove potential pollutants; or improve handling characteristics (Bicudo and Goyal 2003; Ritter et al. 2003; Martinez et al. 2009).

Such practices include the following:

- **Waste treatment and processing**—treating manure or farm wastewater to separate liquids and solids, immobilize pollutants, or remove nutrients from the waste stream
- **Digestion**—processing animal wastes to capture biogas for use as fuel, reducing bulk of remaining residuals for further management. The digestion process removes only carbon, hydrogen, and water from the animal waste; the residuals from digestion contain all the N, P, and trace minerals and about half of the carbon of the original manure.
- **Composting**—composting of animal wastes, possibly combined with other green wastes, to reduce bulk, stabilize nutrient forms, and facilitate export and land application of animal wastes. High temperatures during composting kill manure microorganisms, largely eliminating the risk of contaminating crops with pathogens where composted manure is land-applied. Composting reduces the mass and volume of manure significantly, while P content remains essentially unchanged. Substantial N losses can occur, however, through volatilization of ammonia N created by decomposition of organic N and by conversion of organic N to NO_3 followed by leaching.
- **Constructed Wetland treatment**—to remove nutrients by plant uptake and promotion of denitrification

- **Other biological treatments**—treatment systems using microorganisms, algae, or other plants to break down wastes and absorb nutrients
- **Air quality management**—practices to reduce or capture airborne pollutants like ammonia or fine particulates from animal housing

Practice Effectiveness

Waste treatment and processing—manure and wastewater amendment

Amending poultry litter with alum [$Al_3(SO_4)_2$-$14H_2O$] is a method of economically reducing ammonia volatilization in the poultry house and soluble P in runoff waters (e.g., Amendments for Treatment of Agricultural Waste, NRCS Practice Code 591). In South Korea, Do et al. (2005) reported that application of aluminum chloride ($AlCl_3$-$6H_2O$) to litter lowered atmospheric ammonia concentrations at 42 days by 97.2 percent, whereas ferrous sulfate ($FeSO_4$-$7H_2O$) lowered it by 91 percent. Ammonia concentrations were reduced by 86, 79, 76, and 69 percent by alum, alum + $CaCO_3$, aluminum chloride + $CaCO_3$, and potassium permanganate ($KMnO_4$), respectively, when compared with a control at 42 days. The addition of 6.25 percent zeolite or 2.5 percent alum to dairy slurry in Maryland reduced ammonia emissions by nearly 50 and 60 percent, respectively. Alum treatment retained ammonia by reducing the slurry pH to 5 or less. In contrast, zeolite, (a cation exchange medium) adsorbed ammonium and reduced dissolved ammonia gas (Lefcourt and Meisinger 2001).

In Arkansas, Moore et al. (1999 and 2000) reported that reductions in litter pH in alum-treated broiler litter reduced NH_3 volatilization by 97 percent, which led to reductions in atmospheric NH_3 in the alum-treated houses. Broilers grown on alum-treated litter were significantly heavier than controls (1.73 kg versus 1.66 kg). Soluble reactive P (SRP) concentrations in runoff from pastures fertilized with alum-treated litter were 75 percent lower than those from normal litter. Also in Arkansas, Smith et al. (2001) found that alum and aluminum chloride amendment to swine manure reduced SRP concentrations in runoff by 84 percent that were not statistically different from SRP concentrations in runoff from unfertilized control plots. Smith et al. (2004) reported that the addition of alum to various poultry litters reduced P runoff by 52 to 69 percent from pastures where the litter was applied; the greatest reduction occurred when alum was used in conjunction with dietary modification with HAP corn and phytase.

In Pennsylvania, Dou et al. (2003) reported reductions of soluble P in dairy, swine, and broiler manures of 80 to 99 percent at treatment rates of 100 to 250 g alum/kg manure dry matter. Fluidized bed combustion fly ash reduced readily soluble P by 50 to 60 percent at a rate of 400 g/kg for all three manures. Flue gas desulfurization by-product reduced soluble P by nearly 80 percent when added to swine manure and broiler litter at 150 and 250 g/kg.

Table 2-4. Summary of reported practice effects resulting from waste amendment

Location	Study type	Practice	Practice effects	Source
Korea	Poultry house	Poultry litter amendments	Atmospheric ammonia concentration reductions: 97% (Aluminum chloride), 91% (Ferrous sulfate), 86% (alum), 79% (alum+$CaCO_3$), 76% (aluminum chloride+$CaCO_3$), 69% ($KMnO_4$)	Do et al. 2005
Maryland	Dairy farm	Dairy slurry amendments	50% ammonia emissions reduction (zeolite), 60% ammonia emissions reduction (alum)	Lefcourt and Meisinger 2001
Arkansas	Poultry houses	Alum amendment	97% ammonia volatilization; 75% reduction in soluble P in runoff from pastures receiving treated litter	Moore et al. 1999 and 2000
Arkansas	Field	Alum and aluminum chloride treated poultry litter	52%–69% reduction in P concentration in runoff from pastures where treated litter applied[a]	Smith et al. 2004
Arkansas	Plots	Alum and aluminum chloride treated swine manure	84% reduction in soluble P concentration in runoff from plots receiving treated manure; P concentration not significantly different from un-manured control plots	Smith et al. 2001
Pennsylvania	Laboratory	Dairy, swine, broiler manure amendments	Manure soluble P reductions: 80-99% (alum), 50%–60% (fly ash), 80% (flue gas desulfurization byproduct	Dou et al. 2003
Unknown	Laboratory	Dairy wastewater amendment	93%–99% reduction in ortho-P with alum treatment; ortho-P reduced to < 1 mg P/L by alum and PAM combined	Jones and Brown 2000
Unknown	Laboratory	Dairy manure amendment	Liquid from separated manure amended with alum and polymer had 82% less TP, 36% less TS, and 71% lower COD than untreated manure	Oh et al. 2005
Ohio	Laboratory	Dairy manure amendment	Amending dairy manure with WTR reduced $CaCl_2$-extractable P > 75%	Dayton and Basta 2005
Vermont	Laboratory	Dairy manure amendment	Amending dairy manure with alum-based WTR reduced manure soluble P up to 79%, TP up to 50%	Meals et al. 2007
Idaho	Field	Cattle, swine manure amendment	Amending manure with PAM, alum, and CaO treatments reduced fecal bacteria 90–>99% in runoff from application sites compared to untreated manure control	Entry and Sojka 2000
Taiwan	Laboratory	Swine wastewater amendment	Amending swine wastewater with alum, ferric chloride, calcium hydroxide, and polyaluminum chloride reduced COD by 54%	Cheng 2001

Note:

a. Greatest P reductions when alum used in conjunction with dietary modification

In laboratory studies, alum reduced ortho-P in dairy wastewater 93–99 percent at rates less than three g alum/L. Ortho-P was reduced to one mg P/L or less by a combination of alum and polyacrylamide (PAM) treatment (Jones and Brown 2000).

Oh et al. (2005) reported that alum and polymer addition improved the efficacy of mechanical separation of dairy manure. When compared to the control, waste amended with alum and polymer had 82 percent less TP in the press liquor, which indicates that P was partitioned into the press cake. The combined alum/polymer treatment also resulted in a 36 percent reduction in total solids (TS) and a 71 percent reduction in chemical oxygen demand (COD) in the press liquor when compared to the control.

Codling et al. (2000) recommended substituting Al-rich drinking WTR for alum for reducing water-soluble P in poultry litter. In Ohio, Dayton and Basta (2005) reported that blending WTR to manure at 250 g/kg reduced $CaCl_2$–extractable P by greater than 75 percent. In a Vermont study, Meals et al. (2007) found that additions of alum-based WTR to liquid dairy manure could reduce manure soluble P concentrations up to 79 percent and TP concentrations by up to 50 percent.

In Idaho, Entry and Sojka (2000) reported that treatment of cattle and swine manure with combinations of PAM, aluminum sulfate ($Al(SO4)_3$), and calcium oxide (CaO) treatments reduced fecal bacteria counts by 10- to 1,000-fold in water flowing downstream of treated manure application sites, compared to the untreated manure control.

In Taiwan, Cheng (2001) was able to reduce COD levels in swine wastewater by 54 percent to 190 mg/L using coagulants such as aluminum chloride, ferric chloride, calcium hydroxide, and polyaluminum chloride.

Waste treatment and processing—waste separation

Note that waste separation does not treat wastes in the sense of removing or inactivating pollutants; rather, the process of separation produces a separate liquid and solid waste stream that could facilitate handling, transport, and further use of waste components.

An inclined stationary screen separator removed 61 percent of the TS, 63 percent of the volatile solids, 49 percent of the TKN, 52 percent of the organic-N, and 53 percent of the TP from South Carolina dairy manure in a flush system; the complete manure treatment system consisting of the screen separator, separator, a two–chambered settling basin, and a lagoon removed 93 percent of the TS, 96 percent of the VS, 74 percent of the TKN, 91 percent of the organic-N, and 86 percent of the TP (Chastain et al. 2001).

In Wisconsin, Converse and Karthikeyan (2004) reported that long-term settling of flushed dairy manure will remove 75 to 80 percent of TP from raw flushed manure or separator effluent and concentrate it in the bottom 25 percent of the volume. Cantrell et al. (2008) reported that geotextile filtration of liquid dairy manure in South Carolina reduced volume to less than one percent of total influent volume, concentrated the solids and nutrients in the dewatered material 16 to 21 times greater than the influent, and retained 38 percent of TS, 26 percent of TKN, and 45 percent of TP. In South Carolina, Garcia et al. (2009) used the natural flocculant chitosan to improve the performance of screen separation efficiencies for flushed dairy manure to greater than 95 percent for total suspended sediment (TSS), greater than 73 percent for TKN, and greater than 54 percent for TP.

Table 2-5. Summary of reported practice effects resulting from waste separation

State	Study type	Practice	Practice effects	Source
South Carolina	Farm	Inclined stationary screen separator	For flush-system dairy manure, separator removed 61% of TS, 63% of the volatile solids, 49% of the TKN, 52% of the organic–N, and 53% of the TP	Chastain et al. 2001
South Carolina	Farm	Separator + settling basin + lagoon	For flush-system dairy manure, full system removed 93% of TS, 96% of the volatile solids, 74% of the TKN, 91% of the organic–N, and 86% of the TP	Chastain et al. 2001
Wisconsin	Laboratory	Long-term settling	75%–80% of TP removed from raw flushed dairy manure, concentrated in 25% of original volume	Converse and Karthikeyan 2004
South Carolina	Farm	Geotextile separation	For liquid dairy manure, reduced volume to < 1% of influent volume and retained 38% of TS, 26% of TN, and 45% of TP	Cantrell et al. 2008
South Carolina	Farm	Flocculation + separation	Use of natural flocculant chitosan improved performance of screen separation efficiencies for flushed dairy manure to > 95% for TSS, > 73% for TKN, and > 54% for TP	Garcia et al. 2009
North Carolina	Farm	PAM + screening	For swine waste, addition of PAM before screening increased separation efficiencies to 95% TSS and VSS, 92% organic P, 85% organic N, 69% COD, and 59% BOD_5;	Vanotti et al. 2002
North Carolina	Farm	Flocculation + filtration	System removed 97% of TSS and VSS, 85% of BOD, 83% of COD, 61% TKN, and 72% of TP from flushed swine manure	Vanotti et al. 2005

Although screening alone was not effective for separating swine waste in a North Carolina study, Vanotti et al. (2002) found that adding PAM before screening increased separation efficiencies to 95 percent TSS and volatile suspended solids (VSS), 92 percent organic P, 85 percent organic N, 69 percent COD, and 59 percent BOD_5; the N:P ratio was improved from 4.79 to 12.11, resulting in a more balanced effluent for fertilizing crops. In a subsequent study, Vanotti et al. (2005) reported that a combined flocculation and filtration treatment system removed 97 percent of TSS and VSS, 85 percent of BOD, 83 percent of COD, 61 percent TKN, and 72 percent of TP from flushed swine manure.

Waste treatment and processing—lagoon treatment

Waste treatment processes typically leave a residual material after producing a cleaner effluent; thus, the reductions cited in the literature generally refer to the treated effluent compared to the original waste. In all cases, the residual should be managed properly to prevent pollution impacts.

Aerobic lagoon treatment of swine waste in Nova Scotia accomplished removals of 59–71 percent TSS, 59–73 percent VSS, 42–60 percent TKN, and 42–51 percent NH_4-N (Trias et al. 2004). In France, combined aerobic/anoxic treatment of swine manure wastewater achieved 86 percent reduction in TSS, 90 percent reduction in TN and COD (Prado et al. 2009); 50 percent of soluble P was biologically removed by an intermittent aerobic/anoxic sequence.

In Korea, Ra et al. (1998) reported that a two-stage sequencing batch reactor system achieved removal efficiencies of 98 percent total organic carbon (TOC), 100 percent NH_4-N, 98 percent TKN, 97 percent ortho-P, 98 percent TP, 97 percent suspended solids (SS) and 97 percent VSS.

Vanotti and Szogi (2008) tested a new swine waste treatment system combining liquid-solids separation with biological N and P removal in North Carolina and reported removal of 73–98 percent TSS, 40–76 percent of TS, 77–100 percent of BOD_5, 85–98 percent of TKN and NH_4-N, 38–95 percent of TP, and 37–99 percent of Zn and Cu. A second-generation version of the system removed 98 percent TSS, 97 percent NH_4-N, 95 percent TP, 99 percent Zn and Cu, 99.9 percent odors, and 99.99 percent pathogens (Vanotti et al. 2009).

Table 2-6. Summary of reported practice effects resulting from lagoon treatment

Location	Study type	Practice	Practice effects	Source
Nova Scotia	Farm	Aerobic lagoon	For swine waste, removals of 59%–71% TSS, 59%–73% VSS, 42%–60% TKN, and 42%–51% NH_4-N	Trias et al. 2004
France	Farm	Aerobic/anoxic lagoons	For swine manure wastewater, achieved 86% TSS reduction, 90% TN and COD reduction; 50% of soluble P was biologically removed by an intermittent aerobic/anoxic sequence.	Prado et al. 2009
Korea	Farm	Two-stage sequencing batch reactor	Removal efficiencies of 98% TOC, 100% NH_4-N, 98% TKN, 97% ortho-P, 98% TP, 97% suspended solids, and 97% volatile suspended solids from swine waste	Ra et al. 1998
North Carolina	Farm	Solids separation + biological N and P removal	For swine waste treatment, removal of 73-98% TSS, 40%–76% of TS, 77%–100% of BOD_5, 85-98% of TKN and NH_4-N, 38%–95% of TP, and 37%–99% of Zn and Cu.	Vanotti and Szogi 2008
North Carolina	Farm	Solids separation + biological N and P removal (2nd generation)	For swine waste treatment, removal of 98% TSS, 97% NH_4-N, 95% TP, 99% Zn and Cu, 99.9% odors, and 99.99% pathogens	Vanotti and Szogi 2009

Waste treatment and processing—other treatment

Masse et al. (2007) reviewed the most recent literature on membrane filtration for manure concentration and treatment and found studies of ultrafiltration of manure that reported up to 100 percent removal of coliform and SS, 87 percent P reduction, but no effect on soluble COD from ultrafiltration (0.01 μm) and lower efficiency from microfiltration (0.2 μm), e.g., 75 percent SS removal.

In Ireland, Healy et al. (2004) tested recirculating sand filters for treatment of dairy wastewater and reported TN reduction of 27 to 41 percent; TN reduction increased to 83 percent when sand filter effluent was recirculated through an anoxic zone. A subsequent study (Healy et al. 2007) reported consistent COD and TSS removals of greater than 99 percent, and an 86 percent reduction in TN.

Lee and Song (2006) reported average removal of 81 percent COD, 92 percent SS, 68 percent TN, and 95 percent TP using ozone to treat livestock wastewater through a dissolved air flotation system in Korea. Separation, collection, and treatment of swine waste with an ammonia recovery process using a metal ion treated resin bed achieved greater than 90 percent reduction in ammonia content in North Carolina (Loeffler and van Kempen 2003). Removal of up to 90 percent of P from swine waste treated by chemical precipitation with struvite and hydroxyapatite was reported in South Korea (Choi et al. 2008).

Table 2-7. Summary of reported practice effects resulting from other wastewater treatment

Location	Study type	Practice	Practice effects	Source
Numerous	Review	Membrane filtration	Ultrafiltration (0.01 μm) of manure: up to 100% removal of coliform and SS, 87% P reduction, no effect on soluble COD; lower efficiency from microfiltration (0.2μm: 75% SS removal.	Masse et al. 2007
Ireland	Farm	Recirculating sand filter	For dairy wastewater, reported TN reduction of 27 to 41%; TN reduction increased to 83% when sand filter effluent was recirculated through an anoxic zone	Healy et al. 2004
Ireland	Farm	Recirculating sand filter	For dairy wastewater, COD and TSS removals of > 99%, and an 86% reduction in TN	Healy et al. 2007
Korea	Farm	Ozone dissolved air flotation system	Average removals of 81% COD, 92% SS, 68% TN, and 95% TP removal from livestock wastewater	Lee and Song 2006
North Carolina	Farm	Separation + ammonia recovery[a]	Achieved > 90% reduction in ammonia content in swine waste	Loeffler and van Kempen 2003
Korea	Farm	Chemical precipitation[b]	Up to 90% removal of P from swine waste	Choi et al. 2008

Notes:

a. Ammonia recovery using a metal ion treated resin bed

b. Struvite and hydroxyapatite

Digestion

Anaerobic digestion of manure can offer substantial benefits, both economic and intangible, to animal feeding operators and surrounding communities, such as renewable energy generation; reduction in bulk and improvement of handling characteristics; production of stable, liquid fertilizer and high-quality solid soil amendment; reduction in odors; reduction of greenhouse gasses (GHGs); and reduction in ground and surface water contaminants (Demirer and Chen 2005; Cantrell et al. 2008; Garrison and Richard 2005). There is ample literature concerning digester performance and yield, but not all studies report performance relevant to water quality concerns. It should be noted that digestion does not generally remove nutrients from the original waste material, and the residuals from digestion require further management.

Costa et al. (2007) evaluated the efficiency of the anaerobic digestion in reducing the organic load of swine waste. Results showed an average reduction of COD of 58 percent.

In Turkey, Gungor-Demirci and Demirer (2004) investigated the potential biogas generation from anaerobic digestion of broiler and cattle manure. The efficiency of total COD removal was 32–43 percent and 40–50 percent for initial COD concentrations of 12,000 and 53,500 mg/L, respectively. The biogas yields observed for initial COD concentrations of 12,000 and 53,500 mg/L were 180–270 and 223–368 mL gas/g COD added, respectively.

A thermochemical conversion process applied to the treatment of swine manure for oil production in Illinois achieved a 75 percent reduction in COD (He et al. 2000). Lansing et al. (2008a) reported 84 percent reduction in COD and a 78 percent increase in dissolved NH_4-N concentration in a study of seven low-cost digesters in Costa Rica. In a companion study of very small farms, Lansing et al. (2008b) reported reductions in COD of 86 percent for dairy digester and 92 percent for a swine digester.

Thermophilic aerobic digestion reduced volatile solids by 28–54 percent in Ireland, while producing Class A biosolids suitable for land application (Layden et al. 2007). Anaerobic digestion of poultry feces in Nigeria achieved greater than 99 percent reductions in *E. coli* bacteria counts compared to an undigested, but equal-aged control (Yongabi et al. 2009).

In China, adding undigested swine wastewater to digested wastewater in a sequencing batch reactor process significantly improved COD removal to greater than 80 percent and NH_4-N removal up to 99 percent (Deng et al. 2005). The effluent COD concentration was in the range of 250 mg/L to 350 mg/L and effluent NH_4-N concentration was less than 10 m/L. A pilot-scale sequencing batch reactor built to treat swine waste in Australia achieved NH_4-N and odor reductions of greater than 99 percent as well as 79 percent removal of COD and a 49 percent reduction of PO_4-P on a mass balance basis because of struvite formation within the reactor (Edgerton et al. 2000).

In China, enhancement of a traditional sequencing batch reactor for swine waste with two-step feeding and low-intensity aeration at laboratory scale yielded reductions of 94 percent TN, 99 percent TP, and 99.9 percent BOD_5, possibly reflecting the activity of denitrifying P-accumulating organisms (Lue et al. 2008; Lu et al. 2009).

Table 2-8. Summary of reported practice effects resulting from manure digestion

Location	Study type	Practice	Practice effects	Source
Unknown	Farm	Anaerobic digestion	Average reduction of COD of 58%.	Costa et al. 2007
Turkey	Pilot	Anaerobic digestion	For digestion of broiler and cattle manure, COD removal was 32%–43% and 40%–50% for initial COD concentrations of 12,000 and 53,500 mg/L, respectively. The biogas yields observed for initial COD concentrations of 12,000 and 53,500 mg/L were 180-270 and 223-368 mL gas/g COD added, respectively	Gungor-Demirci and Demirer 2004
Illinois	Pilot	Thermochemical conversion	75% reduction in COD of swine manure	He et al. 2000
Costa Rica	Farms	Anaerobic digestion	84% reduction of COD; 78% increase in NH_4-N	Lansing et al. 2008a
Costa Rica	Farms	Anaerobic digestion	86% reductions of COD for dairy digester 92% reductions of COD for a swine digester	Lansing et al. 2008b
Ireland	Farm	Thermophilic aerobic digestion	28%–54% reduction in volatile solids[a]	Layden et al. 2007
Nigeria	Farm	Anaerobic digestion	> 99% reductions in *E. coli*[b]	Yongabi et al. 2009
China	Farm	Sequencing batch reactor	Adding additional undigested swine wastewater to digested wastewater in a sequencing batch reactor process significantly improved with COD removal to > 80% and NH_4-N removal up to 99%	Deng et al. 2005
Australia	Pilot	Sequencing batch reactor	For swine waste, > 99% NH_4-N and odor reductions, 79% removal of COD, and a 49% reduction of PO_4-P on a mass balance basis[c]	Edgerton et al. 2000
China	Laboratory	Enhanced sequencing batch reactor[d]	Reductions of 94% TN, 99% TP, and 99.9% BOD_5, possibly from growth of denitrifying P-accumulating organisms	Lue et al. 2008; Lu et al. 2009

Notes:

a. Produced Class A biosolids suitable for direct land application
b. Compared to an undigested, but equal-aged control
c. Due to struvite formation within the reactor
d. Addition of two-step feeding and low-intensity aeration to traditional SBR

Composting

Composting of animal manure can reduce bulk, kill microorganisms, improve handling, and provide a value-added product (Brodie et al. 2000). While significant quantities of N can be lost through volatilization in the composting process (consider air quality issues), composting has no net effect on the TP content of the material.

In Texas, Bekele et al. (2006) documented a 19–23 percent decrease in soluble P in streams draining areas where significant quantities of manure had been composted and removed from the watershed. While composting did not change the P content of the end product, composting facilitated transport and marketing of the final product.

Gibbs et al. (2002) measured nutrient losses from aerobic composting of cattle manure in the UK. Total mass loss ranged from 23 percent for an unturned static composting to 67 percent of the initial mass for the indoor composting turned three times. N losses from the manure heaps ranged from 8 to 68 percent of the initial total manure N content. Gaseous N losses, primarily as NH_3, accounted for between 7 and 67 percent of the initial manure N content.

Table 2-9. Summary of reported practice effects resulting from manure composting

Location	Study type	Practice	Practice effects	Source
Texas	Watershed	Composting + export	19%–23% decrease in soluble P in streams draining areas where significant quantities of manure had been composted and removed from the watershed	Bekele et al. 2006
U.K.	Farm	Aerobic composting	23% mass loss for an unturned static composting; 67% mass loss for the indoor composting turned 3 times Compost piles lost 8%–68% of initial TN; gaseous N losses, primarily as NH_3, accounted for 7%–67% of the initial manure N	Gibbs et al. 2002
Canada	Farm	Aerobic composting	Exposure to temperatures > 55 °C for 15 d inactivated *Giardia* cysts and *Cryptosporidium* oocysts in beef feedlot manure	Larney and Hao 2007
Georgia	Farm	Co-composting	Co-composting of chicken hatchery waste and poultry litter was effective in eliminating 99.99% of *E. coli* bacteria	Das et al. 2002

In beef feedlot manure composting in Alberta, Canada, Larney and Hao (2007) reported that exposure of manure to temperatures above 55 °C for a period of 15 days appears to be an effective method of inactivating both *Giardia* cysts and *Cryptosporidium* oocysts in feedlot manure. The authors report mean carbon and N concentrations in eight feedlot manure composts: total carbon 228 g/kg, TN 16.0 g/kg, soluble carbon11.3 g/kg, soluble N 1.6 g/kg.

Das et al. (2002) reported that co-composting of chicken hatchery waste and poultry litter was effective in eliminating 99.99 percent of *E. coli* bacteria in Georgia. Koenig et al. (2005) reported that alum and process controls such as moisture content, carbon source and particle size have the potential to reduce NH_3 loss from poultry manure composted inside high-rise layer structures.

Constructed wetland treatment

N in wastewater from dairy and swine operations has been successfully treated in constructed wetlands (Hunt and Poach 2001). Plants are an integral part of wetlands. Cattails and bulrushes are commonly used in constructed wetlands for nutrient uptake, surface area, and oxygen transport to sediment. Improved oxidation and nitrification can also be obtained by using the open water of marsh-pond-marsh designed wetlands. High levels of N removal by denitrification have been reported from constructed wetlands, especially when the wastewater is partially nitrified (Hunt et al. 2009). Manure solids must be removed before wetland treatment is essential for the wetland to function long term.

A constructed wetland to treat incoming barnyard runoff in Ireland retained greater than 60 percent of the P load delivered to the wetland (Dunne et al. 2004). A subsequent study (Dunne et al. 2005) reported that P retention by the wetland varied with season (5–84 percent) with lowest retention occurring in winter.

In a review of 12 constructed wetlands treating livestock wastewater on the south coast of Ireland, Harrington and McInnes (2009) reported that over an 8-year period, mean reduction of total and soluble P exceeded 95 percent and the mean removal of ammonium-N exceeded 98 percent.

Mustafa et al. (2009) reported removal efficiencies of 98 percent BOD, 95 percent COD, 94 percent SS, 99 percent ammonia N, 74 percent NO_3-N, and 92 percent soluble P in dairy wastewater treatment through a constructed wetland system in Ireland.

Lee et al. (2004) reported that average reduction efficiencies in subsurface flow constructed wetlands in Taiwan were SS 96–99 percent, COD 77–84 percent, TP 47–59 percent, and TN 10–24 percent. While physical mechanisms were dominant in removing pollutants, the contributions of microbial mechanisms increased with the duration of wetland use, achieving 48 percent of COD removed and 16 percent of TN removed in the last phase. Water hyacinth made only a minimal contribution to the removal of nutrients.

In Kansas, Mankin and Ikenberry (2004) evaluated a constructed wetland without vegetation as a sequencing batch reactor. Using 3-week batch periods without plants, overall mass removal averaged 54 percent for COD, 58 percent for TSS, 90 percent for TN, 72 percent for NH_4, -54 percent for NO_3, 38 percent for TP, and -8 percent for PO_4.

Prantner et al. (2001) reported that a U.K. wetland system treating liquid swine manure after soil infiltration removed 94 percent of the NH_3-N and NH_4-N, 95 percent of the NO_3-N, and 84 percent of the TP.

Table 2-10. Summary of reported practice effects resulting from wetland treatment

Location	Study type	Practice	Practice effects	Source
Ireland	Farm	Constructed wetland	Retained > 60% of the P load delivered in barnyard runoff; P retention by the wetland varied with season (5%–84%) with lowest retention occurring in winter	Dunne et al. 2004, 2005
Ireland	Review	Constructed wetland	8-year mean reduction of total and soluble P > 95% and the mean removal of ammonium-N > 98%.	Harrington and McInnes 2009
Ireland	Farm	Constructed wetland	Removal efficiencies of 98% BOD, 95% COD, 94% SS, 99% ammonia N, 74% NO_3-N, and 92% soluble P in dairy wastewater treatment	Mustafa et al. 2009
Taiwan	Review	Constructed wetlands (subsurface flow)	Average reduction efficiencies in subsurface flow constructed wetlands in Taiwan were SS 96-99%, COD 77–84%, TP 47–59%, and TN 10–24%[a]	Lee et al. 2004
Kansas	Wetland	Constructed wetland without vegetation	Mass removal averaged 54% COD, 58% TSS, 90% TN, 72% NH_4, -54% NO_3, 38% TP, and -8% PO_4	Mankin and Ikenberry 2004
U.K.	Farm	Constructed wetland	Treating liquid swine manure after soil infiltration removed 94% of NH_3-N and NH_4-N, 95% of NO_3-N, and 84% of TP.	Prantner et al. 2001
Maryland	Farm	Constructed wetland	Treating dairy wastewater TN reduced 98%, ammonia 56%, TP 96%, ortho-P 84%, SS 96%, and BOD 97%; NO_3/ NO_2 increased 82%	Schaafsma et al. 2000
Nova Scotia	Farm	Constructed wetland	Load reductions from 62%–99% for BOD, TSS, TP, and NH_3-N treating agricultural wastewater	Smith et al. 2006
Nova Scotia	Farm	Constructed wetland	Load reductions of 54% TP and 53% soluble P treating milkhouse wash water and liquid manure	Wood et al. 2008
Vermont	Farm	Subsurface flow constructed wetland with slag filter	Removed 75% of P mass from dairy barnyard runoff and milk parlor waste	Weber et al. 2007

Note:

a. Physical mechanisms were dominant in removing pollutants; the contributions of microbial mechanisms increased with the duration of wetland use. Water hyacinth made only a minimal contribution to the removal of nutrients.

Flow of dairy wastewater through the wetland system in Maryland resulted in significant reductions in concentrations of all analytes except NO_3/NO_2 (Schaafsma et al. 2000). Relative to initial concentrations, TN was reduced 98 percent, ammonia 56 percent, TP 96 percent, ortho-P 84 percent, SS 96 percent, and BOD 97 percent. NO_3/NO_2 increased by 82 percent, although mean concentrations were much lower than concentrations of ammonia or TN.

In Nova Scotia, Smith et al. (2006) reported load reductions from 62 to 99 percent for BOD, TSS, TP, and NH_3-N in wetlands treating agricultural wastewater. Also in Nova Scotia, Wood et al. (2008) reported mass reductions of 54 percent for TP and 53 percent soluble P over 4 years in a surface flow constructed wetland milkhouse wash water and liquid manure. In Vermont, a subsurface flow constructed wetland with a slag filter removed 75 percent of P mass from dairy barnyard runoff and milk parlor waste (Weber et al. 2007).

Other biological treatment

A multiple-pond system (APS) treating dairy milking parlor effluent in New Zealand produced effluent with 50–60 percent less BOD, TSS, TKN and ammonia-N than equivalently sized two-pond systems with medians of 43, 87, 61, and 39 mg/L, respectively. TP was reduced by 70 percent to 19 mg/L. *E. coli* were reduced in the APS by two orders of magnitude to 918 MPN/100 mL (Bolan et al. 2009).

In Morocco, El Hafiane et al. (2003) reported average removals of 70 percent for N and 40 percent for P in a high-rate algal pond treating wastewater. Water hyacinth ponds were reported to achieve approximately 50 percent removal of applied organic loads (COD, BOD, TN, and TP) from swine waste in Brazil (Costa et al. 2000).

In Scotland, an algal-based bioreactor achieved sustained nutrient removal efficiencies (up to 99 percent and 86 percent for NH_4-N and PO_4-P, respectively) from swine wastewater while total COD was removed up to 75 percent (Gonzalez et al. 2008). Lu et al. (2008) augmented a wetland treating duck waste in China with water hyacinth and reported removal of 64 percent of COD, 22 percent TN, and 23 percent TP loads. The hyacinth was harvested and recycled as duck feed.

Anaerobically digested dairy manure effluent was treated with algal turf scrubber raceways in Maryland (Mulbry et al. 2008). Removal rates of 70 to 90 percent of input N and P were achieved at loading rates below one g TN, 0.15 g TP $/m^2/d$; N and P removal rates decreased to 50–80 percent at higher loading rates.

Table 2-11. Summary of reported practice effects resulting from other biological treatment

Location	Study type	Practice	Practice effects	Source
New Zealand	Farm	Multiple pond system	Treating dairy milking parlor effluent produced effluent with 50%–60% less BOD, TSS, TKN and ammonia-N than equivalently sized two-pond systems. TP was reduced by 70% to 19 mg/L. *E. coli* reduced by two orders of magnitude.	Bolan et al. 2009
Morocco	Farm	High-rate algal pond	averaged removals of 70% N and 40% P	El Hafiane et al. 2003
Brazil	Farm	Water hyacinth ponds	About 50% removal of applied organic loads (COD, BOD, TN, TP) from swine waste	Costa et al. 2000
Scotland	Farm	Algal bio-reactor	Removed 99% NH_4-N, 86% of PO_4-P, and 75% of COD mass from swine wastewater	Gonzalez et al. 2008
China	Farm	Water hyacinth wetland	Removed 64% COD, 22% TN, and 23% TP loads from duck waste[a]	Lu et al. 2008
Maryland	Farm	Algal turf scrubber	Treating anaerobically digested dairy manure effluent, removal rates of 70-90% of input N and P were achieved at loading rates below 1 g TN, 0.15 g TP /m^2/d; N and P removal rates decreased to 50–80% at higher loading rates.	Mulbry et al. 2008
Hawaii	Farm	Entrapped mixed microbial cells process	Removed 84% of COD and 98% of TP from dilute swine wastewater	Yang et al. 2003

Note:

a. Water hyacinth was harvested and recycled as duck feed.

An entrapped mixed microbial cells process was used to investigate the simultaneous removal of carbon and N from dilute swine wastewater in Hawaii (Yang et al. 2003). COD removal efficiencies were 84 percent and TP removal efficiencies of 98 percent were achieved.

Air quality

Ammonia, dust, and odors associated with animal agriculture—especially on large facilities—can be important local air pollutants. For example, Melse and Timmerman (2009) reported that N emissions in exhaust air from pig houses in the Netherlands can represent as much as 25 percent of the TN excretion by the animals. Airborne ammonia can also become a significant water pollutant when deposited in local waterbodies. Indoor air quality can affect animal health as well, especially at large poultry and hog facilities. Animal production facilities can be important producers of greenhouse gases (van der Meer 2008).

Ullman et al. (2004) reviewed abatement technologies available to reduce atmospheric emissions from animal production facilities and summarized the following:

- Scrubbers have been shown to reduce odors by 60–85 percent and to reduce ammonia by 15–45 percent.
- Filter systems can reduce airborne dust from broiler operations by up to 50 percent.
- Biofilters can exhibit 90 percent or better reductions of odor-causing chemicals such as hydrogen sulfide, methanethiol, dimethyl sulfide, and dimethyl disulfide.
- Ionization systems can reduce dust concentrations 68–92 percent.
- Indoor ozone systems can decrease total dust concentrations by 60 percent and ammonia levels by 58 percent compared to similar buildings without ozone treatment.

The authors added that poultry litter amendments such as sodium bisulfate and alum can reduce odor and ammonia emissions and natural windbreaks can provide an entrapment mechanism for odorous compounds that require minimal maintenance. Windbreaks placed downwind of exhaust fans and litter storage areas can provide an economical management practice for broiler producers when used in conjunction with other air-cleaning practices.

In Kentucky, Singh et al. (2009) reported that adding a commercially available urease inhibitor to poultry litter resulted in a significant reduction in equilibrium ammonia concentration over time by disrupting the enzymatic degradation of uric acid.

Melse and Timmerman (2009) reported average ammonia removal efficiencies of 70–96 percent for farm-scale operated acid scrubbers on swine facilities in the Netherlands. Reported average removal efficiency for odor was only 31 percent and showed a large variation. Multi-pollutant scrubbers removed an average of 66 percent of ammonia, 42 percent of odor, 50 percent of PM_{10}, and 57 percent of $PM_{2.5}$.

Adrizal et al. (2008) evaluated the potential of trees planted around Pennsylvania commercial poultry farms to trap ammonia and dust or particulate matter. Results indicated that poplar, hybrid willow, and Streamco willow are appropriate species to absorb poultry house aerial NH_3-N, whereas spruce and hybrid willow are effective traps for dust and its associated odors.

Koenig et al. (2005) reported that alum and process controls such as moisture content, carbon source and particle size have the potential to reduce ammonia loss from poultry manure composted inside high-rise layer structures. Although both low moisture and temperature reduced NH_3 capture, managing temperature and moisture to achieve low NH_3 would adversely affect microbial activity and other desired benefits of composting.

In a Texas laboratory study, Shi et al. (2001) evaluated amendments for reducing ammonia emissions from open-lot beef cattle feedlots and found that cumulative ammonia emissions after 21 days compared to the untreated control were 2–8 percent for alum, 22–29 percent for $CaCl_2$, 32–40 percent for humate, 34–36 percent for a urease-inhibitor NBPT, and 68–74 percent for a commercial product.

In North Carolina, Szogi and Vanotti (2007) demonstrated that solid-liquid separation technologies can substantially reduce ammonia emissions from anaerobic swine lagoons. Ammonia emissions from a lagoon with solid-liquid separation had 73 percent lower ammonia emissions compared to an anaerobic lagoon.

Table 2-12. Summary of reported practice effects for air quality issues

Location	Study type	Practice	Practice effects	Source
Numerous	Review	Various	Scrubbers can reduce odors by 60%–85% and reduce ammonia by 15%–45% Filter systems can reduce airborne dust from broiler operations by up to 50% Biofilters can exhibit 90% or better reductions of odor-causing chemicals Ionization systems can reduce dust concentrations 68%–92% Indoor ozone systems can decrease total dust concentrations by 60% and ammonia levels by 58% compared to similar buildings without ozone treatment	Ullman et al. 2004
Netherlands	Farm	Acid scrubbers	Average 70%–96% ammonia removal, 31% odor removal on swine facilities; multi-pollutant scrubbers removed 66% of ammonia, 42% odor, 50% PM_{10} removal, and 57% $PM_{2.5}$	Melse and Timmerman 2009
Pennsylvania	Farm	Tree windbreaks	Poplar, hybrid willow, and *Streamco* willow absorb poultry house aerial NH_3-N; whereas spruce and hybrid willow are effective traps for dust and odors.	Adrizal et al. 2008
Texas	Laboratory	Beef feedlot amendments	21-day cumulative ammonia emissions compared to untreated control were: 2%–8% for alum, 22%–29% for $CaCl_2$, 32%–40% for humate, 34%–36% for a urease-inhibitor NBPT, and 68%–74% for a commercial product.	Shi et al. 2001
North Carolina	Farm	Liquid-solid separation	Ammonia emissions from a lagoon with solid-liquid separation had 73% lower ammonia emissions compared to an anaerobic lagoon.	Szogi and Vanotti 2007
North Carolina	Farm	Aerobic lagoon	Reduced GHG emissions 96.9%, from 4,972 t to 153 t of carbon dioxide equivalents (CO_2-eq)/yr	Vanotti et al. 2008

Replacing swine waste lagoon technology with cleaner aerobic technology in North Carolina reduced GHG emissions 96.9 percent—from 4,972 metric tons (MT) to 153 MT of carbon dioxide equivalents (CO_2-eq)/yr (Vanotti et al. 2008).

Practice Costs

Systematic cost data for most practices are rarely given in the scientific literature; better cost data might be available on a state or county basis from producers, groups, or agencies funding or managing implementation. Among reported cost data, there is a lack of consistency in unit costs (e.g., $/cow, $/kg P removed, or $/L of waste treated) that sometimes makes comparison among practices difficult. Cost figures are reported in dollars for the year given by the authors.

In laboratory studies, Jones and Brown (2000) estimated chemical cost (2010 dollars) for combinations of alum and PAM of $74–$200/kg ortho-P removed from dairy wastewater. For supplementary precipitation of soluble P in the treatment of dairy manure by mechanical separation, Oh et al. (2005) estimated costs for alum and polymer addition of about $3.21 per 1,000 L (2010 dollars) of treated manure slurry.

Moore et al. (2000) found that alum applications to poultry litter was cost-effective, with a benefit/cost ratio of 1.96 partly from heavier birds, better feed conversion, and lower energy use to vent ammonia from the houses.

In a cost analysis of anaerobic digestion and methane production, Garrison and Richard (2005) noted that the economic feasibility of the energy conversion technology varies widely with scale, with significant advantages for larger facilities. Farrow-to-finish and finishing swine operations needed more than 20,000 head and 5,000 head, respectively, to be economically feasible. Dairy operations in the midwestern United States hold considerably more economic promise, with feasible herd counts in the 150- to 350-head range for electricity prices of $0.13/kWh (2010 dollars). Results indicate that increased energy prices and financial assistance will be needed to encourage significant numbers of facilities to recover energy from manure.

In Virginia, covered lagoon anaerobic digesters run from about $112/head for swine to about $318/head for dairy, with plug-flow digesters for dairy costing just under $700/head (USDA-NRCS 2010). Typical total costs are about $112,000 for covered lagoons for swine, $240,000 for covered lagoons for dairy, and just over $512,000 for plug-flow anaerobic digesters for dairy.

Brodie et al. (2000) studied technologies to manufacture compost from poultry litter and reported that screened compost was produced at an operational cost of $37 (2010 dollars) while unscreened compost could be produced for about $25 per ton of compost. A production scheme where poultry litter is a static pile composted on farms for later transport to regional processing centers appeared feasible.

Kemper and Goodwin (2009) reported that in composting poultry litter and eggshell waste into a marketable soil amendment, compost could be produced at an average cost of $17.73 to $20.38/ton (2010 dollars) for small-scale and large-scale systems, respectively. The cost for disposing of eggshell waste in landfills was $25.36/ton (2010 dollars).

Static pile/windrow composting facilities with a concrete floor that are used for vegetative materials cost about $55/yd^3, with typical facilities costing about $18,100 (USDA-NRCS 2010). Animal mortality composting facilities cost about $330/yd^3 for either poultry or swine. Typical dead-poultry composting facilities cost about $12,000, whereas typical dead-swine composting facilities cost much more—about $35,000. A static pile/windrow composter with a concrete floor for animal mortality is a lower cost option that runs about $107/yd^3, with typical total costs of under $9,500. Larger (1,500-lb capacity) dead-animal incinerators cost about $10.60 per pound of capacity, while smaller incinerators (400-lb capacity) cost $23.44 per pound of capacity, with typical costs of about $16,000 and $9,500 each for larger and smaller incinerators, respectively. Gasification units are a higher-end option for dead animals, ranging from just over $58 to nearly $150 per pound of capacity, with units typically costing $40,000 to $70,000 depending on size. Even more expensive are forced aeration composters. They can cost from about $900 to $1,300/yd^3 depending on capacity and whether a grinder is included, with typical facility costs ranging from about $130,000 each to just over $250,000 each.

In a study of using filamentous green algae grown in outdoor raceways to treat dairy manure effluent, Mulbry et al. (2008) projected annual operational costs of $788 per cow (2010 dollars). For comparison, the operational costs of $11.12 per kg N removed are well below the costs cited for upgrading existing water treatment plants.

Vegetative environmental buffers (strategically planted trees and shrubs) around poultry houses cost $4.05/ft in the form of containerized plants, with typical costs reaching $4,055 in Virginia (USDA-NRCS 2010). Windbreaks or shelterbelts consisting of pines, hardwoods, and mixed shrubs cost $82.50, $909, and $1,453 per acre, respectively, with respective typical total costs of $41.25, $456, and $726.

Shi et al. (2001) calculated the costs of six amendments for reducing ammonia emissions from open-lot beef cattle feedlots, ranging from $0.15 to $6.81 (2010 dollars) per application per head. Only one treatment had a benefit/cost ratio greater than 1.0. Results suggest that amendments can reduce ammonia emissions from open feedlots, but the costs might be prohibitive.

Vanotti et al. (2008) analyzed GHG emission reductions from implementing aerobic technology on swine farms in North Carolina and estimated emission reductions of 4,776.6 MT CO_2-eq per year or 1.10 MT CO_2-eq/head per year. The dollar value from implementation was $19,312/year (2010 dollars) using current Chicago Climate Exchange trading values of $4.04/t CO_2 (2010 dollars). That translates into a direct economic benefit to the producer of $1.77 (2010 dollars) per finished pig. The authors suggest that GHG emission reductions and credits can help compensate for the higher installation cost of cleaner aerobic technologies and facilitate producer adoption of environmentally superior technologies to replace current anaerobic lagoons.

In studies of poultry litter amendments to reduce odor and ammonia volatilization, Ullman et al. (2004) found that sodium bisulfate and alum treatments ranged in price from $253 to $530 per ton (2010 dollars), resulting in a cost of $13 to $18 for 92.9 m^2 (1,000 ft^2) at recommended application rates. Another cost benefit analysis showed that ammonia reduction by ventilation during cold periods would cost $4,400 per flock (19,000 birds weighing four lb each).

Unit and typical total costs for various amendments to treat agricultural waste are the following (USDA-NRCS 2010):

- Ferric sulfate or alum for broiler house litter: $0.199/$ft^2$, $3,750 total
- Ferric sulfate or alum for turkey or rooster house litter: $0.159/$ft^2$, $3,000 total
- Liquid alum treatment for very dry broiler house litter: $0.268/$ft^2$, $5,060 total
- Liquid alum treatment for turkey or rooster house litter: $0.214/$ft^2$, $4,050 total
- Sodium bisulfate treatment for broiler house litter: $0.205/$ft^2$, $3,880 total
- Sodium bisulfate treatment for turkey or rooster house litter: $0.164/$ft^2$, $3,100 total

3 Implementation Measures and Practices for Cropland In-Field Control

The best approach to minimize nutrient transport to local waters depends on whether the nutrient is in the dissolved phase or is attached to soil particles. For dissolved nutrients, effective management includes source reduction and reduction of water runoff or leaching. Erosion and sediment transport controls are necessary to reduce transport of nutrients attached to soil particles. Practices that focus on controlling the transport of smaller soil particle sizes (e.g., clays and silts) are most effective because they are the soil fractions that transport the greatest share of adsorbed nutrients.

3.1 Field Nutrient Management

Strategies for in-field control on cropland focus on managing the form, application method, and timing of waste and nutrient applications and on controlling soil conditions to reduce the potential for runoff of nutrients. Pasture management strategies address managing animal stocking rates and timing as well as maintaining vigorous vegetation to provide for soil stability and nutrient recycling.

Implementation Measure A-10:

Manage nutrient applications to cropland to minimize nutrients available for runoff. In doing so

- Apply manure and chemical fertilizer during the growing season only
- Do not apply any manure or fertilizer to saturated, snow-covered, or frozen ground
- Inject or otherwise incorporate manure or organic fertilizer to minimize the available dissolved P and volatilized N
- Apply nutrients to HELs only as directed by the nutrient management plan, while at the same time implementing all aspects of the soil conservation plan

In many crop areas, nutrient imports into the watershed from feed and fertilizers exceed nutrient exports in crops and livestock produced; that imbalance often exists at both the individual field and the watershed level (Beegle 2000). In such circumstances, nutrients can accumulate in soils from over-application of fertilizer or animal waste relative to crop need. Excessive soil nutrient levels have been linked to high P losses in runoff and leaching losses of N, especially in areas of animal-based agriculture.

Nutrient management is an important tool to match nutrient inputs more closely to crop needs. The USDA-NRCS Nutrient Management Practice (NRCS Practice Code 590) generally defines nutrient management as, “managing the amount, source, placement, form and timing of the application of nutrients and soil amendments.” The Nutrient Management Practice can be applied for a number of purposes:

- To budget and supply nutrients for plant production
- To properly use manure and organic byproducts or biosolids as a plant nutrient source
- To minimize agricultural nonpoint source pollution of surface and ground water resources
- To protect air quality by reducing N emissions and the formation of atmospheric particulates
- To maintain or improve the physical, chemical, and biological condition of soil

This section presents information concerning several management practices to manage nutrients on cropland to reduce nutrient losses:

- **Manure and fertilizer form and rate**—selecting the form (N and P amounts in solid, semi-solid, or liquid manure) and rate of nutrients applied to cropland to reduce runoff or leaching losses
- **Nutrient application methods and timing**—selecting the method and timing of manure or fertilizer application to cropland to support crop growth and reduce runoff or leaching losses
- **Nutrient management planning**—preparing and implementing a comprehensive plan to manage nutrients from all sources to provide for crop growth while minimizing runoff and leaching losses of nutrients
- **Soil and manure amendment**—treating soils or manure to reduce the availability or mobility of nutrients

Using the products and methods described in this section should be considered carefully relative to existing practices because timing and placement of fertilizers play an important role in maximizing NUE. For example, if a producer replaces side dressing with use of a urease inhibitor, the timing and fertilizer placement must be a factor in the decision to switch. Also, emerging technologies will allow producers who use no-till on their cropland to inject manure so that no-till is continuous. That type of technology is welcome and should continue to be developed and widely implemented.

Reference documents are available that provide guidance on selection of practices with consideration for fertilizer source as well as timing, placement, and rate of application. Some examples are listed below (all Web sites were accessed April 24, 2010). Other regional- or state-specific guidance should be available from NRCS Field Offices and Land Grant Universities in each state.

- EPA's National Management Measures for the Control of Nonpoint Pollution from Agriculture
- NRCS Agricultural Waste Management Field Handbook
- eXtension Resource Areas including Animal Manure Management and several industry-specific resource areas (http://www.extension.org/main/communities)
- Fertilizer Nitrogen BMPs to Limit Losses that Contribute to Global Warming (Snyder 2008)
- Best Management for Fertilizers on Northeastern Dairy Farms (Bruulsema and Ketterings 2008)
- Optimizing Nitrogen Fertilizer Decisions (Nielsen 2001)
- Cornell University's Whole Farm Nutrient Management Tutorials (http://instruct1.cit.cornell.edu/Courses/css412/index.htm)
- Penn State Cooperative Extension Nutrient Management Planning Tools and Resources (http://panutrientmgmt.cas.psu.edu/main_planning_tools.htm)
- Penn State Agronomy Guide, Section 2 Soil Fertility Management, (http://agguide.agronomy.psu.edu/cm/sec2/sec2toc.cfm)
- Delaware Nutrient Management Program Publications and Resources (http://dda.delaware.gov/nutrients/NM_Pubs_resources.shtml)
- University of Maryland Agricultural Nutrient Management Program (http://anmp.umd.edu/)
- West Virginia University Extension Service Nutrient/Waste Management Web page (http://www.wvu.edu/~agexten/wastmang/index.html)

EPA encourages producers to consult with crop advisors, nutrient management planners, NRCS Field Offices and Cooperative Extension Services for assistance in evaluating the relative costs and benefits of a particular practice or system.

Practice Effectiveness

Manure and fertilizer form and rate

Chien et al. (2009) reviewed recent developments of fertilizer production and use that improve nutrient efficiency and minimize environmental impact. Improving N use efficiency includes using the following:

- Controlled-release coated urea products
- Nitrification inhibitors (NI) to reduce NO_3 leaching and denitrification
- Urease inhibitors to reduce ammonia hydrolysis from urea, with subsequent volatilization
- Ammonium sulfate to enhance N efficiency of urea by reducing ammonia volatilization from urea

As indicated above, field conditions and relative benefits must be carefully considered when evaluating use of these products to improve N use efficiency. Nielsen (2006) reports that, even when compared to urease inhibitors or nitrification inhibitors, using a more traditional sidedress application strategy remains one of the easiest and least expensive ways to maximize N use efficiency because other application methods need to be carefully matched to the N fertilizer source to minimize the risk of N loss before plant uptake.

Little research is available that directly compares the effectiveness of ammonium sulfate versus urease inhibitors in reducing ammonia volatilization from urea. A widely used and intensively researched urease inhibitor has been shown to reduce ammonia volatilization by an average of 60 percent compared to urea alone (Cantarella et al. 2005). Other studies (Fleisher and Hagin 1981, Kumar and Aggarwal 1998, and Goos and Cruz 1999) found that application of ammonium sulfate 2 to 4 weeks in advance of urea reduced ammonia volatilization by approximately 50 percent.

Practicality and cost are also important considerations. Goos and Cruz (1999) suggest that application of ammonium sulfate in advance of urea could be limited in practical application because it is not always possible to replicate the fertilizer applications in the same field location. Other studies (Lara-Cabezas et al. 1992, 1997; Oenema and Velthof 1993; Vitti et al. 2002) suggest that substituting ammonium sulfate for part of the urea mixture at application could be effective in reducing ammonia volatilization, but as Chien et al. (2009) point out, this use must be weighed in terms of its relative cost including an increase in the transportation cost for ammonium sulfate compared to urea because ammonium sulfate contains less N.

Chien et al. (2009) report that slow-release urea-aldehyde polymer fertilizers are generally more efficient than soluble N sources when the gradual supply of N is an advantage to crops. Under certain conditions, however, using slow-release urea-aldehyde polymer products might provide no production advantage. For example, Cahill et al. (2007) reported that grain yield and N use efficiency with urea NH_4NO_3 solution was statistically similar to or better than with urea formaldehyde polymer. Shaviv (2005) reports that the high cost of slow-release polymers limits their use in agriculture, but the potential for increased use is high where the products have been shown to increase nutrient recovery, sustain high yields, and reduce nutrient losses and associated environmental impacts based on reduced application levels and the ability to match release characteristics with plant demand. Bundick et al. (2009) describe advantages for the use of controlled-release fertilizers including reduced leaching, denitrification or volatilization losses, and more uniform crop growth because of reduced risk of seedling burn or salt damage. Disadvantages include cost, ineffectiveness when a quick release is needed (e.g., when side dressing corn at the 6-leaf stage).

Using urea supergranules for deep placement has been shown to improve N use efficiency used in small-scale rice production where plants are fertilized by hand. If problems related to labor cost and difficulty in deep placement of urea supergranules in upland soils can be solved, Chien et al. (2009) expect that deep placement of urea supergranules should also perform well as an N source for upland food crops.

Using nonconventional P fertilizers includes phosphate rock (PR) for direct application, a mixture of PR and water-soluble P sources, and nonconventional acidulated P fertilizers containing water-insoluble P compounds (Chien et al. 2009). PR has been studied for agronomic use for more than 50 years and can be agronomically beneficial depending on the solubility of PR, soil properties, management practices, climate, and crop species. For example, it is most effective where the PR is highly reactive and when used in acidic soils or tropical climates. Several decision support systems (PRDSS) have been developed to help integrate such factors to evaluate the effectiveness of PR for direct application under specific conditions. Where use of PR is not as feasible as water-soluble P sources, PR can be mixed with water-soluble P sources to economically achieve the same results as use of the water-soluble P source or PR alone because the water-soluble P source has a starter effect that allows for better initial root development, resulting in more effective PR utilization. Recent research has focused on eutrophication reduction when PR is used to replace water-soluble P sources as well as the use of PR in organic farming. Several studies have been conducted under controlled conditions to determine the relative effectiveness of nonconventional acidulated fertilizers made from lower quality PR ore compared to those with a higher proportion of water-soluble P. The review stresses that additional field studies are needed to adequately evaluate the agronomic use of PR under a variety of conditions.

Chien et al. (2009) indicate that using fluid P fertilizers can improve the efficiency of conventional P fertilizers, although additional research is needed. Recent research in Australia indicates that fluid P fertilizers were more effective than the commercial granular P fertilizers using the same P compound in increasing crop yield in calcareous and alkaline soils (Holloway et al. 2001) and that total and labile P from fluid sources diffused further into the soil than when granular sources are used (Hettiarachchi et al. 2006; Lombi et al. 2004). However, a number of earlier studies also showed no difference in P use efficiency between liquid and granular forms.

Slow-release fertilizer (SRF) and controlled-release fertilizer (CRF) materials can improve nutrient uptake efficiency and reduce the leaching potential of nutrients (Morgan et al. 2009). Those considerations are particularly important for crops grown on sandy soils with relatively low nutrient- and water-holding capacities.

In New Zealand, Sojka (2009) compared the efficacy of matrix-based fertilizers (MBFs) formulated to reduce NO_3, ammonium, and TP leaching with conventional SRFs, and an unfertilized control. SRF leachate contained higher amounts of NO_3, ammonium, and TP than leachate from all other fertilizers. There were no consistent differences in the amount of NO_3, ammonium, and TP in the MBF leachates compared to the control leachate.

Penn et al. (2004) tested the effects of phytase enzyme and HAP corn supplemented diets on runoff P concentrations from Virginia pasture soils receiving surface applications of turkey manure. The alternative diets caused a decrease in manure total and water-soluble P compared with the standard diet. Runoff dissolved P concentrations were significantly higher from HAP manure-amended soils, while dissolved P losses from other manure treatments were not significantly different from each other.

In a laboratory study, Loria and Sawyer (2005) compared the effect of raw and digested liquid swine manure application on soil test P and inorganic N. Raw and digested manure produced the same NH_4-N disappearance, NO_3-N formation, net inorganic N, and an increase in soil test P. Routine soil test P methods estimated similar P recovery with both manure sources.

In Iowa, Loria et al. (2007) found no difference between raw swine manure and manure digested for biogas as a source of N for plant use in the year of application or in the residual year; equivalence to fertilizer N was the same with both raw and digested swine manure.

In Georgia, Risse and Gilley (2000) reported that runoff was reduced from one to 68 percent, and soil loss decreased from 13 to 77 percent for locations on which manure was added annually. Measured runoff and soil loss values were found to be strongly influenced by manure application rates. Regression equations were developed relating reductions in runoff and soil loss to manure application rates.

In Colorado, Shoji et al. (1999) conducted field trials on CRFs and an NI to show their potential to increase NUE. TN fertilizer losses averaged 15 and 10 percent in the NI and urea treatments, respectively. On the other hand, those from the CRF treatment averaged only 1.9 percent, indicating that CRF showed the highest potential to increase N use efficiency.

King and Torbert (2007) designed an Ohio plot study to compare temporal losses of NO_3-N and NH_4-N from three SRFs (sulfur-coated urea, composted dairy manure, and poultry litter) and one fast-release fertilizer (NH_4NO_3) applied to Bermuda grass turf. Cumulative NO_3-N loss from plots receiving application of the manufactured (NH_4NO_3 and sulfur-coated urea) products was significantly greater than the measured losses from plots receiving application of composted dairy manure and poultry litter. The cumulative NO_3-N recovered in the runoff expressed as a proportion of applied N was 0.37 for NH_4NO_3, 0.25 for sulfur-coated urea, 0.10 for composted dairy manure, and 0.07 for poultry litter.

Table 2-13. Summary of reported practice effects resulting from management of manure and fertilizer form and rate

Location	Study type	Practice	Practice effects	Source
New Zealand	Plot	Fertilizer formulation	Leachate from conventional SRFs contained higher amounts of NO_3, ammonium, and TP than leachate from all other fertilizers	Sojka 2009
Brazil	Field	Urease inhibitor	The percentage of reduction in volatilization due to NBPT application ranged from 15% to 78% depending on the weather conditions during the days following application of N. Addition of NBPT to urea helped to control ammonia losses, but the inhibitor was less effective when rain sufficient to incorporate urea into the soil occurred only 10 to 15 days or later after fertilizer application.	Cantarella et al. 2005
North Carolina	Field	Slow-release urea formaldehyde polymer	In all cases aqueous urea ammonium nitrate (UAN) outperformed or was statistically similar to urea formaldehyde polymer (UFP). UFP would be economically viable only if priced similar to UAN. UFP released N on a time scale similar to UAN (1 to 2 weeks). Similarity of the two N sources might have been because the release rate of UFP might not be optimal for the crops or varieties at the chosen application timings.	Cahill et al. 2007
Australia	Field	Fluid P fertilizer	70 of 103 wheat experiments showed positive yield increases compared to granular P sources when fluids were applied over calcareous soils. The positive increase rate with fluids was much greater when micronutrients were applied in solution with P and N.	Holloway et al. 2001

Table 2-13. Summary of reported practice effects resulting from management of manure and fertilizer form and rate *(continued)*

Location	Study type	Practice	Practice effects	Source
Australia	Laboratory	Fluid P fertilizer	When P is supplied in granular form, P diffusion and isotopic lability in calcareous soils are reduced compared with equivalent liquid fertilizer formulations, probably due to precipitation reactions induced by osmotically induced flow of soil moisture into the fertilizer granule.	Hettiarachchi et al. 2006; Lombi et al. 2004
Virginia	Field	Poultry litter from phytase and HAP feeding	Alternative diets decreased manure total and water-soluble P compared with the standard diet. Runoff dissolved P concentrations were significantly higher from HAP manure-amended soils than from phytase manure applications, while dissolved P losses from other manure treatments were not significantly different from each other.	Penn et al. 2004
Iowa	Plot	Slow release fertilizers	Raw and digested manure produced the same NH_4-N disappearance, NO_3-N formation, net inorganic N, and an increase in soil test P. Routine soil test P methods estimated similar P recovery with both manure sources.	Loria and Sawyer 2005
Iowa	Plot	Raw vs. digested swine manure	No difference between raw swine manure and manure digested for biogas as a source of N for plant use in the year of application or in the residual year; equivalence to fertilizer N was the same with both raw and digested swine manure.	Loria et al. 2007
Georgia	Fields	Manure application rates	Runoff was reduced from 1%–68%, and soil loss decreased from 13%–77% where manure was added annually. Measured runoff and soil loss values were found to be strongly influenced by manure application rates; regression equations were developed relating reductions in runoff and soil loss to manure application rates.	Risse and Gilley 2000
Colorado	Field trials	CRF, NIs	TN fertilizer losses averaged 15% and 10% in the NI and urea treatments, respectively. N losses from the controlled release fertilizer treatment averaged only 1.9%	Shoji et al. 1999
Ohio	Plot	SRFs	Cumulative NO_3-N loss from plots receiving application of manufactured (NH_4NO_3 and sulfur-coated urea) products was significantly greater than the measured losses from plots receiving application of composted dairy manure and poultry litter. The cumulative NO_3-N recovered in the runoff expressed as a proportion of applied N was 0.37 for NH_4NO_3, 0.25 for sulfur-coated urea, 0.10 for composted dairy manure, and 0.07 for poultry litter.	King and Torbert 2007

Nutrient application methods and timing

In soil column and field studies in New York, Geohring et al. (2001) reported that high P concentrations observed in tile drain effluent soon after dairy manure application can be attributed to macropore transport processes. Plowing-in manure apparently disturbs these macropores and promotes matrix flow, resulting in greatly reduced P concentrations in the drainage effluent.

In New York, Lewis and Makarewicz (2009) reported significant decreases in winter concentrations of TP, soluble P, TKN, and NO_3-N but not TSS following cessation of winter dairy manure application to cropland.

Chen and Samson (2002) investigated the effects of fertilizer source and manure application timing, rate, and method on soil nutrient concentrations, corn grain yields, and groundwater NO_3 concentrations in Ontario, Canada. In general, higher NO_3-N concentrations were observed in those plots where N sources had been applied shortly before soil sampling. Trends of residual NO_3-N concentrations varied among experiments, and results were inconclusive. Two-fold higher P concentrations were observed in the manured plots than in the inorganically fertilized plots as a result of higher P_2O_5 inputs from swine manure.

In Kansas plots, Reiman et al. (2009) tested the effect of manure placement depth on corn and soybean yield and N retention in soil. The net effect of placement on TN was that deep manure injection treatments had 31–59 more kg N/ha than the shallow injection treatment 12 to 30 months after application. Higher corn yield in the deep-injected treatment was attributed to increased N use efficiency. Higher inorganic N amounts in the deep injection treatment were attributed to reduced N losses through ammonia volatilization, leaching, or denitrification.

Ali et al. (2007) tested simplified surface irrigation of dairy farm effluents in Quebec, Canada, and reported that seepage losses represented less than one percent of the total volume of effluents (nutrients and bacteria) applied; nutrients and bacteria applied were lost in subsurface drainage, implying a treatment efficiency of greater than 99 percent compared to conventional land spreading.

On-farm trials were conducted near Ottawa, Ontario, to determine the effect of preplant and sidedress fertilizer N application on corn yield, N uptake and N_2O gas emission (Ma 2007). Data showed that for each kg N applied, 70–77 kg ha^{-1} of yield was produced for sidedress compared to 46–66 kg of yield for preplant N application. When the same amount of fertilizer was applied, significantly greater yield (7.6–10.6 percent) was produced with sidedress than preplant N application. Ebelhar et al. (2009) tested nine different N sources in part to determine the N use efficiencies for new fertilizer technologies and evaluate their effects on crop yields. In general, for wet sites, the sidedress injection of N provided the highest corn yields and best N use efficiencies (with a polymer coated urea product second). Note that the sidedress treatment at dry locations appear to be a detriment, likely because dry conditions prevented N from reaching the corn roots when needed.

Harmel et al. (2004) conducted a paired watershed study to evaluate the impact of variable rate N fertilizer application on surface water quality. Few water quality differences were observed during the first year, but overall median NO_3 + NO_2-N concentrations were significantly lower for the variable rate field receiving sidedress N applications in the second year.

In an Ontario, Canada, plot study, Coelho et al. (2006) determined the effects of rate and method of sidedress application of liquid swine manure on N recovery by corn using in-row injection or topdressing to sidedress manure. Coelho et al. (2006) measured grain N uptake and NO_3-N in drainage water, stalks, and topsoil postharvest. Apparent recovery of manure TN was greater with injection (59 percent) than topdress (41 percent) and transport of N to groundwater and surface water was minimized when side dressed at or below rates for optimal yield. When injected N exceeded crop demand, NO_3-N increased to more than 10 mg/kg in topsoil, 20 mg/L in drainage water, and to excessive (3.6 g/kg) levels in stalks.

Drainage NO_3-N concentration and load increased linearly by 0.69 mg NO_3-N/L and 4.6 kg NO_3-N/ha, respectively, for each 10 kg N/ha applied over the minimum of 275 kg N/ha in trials of swine waste application to corn in Spain (Dauden et al. 2004). An increase in irrigation efficiency did not induce a significant increase of leachate concentration, and the amount of NO_3 leached decreased about 65 percent. Application of low manure doses before sowing complemented with side dressing N application and good irrigation management were found to be key factors to reduce NO_3 contamination of water courses.

Hebbar et al. (2004) compared fertigation with various fertilizer sources, rates, and application methods with drip- and flood-irrigated controls in a red sandy loam soil in India. They found that fertigation with 100 percent water-soluble fertilizer (WSF), subsurface drip fertigation, N-potassium fertigation, and half soil–half fertigation increased the hybrid tomato yield significantly over the controls. Significant yield reduction was recorded with 75 percent rate fertigation and normal fertilizer fertigation compared to WSF fertigation. WSF fertigation resulted in a significantly higher number of fruits per plant and fertilizer use efficiency compared to drip- and furrow-irrigated controls. Fertigation also resulted in less leaching of NO_3-N and K to deeper soil layers. Subsurface drip fertigation resulted in higher assimilable P in deeper soil layers. Root growth and NPK uptake was increased by WSF fertigation. Tan et al. (2003) studied the effects of drip irrigation and fertigation on yield, quality, and water and NUE of tomatoes. They found no significant difference in marketable tomato yields between broadcast fertilizer and fertigation for both subsurface and surface drip irrigation on a loamy sand soil.

Various micro-irrigation systems were used to evaluate the impact of fertigation and soil type on the potential for NO_3 leaching to groundwater (Gärdenäs et al. 2005). Seasonal leaching was found to be highest for coarse-textured soils. Modeling also showed that fertigation at the beginning of the irrigation cycle tends to increase seasonal NO_3 leaching, whereas fertigation at the end of the irrigation cycle reduced the potential for NO_3 leaching. Long fertigation times resulted in uniform NO_3 distributions in the wetted regions for three of the four irrigation systems. Surface-applied irrigation on finer-textured soils enhanced lateral spreading of water and nitrates with subsequent infiltration downwards and horizontal spreading of soil NO_3 near the soil surface. Leaching potential increased with the difference between the extent of the wetted soil volume and rooting zone.

Soil injection of swine manure on soybeans in Illinois compared with surface application resulted in runoff concentration decreases of 93, 82, and 94 percent, and load decreases of 99, 94, and 99 percent for dissolved P, TP and algal-available P, respectively (Daverede et al. 2004). Incorporating inorganic P fertilizer also reduced P concentration in runoff significantly. Runoff P concentration and load from incorporated amendments did not differ from the control.

Allen and Mallarino (2008) assessed total runoff P, bioavailable P, and dissolved P concentrations and loads in surface runoff after liquid swine manure application with or without incorporation into soil and different timing of rainfall in Illinois. For events 24 hours after application, P concentrations were two to five times higher for unincorporated manure than for incorporated manure; P loads were 3.8 to 7.7, and 3.6 times higher. A 10- to 16-day rainfall delay resulted in P concentrations that were about three times lower than for 24-hour events across all unincorporated P rates.

Andraski et al. (2003) investigated the effects of manure history and tillage on P levels in runoff from continuous corn in Wisconsin. Soil P levels increased with the frequency of manure applications and P stratification was greater near the surface in no-till than in chisel plow. In chisel plow, soil test P level was linearly related to dissolved P and bioavailable P loads in runoff. In no-till, P loads were reduced by an average of 57 percent for dissolved P, 70 percent for bioavailable P, and 91 percent for TP compared with chisel plow.

In an Iowa plot study, Bakhsh et al. (2009) determined the effects of swine manure application to corn and soybeans on NO_3-N concentrations in subsurface drainage water and corn-soybean yields. Average flow-weighted NO_3-N concentrations and leaching losses increased by greater than 50 percent when manure was applied to both corn and soybean compared to manure application to corn only, while yield differences were less than 4 percent. Those results suggest that fall manure application to both corn and soybean is likely to increase NO_3-N leaching to shallow groundwater without resulting in significant yield benefits.

Kleinman et al. (2009) evaluated losses of P in subsurface and surface flow as a function of dairy manure application to no-till soils in Pennsylvania. Incorporation of manure by tillage lowered P loss in leachate relative to broadcast application because of the destruction of preferential flow pathways. In contrast, rainfall simulations on runoff plots showed that TP losses in surface runoff differed significantly by soil but not by application method. Results confirm the near-term benefits of incorporating manure by tillage to protect groundwater quality but suggest that for surface water quality, avoiding soils prone to runoff is more important.

Warren et al. (2008) compared surface broadcast litter application and subsurface litter banding on grassland in Alabama. Subsurface band applications resulted in forage yields equivalent to those achieved by conventional broadcast litter applications and did not significantly alter the Mehlich 3 extractable P content of soils collected at a depth of 0 to 15 cm.

In Arkansas, Pote et al. (2003) determined the effects of poultry litter incorporation into Bermuda grass and mixed forage plots on quantity and quality of runoff water. Nutrient concentrations and mass losses in runoff from incorporated litter were 80–95 percent less than in runoff from surface-applied litter. Litter-incorporated soils had greater rain infiltration rates, water-holding capacities, and sediment retention than soils receiving surface-applied litter. In a subsequent study, Pote et al. (2009) confirmed that fully mechanized litter subsurface banding increased forage yield while decreasing nutrient N and P loss in runoff by at least 90 percent compared to surface-broadcast litter.

Sistani et al. (2009) evaluated the effect of broiler litter application method and the runoff timing on nutrient and *E. coli* losses from Alabama perennial grassland. TP, inorganic N, and *E. coli* concentrations in runoff from broadcast litter application were all significantly greater than from subsurface litter banding. TP losses from broadcast litter applications averaged 6.8 times greater than those from subsurface litter applications. Average NO_3-N and TSS losses from subsurface banding were reduced by 64 percent and 68 percent, respectively, compared to the broadcast method.

In soil columns, Guo et al. (2009) evaluated nutrient release dynamics of Delmarva poultry litter under local weather conditions. Release of most nutrients occurred principally in the first 100 days, but for P, release would last for years. The nutrient supply capacity of surface-applied Delmarva poultry litter was predicted at 10.9 kg N/Mg (kilograms per megagram) and 6.5 kg P/Mg. The results suggest that Delmarva poultry litter should be applied to conservation tillage systems at 6.6 Mg/ha, which would furnish 25 kg P/ha and 63 kg N/ha to seasonal crops. In repeated annual applications, the rate should be reduced to 5.2 Mg/ha, with supplemental N fertilization to meet crop N requirements.

Table 2-14. Summary of reported practice effects resulting from management of nutrient application methods and timing

Location	Study type	Practice	Practice effects	Source
New York	Soil column, field	Manure incorporation	Plowing-in manure apparently disturbs macropores and promotes matrix flow, resulting in greatly reduced P concentrations in tile drainage effluent.	Geohring et al. 2001
New York	Field	Cessation of winter manure spreading	Significant decreases in winter concentrations of TP, soluble P, TKN, and NO_3-N but not TSS following cessation of winter dairy manure application to cropland.	Lewis and Makarewicz 2009
Ontario	Plots	Nutrient source and timing	Higher NO_3-N concentrations observed in plots where N sources applied shortly before soil sampling. Trends of residual NO_3-N concentrations varied among experiments, and results were inconclusive. Two-fold higher P concentrations were observed in the manured plots than in the inorganically fertilized plots as a result of higher P_2O_5 inputs from swine manure.	Chen and Samson 2002
Ontario	Field	Sidedress N application	For each kg N applied, 70–77 kg ha-1 of yield was produced for sidedress compared to 46-66 kg of yield for preplant N application. When the same amount of fertilizer was applied, significantly greater yield (7.6%–10.6%) was produced with sidedress than preplant N application.	Ma 2007
Illinois	Field	Sidedress N application	Of nine different N sources tested, the sidedress injection of N provided the highest corn yields (164 bu/a) and best N use efficiencies (0.96 lb N/bu) at locations receiving > 12 inches rainfall over the 15 week period after fertilizer application.	Ebelhar et al. 2009
Kansas	Plots	Manure placement depth	Deep manure injection treatments had 31–59 more kg N/ha than the shallow injection treatment 12–30 months after application. Higher corn yield in the deep injected treatment attributed to increased N use efficiency. Higher inorganic N amounts in deep injection treatment attributed to reduced N losses through ammonia volatilization, leaching, or denitrification	Reiman et al. 2009
Quebec, Canada	Fields	Irrigation of dairy effluent	Seepage losses represented < 1% of the total volume of effluents, nutrients and bacteria applied implying a treatment efficiency of > 99% compared to conventional land spreading.	Ali et al. 2007

Table 2-14. Summary of reported practice effects resulting from management of nutrient application methods and timing *(continued)*

Location	Study type	Practice	Practice effects	Source
Ontario, Canada	Plot	Liquid manure injection	Apparent recovery of manure TN was greater with injection (59%) than topdress (41%) and transport of N to ground- and surface waters was minimized when side dressed at or below rates for optimal yield. When injected N exceeded crop demand, NO_3-N increased to over 10 mg/kg in topsoil, 20 mg/L in drainage water, and to excessive (3.6 g/kg) levels in stalks	Coelho et al. 2006
Spain	Plot	Waste irrigation	Drainage NO_3-N concentration and load increased linearly by 0.69 mg NO_3-N/L and 4.6 kg NO_3-N/ha, respectively, for each 10 kg N/ha applied over the minimum of 275 kg N/ha. An increase in irrigation efficiency did not induce a significant increase of leachate concentration and the amount of NO_3 leached decreased about 65%.	Dauden et al.2004
India	Field	Fertigation	Water-soluble fertilizer (WSF) fertigation recorded significantly higher total dry matter (181.9 g) and leaf area index (3.69) over the drip irrigation control. Fertigation with 100% WSF increased the fruit yield by 24.8% over the furrow-irrigated control and by 9.2% over drip irrigation. WSF fertigation resulted in significantly fertilizer-use efficiency (226.48 kg yield/kg NPK) compared to drip- and furrow-irrigated controls. Fertigation resulted in less leaching of NO_3-N and K to deeper layer of soil and subsurface drip fertigation caused higher assimilable P in deeper layers. Root growth and NPK uptake was increased by WSF fertigation.	Hebbar et al. 2004
California	Modeling	Fertigation	An adapted version of the computer simulation model, Hydrus-2D was used to evaluate NO_3 leaching potential under various combinations of micro-irrigation systems, fertigation scenarios, and soil types typical of California conditions. The study concluded that fertigation at the beginning of the irrigation cycle tends to increase seasonal NO_3 leaching.	Gärdenäs et al. 2005
Illinois	Plots	Manure injection	Soil injection of manure on soybeans compared with surface application resulted in runoff P concentration decreases of 82%–99%.	Daverede et al. 2004
Iowa	Plot	Manure incorporation	For events 24 hours after application, P concentrations were 2 to 5 times higher for unincorporated manure than for incorporated manure; P loads were 3.8 to 7.7, and 3.6 times higher.	Bakhsh et al. 2009

Table 2-14. Summary of reported practice effects resulting from management of nutrient application methods and timing *(continued)*

Location	Study type	Practice	Practice effects	Source
Wisconsin	Field	Manure history, tillage	Soil P levels increased with the frequency of manure applications. In no-till, P loads were reduced by an average of 57% for dissolved P, 70% for bioavailable P, and 91% for TP compared with chisel plow	Andraski et al. 2003
Iowa	Plot	Manure application timing	NO_3-N concentrations and leaching losses increased by > 50% when manure applied to both corn and soybean compared to manure application to corn only, while yield differences were less than 4%. Fall manure application to both corn and soybean is likely to increase NO_3-N leaching to shallow groundwater without resulting in significant yield benefits.	Bakhsh et al. 2009
Pennsyl-vania	Plots	Manure incorporation by tillage	Incorporating manure by tillage lowered P loss in leachate relative to broadcast application from the destruction of preferential flow pathways; TP losses in surface runoff differed significantly by soil but not by application method	Pote et al. 2009
Alabama	Field	Subsurface banding of poultry litter	Subsurface band applications resulted in forage yields equivalent to conventional broadcast litter applications and did not significantly alter the Mehlich 3 extractable nutrient content of soils.	Warren et al. 2008
Arkansas	Plots	Litter application rate	Nutrient concentrations and mass losses in runoff from incorporated litter were 80%–95% less than in runoff from surface-applied litter. Litter-incorporated soils had greater infiltration rates, water-holding capacities, and sediment retention than soils receiving surface-applied litter	Guo et al. (2009
Alabama	Plots	Subsurface banding of poultry litter	TP, inorganic N, and *E. coli* concentrations in runoff from broadcast litter application exceeded those from subsurface litter banding. TP losses from broadcast litter applications averaged 6.8 times greater than those from subsurface litter applications. Average NO_3-N and TSS losses from subsurface banding were reduced by 64% and 68%, respectively, compared to the broadcast method.	Kaiser et al. 2009
Delmarva Peninsula	Plot	Soil aeration	Soil aeration reduced runoff volume by 27% in the first runoff event but the effect disappeared after 1 month; aeration did not affect the mass losses of DRP, TKN, or NH4-N from plots fertilized with either inorganic fertilizer or poultry litter	Guo et al. 2006

Table 2-14. Summary of reported practice effects resulting from management of nutrient application methods and timing *(continued)*

Location	Study type	Practice	Practice effects	Source
Iowa	Field	Soil aeration, broiler litter	Unincorporated manure consistently increased concentrations of all runoff P fractions in five sites; on average manure increased dissolved P, bioavailable P, and TP 32, 23, and 12 times, respectively, over the control. Tillage to incorporate manure reduced dissolved P, bioavailable P, and TP by 88, 89, and 77% on average	Kaiser et al. 2009
Georgia	Plot	Soil aeration	Soil aeration reduced runoff volume by 27% in the first runoff event but the effect disappeared after one month; aeration did not affect the mass losses of DRP, TKN, or NH4-N from plots fertilized with either inorganic fertilizer or poultry litter	Butler et al. 2006
Georgia	Field	Soil aeration	On well-drained soils, grassland aeration reduced surface runoff volume and mass losses of DRP in runoff by 35%. However, on poorly drained soils, grassland aeration increased runoff volume and mass losses of dissolved and TP	Franklin et al. 2007
Georgia	Plots	Soil aeration	Core aeration reduced TP export by 55%, dissolved P by 61%, and bioavailable P by 54% plots with applied broiler litter. Core and no-till disk aeration also showed potential for reducing P export from applied dairy slurry.	Butler et al. 2008a
British Columbia, Canada	Field	Soil aeration	For mechanically aerating grassland before liquid manure application, annual runoff amounts were reduced by 47%–81%, suspended and volatile solid loads by 48%–69% and 42%–83%, respectively, TKN loads by 56%–81%, and TP loads by 25%–75%. Loads of the soluble nutrient NH_4-N, DRP, and K were reduced by 41%–83%.	van Vliet et al. 2006

Kaiser et al. (2009) assessed P loss immediately after poultry manure application to soybean residue with and without tillage at eight Iowa fields. Unincorporated manure consistently increased concentrations of all runoff P fractions in five sites. On average, non-incorporated manure increased dissolved P, bioavailable P, and TP 32, 23, and 12 times, respectively, over the control. Tillage to incorporate manure reduced dissolved P, bioavailable P, and TP by 88, 89, and 77 percent on average, respectively.

In a Georgia plot study, Franklin et al. (2006) reported that soil aeration reduced runoff volume by 27 percent in the first runoff event, but the effect disappeared after one month; aeration did not affect the mass losses of dissolved reactive P (DRP), TKN, or NH_4-N from plots fertilized with either inorganic fertilizer or poultry litter.

Franklin et al. (2007) evaluated the effects of slit aeration on runoff volume and P losses from fescue fertilized with broiler litter in Georgia. In the field with mostly well-drained soils, grassland aeration reduced surface runoff volume and mass losses of DRP in runoff by 35 percent. However, on poorly drained soils, grassland aeration increased runoff volume and mass losses of dissolved and TP.

Butler et al. (2008a) evaluated the effects of three aeration treatments on export of TSS and P from grassland plots receiving broiler litter and dairy slurry in Georgia. Core aeration reduced export of TP by 55 percent, dissolved P by 61 percent, and bioavailable P 54 percent on plots with applied broiler litter as compared with the control. Core and no-till disk aeration also showed potential for reducing P export from applied dairy slurry.

In British Columbia, Canada, van Vliet et al. (2006) studied the effect of mechanically aerating grassland before liquid manure application on surface runoff and transport of nutrients and solids. Annual runoff amounts were reduced by 47–81 percent, suspended and volatile solid loads by 48–69 percent and 42–83 percent, respectively, TKN loads by 56–81 percent, and TP loads by 25–75 percent. Loads of the soluble nutrient NH_4-N, DRP, and K were reduced by 41–83 percent.

Soil and manure amendment

Implementation Measure A-11:

Use soil amendments such as alum, gypsum, or water treatment residuals (WTR) to increase P adsorption capacity of soils, reduce desorption of water-soluble P, and decrease P concentration in runoff.

Because runoff losses of P are strongly influenced by the quantity and form of P in the soil (Sharpley 1995; Pote et al. 1996), reducing P runoff from cropland can be accomplished by influencing soil test P levels through soil amendments that change the availability of P and through NMP.

In Arkansas plots, Haustein et al. (2000) surface application of treatment residuals and HiClay® Alumina to soil plots high in P decreased Mehlich 3 soil test P levels and the two highest rates of WTR decreased runoff P levels below those of the control plots.

From a Texas field experiment, Brauer et al. (2005) reported that annual additions of gypsum at 5.0 Mg/ha significantly reduced soil-dissolved P, although soil amendment did not affect Bray 1 P values. Elliott et al. (2002) conducted laboratory and greenhouse studies of the ability of WTR to alter P solubility and leaching in a Texas soil amended with biosolids and triple superphosphate. Without residual amendment, 21 percent of soluble P and 11 percent of biosolids TP leached over 4 months. With co-applied residuals, soluble P losses were reduced to less than 1–3.5 percent of applied P. Amendment with residuals retarded downward P flux such that leachate P was not statistically different than for control (soil only) columns.

In North Carolina, Novak and Watts (2004) conducted laboratory experiments to determine if WTR mixed into soils could significantly increase their P sorption capacities. Mixing residuals into soils increased their P-max values several-fold (between 1.7 to 8.5 mg P/g) relative to soils with no WTR addition. The authors suggested that WTR incorporation into sandy soils has the potential to be a new chemical-based best management practice (BMP) for reducing off-site P transport.

In Oklahoma, Peters and Basta (1996) reported that alum-based WTR applied at 30–100 g/kg soil reduced Mehlich 3 extractable P in soils from 553 mg/kg to 250 mg/kg (55 percent) in one soil and from 296 mg/kg to 110 mg/kg (63 percent) in another soil. Reductions of soluble P followed similar trends. Treatments did not result in excessive soil pH or increase in soil salinity, soil extractable Al, or heavy metals.

In a Maryland study, Codling et al. (2000) reported that addition of poultry litter amended with alum-based WTR led to significant reductions in water soluble P concentrations in several soils. The authors reported reductions in water-soluble P of 72–99 percent in soils amended with 10–50 g/ha treated poultry litter after 2 to 4 weeks. Reductions of 27–89 percent in Bray 1 P were reported in the same soils.

Cornwell et al. (2000) reported a 34 percent reduction in available soil P after application of alum WTR at a rate of 25.7 dry t/ha to Pennsylvania agricultural soils with soil P levels six times higher than optimum level for soybean production.

Novak and Watts (2005) evaluated the ability of alum-based WTR to reduce soil P concentrations in three P-enriched North Carolina Coastal Plain soils. Incorporating residuals into the soils caused a near linear and significant reduction in soil P concentrations. In two soils, 6 percent WTR application caused a soil Mehlich 3 P concentration decrease to below the soil P threshold.

Adding WTR to Oklahoma soil plots treated with poultry litter reduced runoff P by 14–85 percent (Dayton et al. 2003). Reductions in runoff P were strongly correlated with P-max and Al-ox.

Performance of treatment residuals as a P sorbent to reduce runoff P from manured land can be estimated from their P-max or Al-ox content.

In a Connecticut laboratory study, Hyde and Morris (2000) reported that WTR significantly reduced Mehlich 3 P concentrations when added to soils. Adding residuals to soils reduced soil P concentrations by 23–64 percent, depending on how the residuals were dewatered.

Adler and Sibrell (2003) tested the use of flocculants (flocs) resulting from neutralizing acid mine drainage (AMD) (as a possible low-cost amendment to reduce the loss of soluble P from agricultural fields and animal wastewater) in West Virginia. About 70 percent of WEP was sequestered by the floc when applied to agricultural soils at a rate of 20 g floc/kg soil, whereas plant-available P decreased by 30 percent. Under anaerobic conditions simulating manure storage basins, all AMD flocs reduced soluble P by greater than 95 percent.

At two Michigan field sites with a history of heavy manure applications, amendment with WTR reduced water-soluble P concentration by greater than or equal to 60 percent as compared to the control plots, and the residuals-immobilized P remained stable 7.5 years after residuals application (Agyin-Birikorang et al. 2007).

Staats et al. (2004) investigated the efficacy of alum-amended poultry litter in reducing P release from three Delaware Coastal Plain soils. Long-term desorption (25 days) of the incubated material resulted in about 13 percent reductions in cumulative P desorbed when comparing soil treated with unamended poultry litter. In addition, the P release from the soil treated with alum-amended litter was not significantly different from the control (soil alone).

Zvomuya et al. (2006) tested the P-binding ability of various amendment materials in a laboratory soil incubation experiment. Lysimeter breakthrough tests using tertiary-treated potato-processing wastewater showed that alum application reduced leachate TP and SRP concentrations by 27 percent and 25 percent, respectively.

Stout et al. (1999) reported that a 10 g/kg application of a gypsum byproduct to Pennsylvania soils reduced the concentration of water-soluble P by 50 percent. Projection of these results over an agricultural watershed indicated that treating only four percent of the watershed could reduce the loss of water-soluble P by 30 percent. In an Indiana lab study, Favaretto et al. (2006) showed that gypsum addition to soils significantly decreased the mass loss in runoff of dissolved reactive P, TP, soluble NH_4-N, and total N by 85, 60, 80, and 59 percent, respectively. The concentration of these constituents was also significantly decreased by 83, 52, 79, and 50 percent, respectively. Murphy et al. (2010) reported that gypsum addition decreased reactive P solubility by 14–56 percent and organic P solubility by 10–53 percent in five Irish soils.

Table 2-15. Summary of reported practice effects resulting from soil and manure amendment

Location	Study type	Practice	Practice effects	Source
Arkansas	Plot	Soil amendments	Surface application of treatment residuals and HiClay® Alumina to high P soils decreased soil test P levels; the highest rates of WTR decreased runoff P levels below those of the control plots.	Haustein et al. 2000
Texas	Field	Gypsum amendment	Annual additions of gypsum at 5.0 Mg/ha significantly reduced soil dissolved P, although soil amendment did not affect Bray1 P values.	Brauer et al. 2005
Oklahoma	Field	WTR	Alum-based WTRs applied at 30–100 g/kg soil reduced Mehlich 3 extractable P in soils from 55% to 63%.	Peters and Basta 1996
Maryland	Field	WTR	Addition of poultry litter amended with alum-based WTRs led to 72%–99% reductions in water-soluble P and 27%–89% reductions in Bray 1 P of in soils amended with 10–50 g/ha treated poultry litter after 2 to 4 weeks.	Codling et al. 2000
Pennsylvania	Field	WTR	34% reduction in available soil P after application of alum WTRs at a rate of 25.7 dry t/ha to soils with soil P levels six times higher than optimum level for soybean production.	Cornwell et al. 2000
Texas	Laboratory, greenhouse	WTR	Without residual amendment, 21% of soluble P and 11% of biosolids TP leached over 4 months; with co-applied residuals, soluble P losses were reduced to < 1%–3.5% of applied P. Amendment with residuals retarded downward P flux such that leachate P was not statistically different than for control (soil only) columns.	Elliott et al. 2002
North Carolina	Laboratory	WTR	Mixing residuals into soils increased their P-max values several-fold (between 1.7 to 8.5 mg P/g) relative to soils with no WTR addition.	Novak and Watts 2004
North Carolina	Laboratory	WTR	Incorporation of residuals into soils caused a near linear and significant reduction in soil P concentrations. In two soils, 6% WTR application caused a soil Mehlich 3 P concentration decrease to below the soil P threshold.	Novak and Watts 2005
Oklahoma	Plots	WTR	Addition of WTR to OK soil plots treated with poultry litter reduced runoff P by from 14%–85% Reductions in runoff P were strongly correlated with P-max and Al-ox. Performance of treatment residuals as a P sorbent to reduce runoff P from manured land can be estimated from their P-max or Al-ox content.	Dayton et al. 2003

Table 2-15. Summary of reported practice effects resulting from soil and manure amendment *(continued)*

Location	Study type	Practice	Practice effects	Source
Connecticut	Laboratory	WTR	Adding residuals to soils reduced soil P concentrations by 23%–64%, depending on how the residuals were dewatered.	Hyde and Morris 2000
Pennsylvania, Oklahoma, Colorado	Field	WTR	WTRs reduced Mehlich 3 soil test P to less than 200 mg/kg at a 10% loading rate after 1 wk of incubation time. Reductions of soluble P ($CaCl_2$ extraction) were greater than reductions in Mehlich 3 P.	DeWolfe 2006
West Virginia	Laboratory	Neutralized AMD flocs	About 70% of WEP was sequestered by the floc when applied to agricultural soils at a rate of 20 g floc/kg soil; plant-available P decreased by 30%. Under anaerobic conditions simulating manure storage basins, AMD flocs reduced soluble P by > 95%.	Adler and Sibrell 2003
Michigan	Field	WTR	Amendment reduced water-soluble P concentration by $\geq$ 60% vs. control plots, and the residuals-immobilized P remained stable for 7.5 yr.	Agyin-Birikorang et al. 2007
Delaware	Laboratory	Alum amendment	About 13% reductions in cumulative P desorbed vs. soil treated with unamended poultry litter. P release from soil treated with alum-amended litter was not significantly different from the control (soil alone).	Staats et al. (2004)
Various	Laboratory	Alum soil amendment	Lysimeter breakthrough tests showed that alum application reduced leachate TP and SRP concentrations by 27% and 25%, respectively	Zvomuya et al. 2006
Pennsylvania	Laboratory	Gypsum amendment	10 g/kg application of a gypsum byproduct to Pennsylvania soils reduced the concentration of water-soluble P by 50%.	Stout et al. 1999
Indiana	Laboratory	Gypsum amendment	Gypsum addition to soils significantly decreased the mass loss in runoff of dissolved reactive P (85%), TP (60%), soluble NH_4-N (80%), and total N (59%).	Favaretto et al. 2006
Ireland	Laboratory	Gypsum amendment	Gypsum addition decreased reactive P solubility by 14%–56% and organic P solubility by 10%–53%.	Murphy et al. 2010

Nutrient management planning

In a Virginia field study, Maguire et al. (2008) investigated how changing poultry litter application rates from an N to a P basis affected crop yields and soil properties in high P soils over a 7-year period. After 7 years, Mehlich 1 P and water-soluble P were greatest in soils under the N-based treatments, smallest in the no-P treatment, and intermediate in the P-based treatments; there were no significant differences between inorganic fertilizer and poultry litter nutrient sources. The results show that soil test P can be decreased in high-P soils over a few years by changing from an N-based to a P-based nutrient management plan or by stopping P applications without negatively affecting yields.

In Quebec, Canada, Giroux and Royer (2007) measured the effect of three P fertilizer rates on crop yields and evolution of the soil test values, saturation and P solubility. Soil test P values decreased by 11–33 percent over 8 years, even at P application rates above crop removal rates. Annual rates of P-sat decrease were 1.087, 0.891 and 0.750 percent/year respectively for the 0, 30, and 60 kg P_2O_5/ha fertilizer rates. The P-sat value of 13.1 percent of the Quebec regulation was achieved after 10 years for the 0 kg P_2O_5/ha rate.

Table 2-16. Summary of reported practice effects resulting from nutrient application planning

Location	Study type	Practice	Practice effects	Source
Virginia	Field	P-based nutrient management	After 7 years, Mehlich 1 P and water soluble P were greatest in soils under the N-based treatments, smallest in the no P treatment, and intermediate in the P-based treatments. Soil test P can be decreased in high-P soils by changing from an N-based to a P-based nutrient management plan or stopping P applications without negatively affecting yields.	Maguire et al. 2008
Quebec, Canada	Field	P fertilizer rates	Soil test P values decreased by 11%–33% over 8 years, even at P application rates above crop removal. Annual rates of P-sat decrease were 1.087, 0.891 and 0.750%/yr, respectively, for the 0, 30, and 60 kg P_2O_5/ha fertilizer rates. The P-sat value of 13.1% of the Quebec regulation is achieved after 10 years for the 0 kg P_2O_5/ha rate	Giroux and Royer 2007
Texas	Field	Turfgrass sod export	46%–77% of the applied manure P removed in a single turfgrass sod harvest. Total dissolved P concentrations in the runoff were directly related to P concentrations in the soil. 3.8% of the applied P from composted dairy manure was lost in the surface runoff.	Choi et al. 2003
Texas	Plot	Zero P fertilizer	Using only commercial N on soils with high extractable P levels decreased P loadings in edge-of-field runoff by ≥ 40%.	McFarland and Hauck 2004
Texas	Model	P-based manure management	Edge-of-field TP losses can be reduced by about 0.8 kg/ha/year or 14% when manure applications are calibrated to supply all the recommended crop P requirements from manure TP sources only, vs manure applications at N agronomic rate.	Osei et al. 2008

In Texas, Choi et al. (2003) reported that 46–77 percent of the applied manure P was removed in a single turfgrass sod harvest. Total dissolved P concentrations in the runoff were directly related to P concentrations in the soil. A total of 3.8 percent of the applied P from composted dairy manure was lost in the surface runoff.

From Texas plot studies, McFarland and Hauck (2004) reported that using only commercial N on soils with high extractable P levels decreased P loadings in edge-of-field runoff by greater than or equal to 40 percent. However, no notable changes in extractable soil P concentrations were observed after 5 years of monitoring because of drought conditions limiting forage uptake and removal.

In a Texas study using an integrated economic and environmental modeling system across multiple ecoregions, Osei et al. (2008) suggested that edge-of-field TP losses can be reduced by about 0.8 kg/ha/year or 14 percent when manure applications are calibrated to supply all the recommended crop P requirements from manure TP sources only, when compared to manure applications at the recommended crop N agronomic rate.

3.2 Sediment and Erosion Control

Sediment loss is the result of erosion. It is the solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by wind, water, gravity, or ice. The types of erosion associated with agriculture that produce sediment are (1) sheet and rill erosion, (2) ephemeral and classic gully erosion, (3) wind erosion, and (4) streambank erosion. Soil erosion can be characterized as the transport of particles that are detached by rainfall, flowing water, or wind. Eroded soil is either redeposited on the same field or transported from the field in runoff or by wind.

The strategies for controlling erosion and sedimentation involve reducing soil detachment, reducing sediment transport, and trapping sediment before it reaches water. The first objective for both water and wind erosion is to keep soil on the field, and the easiest and often most effective strategy to accomplish that is to reduce soil detachment. Detachment occurs when water splashes onto the soil surface and dislodges soil particles or when wind reaches sufficient velocity to dislodge soil particles on the surface.

Crop residues (e.g., straw) or living vegetative cover (e.g., cover crops, grasses) on the soil surface protect against detachment by intercepting and/or dissipating the energy of falling raindrops. A layer of plant material also creates a thick layer of still air next to the soil to buffer against wind erosion. In some areas, crops that maintain a greater surface coverage could be substituted for existing crops to control erosion.

Implementing tillage practices such as continuous no-till or other forms of conservation tillage also preserves or increases organic matter and soil structure, resulting in improved water infiltration and surface stability. In addition, creating a rough soil surface through practices such as surface roughening will break the force of raindrops and trap water, reducing runoff velocity and erosive forces.

Sediment transport can be reduced in several ways, including using crop residues or conservation buffers. Vegetation slows runoff, increases infiltration and traps sediment. Reductions in slope length and steepness reduce runoff velocity, thereby reducing sediment carrying capacity as well. Practices are also typically needed to trap sediment leaving the field before it reaches a wetland or riparian area. Deposition of sediment is achieved by practices that slow water velocity or increase infiltration.

Properly functioning natural wetlands and riparian areas can significantly reduce nonpoint source pollution by intercepting surface runoff and subsurface flow and by settling, filtering, or storing sediment and associated pollutants. Wetlands and riparian areas typically occur as natural buffers between uplands and adjacent waterbodies. Loss of these systems allows a more direct contribution of nonpoint source pollutants to receiving waters. Degraded wetlands and riparian areas can even become pollutant sources. Thus, natural wetlands and riparian areas should be protected and should not be used as designated erosion control practices. Their nonpoint source control functions are most effective as part of an integrated land management system focusing on nutrient, sediment, and erosion control practices applied to upland areas.

Additional descriptions of erosion and sediment control practices are in previous guidance (USEPA 2003). Also, NRCS provides a host of Practice Codes that can be used to implement sediment and erosion controls.

Implementation Measure A-12:

Use conservation tillage or continuous no-till on cropland to reduce soil erosion and sediment loads except on those lands that have no erosion or sediment loss.

Conservation tillage includes a variety of tillage systems that leave varying amounts of residue on a field. Continuous no-till leaves all residue after harvest on the field, protecting the soil. In general, conservation tillage is any tillage system that maintains 30 percent or more of the soil surface with crop residue after planting (USDA-NRCS 2010e). The amount of residue needed to achieve erosion and sediment reduction goals, however, is dependent on numerous factors; the

Revised Universal Soil Loss Equation (RUSLE) is a tool that can help determine the amount left on the field.

Water erosion rates are affected by rainfall energy, soil properties, slope, slope length, vegetative and residue cover, and land management practices. Rainfall impacts provide the energy that causes initial detachment of soil particles. Soil properties like particle size distribution, texture, and composition influence the susceptibility of soil particles to be moved by flowing water. Vegetative cover and residue can protect the soil surface from rainfall impact or the force of moving water. Those factors are used in the RUSLE, an empirical formula widely used to predict soil loss in sheet and rill erosion from agricultural fields, primarily crop land and pasture, and construction sites (USDA-ARS 2005):

Revised Universal Soil Loss Equation (RUSLE)

$$A = R \times K \times LS \times C \times P$$

where

A = estimated average annual soil loss (tons/acre/year)

R = rainfall/runoff factor, quantifying the effect of raindrop impact and the amount and rate of runoff associated with the rain, based on long-term rainfall record

K = soil erodibility factor based on the combined effects of soil properties influencing erosion rates

LS = slope length factor, a combination of slope gradient and continuous extent

C = cover and management factor, incorporating influences of crop sequence, residue management, and tillage

P = practice factor, incorporating influences of conservation practices such as contouring or terraces

Practice Effectiveness

Past reviews of the effectiveness of sediment control measures have concluded that reduced tillage systems reduce TP losses by 45 percent, TN losses by 55 percent, and sediment losses by 75 percent (USEPA 2003).

Harmel et al. (2006, 2008) have compiled measured annual N and P load data representing field scale transport from agricultural land uses. The 2006 compilation includes results from 40 scientifically peer-reviewed studies but draws heavily from the 1980s. The more recent data (2008 update) include 15 additional studies. In all, the database contains 1,677 watershed years of data for various agricultural land uses and practices. Most data are from the Southeast and upper Midwest, with only one study from the Chesapeake Bay Drainage area. Table 2-17, below, provides a summary of median N and P export coeffcients from Harmel et al. (2006) from which N and P reductions could be estimated. The current version is at http://www.ars.usda.gov/spa/manage-nutrient.

Table 2-17. Median N and P export coefficients

Table 4. Median annual dissolved, particulate, and TN and P export coefficient values (kg/ha) for selected treatments

Treatment*	**TN** (kg/ha)	**Dissolved N** (kg/ha)	**Particulate N** (kg/ha)	**TP** (kg/ha)	**Dissolved P** (kg/ha)	**Particulate P** (kg/ha)
Tillage						
Conventional	7.88a	2.41a	7.04a	1.05a	0.19b	0.64a
Conservation	7.70a	2.30ac	3.40c	1.18ac	0.65ac	1.00a
No-Till	1.32b	4.20c	1.80bc	0.63c	1.00c	0.80a
Pasture/Range	0.97b	0.32b	0.62b	0.22b	0.15b	0.00b
Conservation Practice						
None	2.19a	1.60a	1.70a	0.41a	0.26ab	0.64ab
One Practice	6.73b	1.33a	14.80a	0.61ab	0.14a	0.37a
2+ Practices	8.72b	2.61b	3.30a	1.22b	0.50b	0.75b
Soil Texture						
Clay	4.93a	4.47a	2.00a	0.92a	0.50a	0.55a
Loam	4.05a	1.64b	5.78b	0.41b	0.18b	0.93a
Sand	2.74a	1.70ab	–**	1.50ab	0.07ab	–**

Source: Harmel et al. 2006

* For each nutrient form within a treatment, medians followed by a different letter are significantly different (a – 0.05).

** No particulate N or P data were available for sandy soils.

In another literature review, Merriman et al. (2009) developed a compilation of BMP effectiveness results. Table 2-18 presents a listing of individual results for conservation tillage practices along with percent reductions for TP, TN, and sediment. Additional data on reductions for particulate P, dissolved P, NO_3-N, and ammonium are also available.

Soil loss and ortho-P transport were measured from a conventional and two conservation tillage treatments (zero and ridge tillage) from January 1988 to September 1990 in southwestern Ontario (Gaynor and Findlay 1995). Compared to conventional tillage, conservation tillage reduced average soil loss by 49 percent (899 kg/ha) and increased ortho-P concentrations in runoff 2.2 times (0.25 mg/L).

Table 2-18. TP, TN, and sediment reductions for various conservation tillage practices

Reference (as cited by Merriman et al. 2009)	State	BMP name	Study scale	3-8	C		TN %	Total sediment %
Zhu et al. 1989	Missouri	No-till	Field plot	3	D			92%
Zhu et al. 1989	Georgia	No-till	Field plot	3	D			90%
Zhu et al. 1989	Georgia	No-till	Field plot	3	D			92%
Dabney et al. 1993	Mississippi	No-till	Field plot	3-8	C			72.3%
Dabney et al. 1979	Georgia	No-till	Field plot	3	B			86%
Dabney et al. 1979	Georgia	No-till	Field plot	3	C			86%
Dabney et al. 1993	Mississippi	No-till	Field	3-8	B			95.49%
Yoo et al. 1988	Alabama	No-till	Field plot	3-8	B	5%	7.6%	20.8%
Mutchler et al. 1985	Mississippi	No-till	Field plot	3-8	C			47%
Meyer et al. 1999	Mississippi	No-till	Field plot	3-8	C	84%	90%	99%
McGregor and Greer 1982	Virginia	No-till	Field plot	8	C			95.49%
Yoo et al. 1986	Alabama	No-till	Field plot	8	B		-2.76%	54.44%
Meyer et al. 1999	Virginia	No-till	Field plot	8	C			85.11%
Meyer et al. 1999	Louisiana	No-till	Field plot	3-8	C			90.84%
Hairston et al. 1984	Virginia	No-till	Field plot	3-8	D			16.28%
McGregor et al. 1975	Virginia	No-till	Field plot	8	B			85.71%
McGregor et al. 1975	Mississippi	No-till	Field plot	3-8	C			85.71%
Mutchler and Greer 1984	Mississippi	No-till	Field plot	3-8	C			94.08%
Hairston et al. 1984	Mississippi	No-till	Field plot	3-8	C			92.7%
Langdale et al. 1979	Georgia	No-till	Field plot	3-8	B			86%
Truman et al. 1979	Georgia	No-till	Field plot	3-8	C			86%
Dabney et al. 1993	Mississippi	No-till	Field plot	3-8	C			56.76%
Dabney et al. 1993	Mississippi	No-till	Field plot	3-8	C			50%
Dabney et al. 1993	Mississippi	No-till	Field plot	3-8	C			66.67%

Table 2-18. TP, TN, and sediment reductions for various conservation tillage practices *(continued)*

Reference (as cited by Merriman et al. 2009)	State	BMP name	Study scale	3-8	C		TN %	Total sediment %
Dabney et al. 1993	Mississippi	No-till	Field plot	3-8	C			83.33%
Yoo et al. 1988	Alabama	No-till	Field plot	3-8	B	22.5%	23.8%	52.3%
Schreiber and Cullum 1998	Mississippi	No-till	Large watershed	3-8	C	76.52%	67.68%	
Meyer et al. 1999	Mississippi	No-till	Field plot	3-8	C			88.47%
Mostaghimi, Dillaha, Shanholtz 1988	Virginia	No-till	Field plot	8-15	C	97%		98%
Mostaghimi et al. 1992	Virginia	No-till	Field plot	8-15	C	65.52%	90.55%	69.47%
Mostaghimi et al. 1991	Virginia	No-till	Field plot	8-15	C		90.55%	94.75%
Feagley et al. 1992	Louisiana	No-till	Field plot	N/A	D			74.25%
Daniels and Gilliam 1996	Virginia	No-till with subsurface injection	Field plot	3-8	B	91%		92%
Mostaghimi et al. 1991	Virginia	No-till with subsurface injection	Field plot	8-15	C		95.42%	
McGregor and Greer 1982	Mississippi	Reduced Tillage	Field plot	3-8	C			91.84%
McGregor and Greer 1982	Mississippi	Reduced Tillage	Field plot	3-8	B			91.84%
Hairston et al. 1984	Mississippi	Reduced Tillage	Field plot	3-8	D			13.85%
Mutchler and Greer 1984	Mississippi	Reduced Tillage	Field plot	3-8	C			58.78%
Truman et al. 2003	Alabama	Cover crop (general)	Field plot	N/A	B			46%

Source: Merriman et al. 2009

Using a rain simulator on plots, Avalos et al. (2007) found that corn straw residue decreased N losses from 88.82 to 16.65 kg/ha (81 percent reduction) and decreased TP losses from 7.87 to 1.72 kg/ha (78 percent reduction). In another plot study using rainfall simulation, it was found that under no-till conditions, plots with corn residue and grass hedges averaged 52 percent less runoff and 53 percent less soil loss than similar plots without grass hedges (Gilley et al. 2000). Under tilled conditions, the plots with corn residue and grass hedges averaged 22 percent less runoff and 57 percent less soil loss than comparable plots without grass hedges. The plots with corn residue removed but with grass hedges present averaged 41 percent less runoff and 63 percent less soil loss than similar plots without grass hedges.

One alternative to reduce compaction and restricted infiltration under long periods of no-till is rotational tillage (Smith et al. 2007). In the first year of converting from long-term, no-till to rotational tillage on small plots that had been in a no-till corn-soybean rotation for 15 years, runoff volumes and nutrient concentrations for NH_4-N, NO_3-N, and dissolved P were greater from the no-till field. Before fertilization, no-till resulted in 83 g/ha greater NH_4-N and 32.4 g/ha greater dissolved P losses than rotational tillage. After fertilization, no-till was observed to lose 5.3 kg/ha more NH_4-N, 1.3 kg/ha more NO_3-N, and 2.4 kg/ha more dissolved P than rotational tillage.

Conventional tillage, conservation tillage with cover crop, and no-till with cover crop were compared in a small grain-corn rotation in Austria in a field study from 1994 to 1999 (Klik et al. 2001). The field plots ranged from 3–4 m in width and 15-m long, and slope ranged from 6 to 16 percent. Runoff was not statistically different among the practices, but nutrient losses from April to October were 13.7 kg/ha for conventional tillage, 9.1 kg/ha (34 percent decrease) for conservation tillage, and 7.7 kg/ha (44 percent decrease) for no-till. P losses were 6.5, 3.1 (52 percent decrease), and 2.0 kg/ha (69 percent decrease), respectively. In a 9-year field study in Finland, Puustinen et al. (2005) found that traditional cultivation treatments produced the highest TSS concentrations (1.38 and 1. 18 mg/L, respectively), whereas values between 0.44 and 0.53 mg/L were measured for three treatments with reduced (or no) tillage. Particle-bound P concentrations closely followed those of TSS, but DRP showed contrasting behavior.

Finnish researchers (Turtola et al. 2007) found that the frequency of tillage, rather than the depth of tillage, has a greater effect on erosion on clayey soils. Shallow autumn tillage produced erosion as high as moldboard plowing (407–1,700 kg/ha-yr), but 48 percent and 12 percent lower erosion levels were measured from plots left untilled in autumn, covered by grass or barley residues, respectively. In a companion study, Uusitalo et al. (2007) found that stubble treatment yielded higher DRP losses (104–259 g/ha-yr) than autumn plowing (77–96 g/ha-yr), and equally high particulate P (PP) losses (mean 660, 235–1,300 g/ha-yr). Shallow autumn tillage produced 28 percent higher DRP losses (mean 120, 107–136 g/ha-yr) than plowing (83–117 g/ha-yr) and 11 percent higher PP losses (mean 1,090, 686–1,336 g/ha-yr) than plowing (783–1253 g/ha-yr).

Practice Costs

In an analysis of various combinations of practices to control sediment loss in a 12-ha subwatershed of the Mississippi Delta Management System Evaluation Area using the Annualized Agricultural Nonpoint Source pollutant loading model (AnnAGNPS 2.1), it was found that the most cost-effective practices were management of volunteer winter weeds as cover crops and various types of edge-of-field, grade-control pipes (Yuan et al. 2002; Dabney et al. 2001). The average marginal cost using practices for sediment yield reduction was about $10/MT (2010 dollars) for conventional and reduced tillage. The cost was higher, about $13/MT for no-till because the practice of no-till alone reduced sediment yield by half, and further marginal reductions were more expensive.

Using the Water Erosion Prediction Project, or WEPP, model calibrated to a 6.4-ha site within Four Mile Creek watershed in eastern Iowa, Zhou et al. (2009) compared the cost of lost soil for chisel plow, disk tillage, and no-tillage. The value of lost soil resulting from soil erosion ranged between $11 and $139/ha-yr (2010 dollars) for the simulated scenarios in the study when a soil value of $6.19/t was considered. When factoring in the value of soil, no-tillage was the most efficient practice with the highest net benefit of $95.86/ha-yr.

Both national and selected state costs for a number of common erosion control practices are presented in Table 2-19. The variability in costs for practices can be accounted for primarily through differences in site-specific applications and costs, differences in the reporting units used, and differences in the interpretation of reporting units. For example, grassed waterways in Virginia cost $3,237/ac and terraces cost $0.59/ft with typical total costs of $2,972 and $295, respectively (USDA-NRCS 2010).

Table 2-19. Representative costs of selected erosion control practices

Practice	Unit	Range of capital costs[a]	References
Diversions	ft	$2.63–$7.36	Sanders et al. 1991 Smolen and Humenik 1989
Terraces	ft a.s.[b]	$4.43–$19.75 $32.24–$89.15	Smolen and Humenik 1989 Russell and Christiansen 1984
Waterways	ft ac a.e.[c]	$7.85–$11.84 $151–$5,684 $1,669–$2,902	Sanders et al. 1991 Barbarika 1987; NCAES 1982; Smolen and Humenik 1989 Russell and Christiansen 1984
Permanent Vegetative Cover	ac	$92–$360	Barbarika 1987; Russell and Christiansen 1984; Sanders et al. 1991; Smolen and Humenik 1989
Conservation Tillage	ac	$12.68–$84.58	NCAES 1982; Russell and Christiansen 1984; Smolen and Humenik 1989

Notes:

a. Reported costs inflated to 1998 dollars by the ratio of indices of prices paid by farmers for all production items, 1991 = 100. 1998 dollars then converted to 2010 dollars.

b. acre served

c. acre established

[Note: 1991 dollars from CZARA were adjusted by +15%, based on ratio of 1998 Prices Paid by Farmers/1991 Prices Paid by Farmers, according to USDA National Agricultural Statistics Service, http://www.allcountries.org/uscensus/1114_indexes_of_prices_received_and_paid.html, 28 September 1998]. 1998 dollars then converted to 2010 dollars.

The cost estimates for control of erosion and sediment transport from agricultural lands in Table 2-20 are based on experiences in the Chesapeake Bay Program.

Table 2-20. Annualized cost estimates and life spans for selected management practices from Chesapeake Bay installations[a]

Practice	Practice life span	Median annual costs[b] (Years) (EAC[c]) ($/acre/yr)
Nutrient Management	3	4.00
Strip-cropping	5	19.32
Terraces	10	140.75
Diversions	10	86.74
Sediment Retention Water Control Structures	10	148.56
Grassed Filter Strips	5	12.17
Cover Crops	1	16.65
Permanent Vegetative Cover on Critical Areas	5	117.72
Conservation Tillage[d]	1	28.87
Reforestation of Crop and Pastured	10	77.69
Grassed Waterways[e]	10	1.67/LF/yr
Animal Waste System[f]	10	6.26/ton/yr

Source: Camacho 1991

Notes:

a. Median costs (1990 dollars) obtained from the Chesapeake Bay Program Office (CBPO) BMP tracking database and Chesapeake Bay Agreement Jurisdictions' unit data cost. Costs per acre are for acres benefited by the practice. 1990 dollars converted to 2010 dollars.
b. Annualized BMP total cost including O&M, planning, and technical assistance costs.
c. EAC = equivalent annual cost: annualized total; costs for the life span. Interest rate = 10%.
d. Government incentive costs.
e. Annualized unit cost per linear foot of constructed waterway.
f. Units for animal waste are given as $/ton of manure treated.

Practice Savings

It is important to note that for some practices, such as conservation tillage, the net costs often approach zero and in some cases can be negative because of the savings in labor and energy. In fact, it is reported that cotton growers can lower their cost per acre by $88/ha (2010 dollars) because of lower fixed costs associated with conservation tillage (Zeneca 1994).

3.3 Cover Crops

Implementation Measure A-13:

Use the most suitable cover crops to scavenge excess nutrients and prevent erosion at the site on acres that have received any manure or chemical fertilizer application. Cover crops should be used during a non-growing season (including winters) or when there is bare soil in a field.

A cover crop is any crop grown to provide soil cover, primarily to prevent soil erosion by wind and water (Sullivan 2003) (NRCS Practice Code 340). Cover crops can be annual, biennial, or perennial plants grown in a pure or mixed stand during all or part of the year to provide ground cover, fix N (legumes), suppress weeds, reduce insect pests and diseases, and reduce nutrient leaching following a main crop. The Midwest Cover Crop Council Web site (www.mccc.msu.edu/CCinfo/cropbycrop.html) provides information on a variety of options for planting cover crops, and describes the various plant species available. Cover crops come in several forms, depending on the situation and objectives.

A *winter cover crop* is planted in late summer or fall to provide soil cover during the winter; a legume is often planted to generate N for the subsequent crop (Sullivan 2003). Legumes, however, are not recommended for reducing NO_3 leaching. In general, a winter cover crop is planted shortly before or soon after the main crop is harvested and remains on the field through the winter. It is then killed or removed before or soon after planting of the subsequent season's main crop.

A *summer green manure* is a warm-season cover crop used to fill a niche in crop rotations, to improve the conditions of poor soils, or to prepare land for a perennial crop (Sullivan 2003). Legumes such as cowpeas, soybeans, annual sweet clover, sesbania, guar, crotalaria, or velvet beans are often grown to add N and organic matter, while non-legumes such as sorghum-sudangrass, millet, forage sorghum, or buckwheat are grown for biomass, to smother weeds, and to improve soil tilth.

A *living mulch* is a cover crop that is interplanted with an annual or perennial cash crop to suppress weeds, reduce soil erosion, enhance soil fertility, and improve water infiltration (Sullivan 2003). Producers should plant a species that is suppressed during the intensive growth period of the main crop and is taking in excess available nutrients and is growing as the main crop matures or after it is harvested. Living mulches can be incorporated into bare earthen rows during a cropping season for corn, vegetables and many other crops grown in the Chesapeake Bay. For example, New York vegetable growers can interseed ryegrass or clover into a standing vegetable crop or plant barley windbreaks in muck-grown onions (Stivers et al. 1998).

A *catch crop* is a cover crop established after harvesting the main crop and is used primarily to reduce nutrient leaching from the soil profile but can also be used to fill a niche within a crop rotation (Sullivan 2003). When applying cover crops for the purpose of capturing and recycling excess nutrients in the soil profile, NRCS Practice Code 340 specifies that they should be established and actively growing before the expected period(s) of nutrient leaching and that cover crop species will be selected for their ability to take up large amounts of nutrients from the rooting profile of the soil. Deep-rooted crops, such as winter annual grasses (rye, wheat, and barley) can absorb excess nutrients from the soil and then release them through decomposition for the subsequent crop, in effect capturing nitrates that could otherwise leach through the root zone to groundwater (Poole 2004). Greater amounts of N can be taken up by cover crops when a drought-stricken summer crop has failed to use most of the fertilizer applied or on soils that mineralize large amounts of N in the fall because of previous manure applications (Weil et al. 2009).

According to the Sustainable Agriculture Network, an excellent resource for information on cover crops, the best cover crops to use for NO_3 conservation are non-legumes (e.g., rye, sorghum-sudan) that form deep, extensive root systems quickly after cash crops are harvested (SAN 2007). Cereal rye is the best choice for catching nutrients after a summer crop over much of the United States. Rye has cold tolerance that allows it to continue to grow in late fall and develop roots to a depth of 3 feet or more; rye can also grow through mild winter months. Weil et al. (2009) report that because of their exceptionally deep root system, rapid growth, and heavy N feeding, forage radish cover crops can take up most of the soluble N left in the soil profile after summer crops have ceased their uptake. The forage radish takes up N from both the topsoil and from deep soil layers, typically taking up 112 to 168 kg/ha of N if planted while soils are warm. Brassica cover crops (e.g., forage radish, oilseed radish, and rape) are new to the mid-Atlantic region, however, and one of their limitations is the need for early planting. Farmers in the region have successfully planted Brassica cover crops after harvest of corn silage, small grains, and sweet corn, but their application in the widespread corn grain–soybean rotations might require a more risky broadcast seeding into standing crop canopies.

In summary, the top N scavengers include the following (SAN 2007):

1. Excellent N scavengers
    a. Rye
    b. Sorghum-sudan
    c. Radish

2. Very good N scavengers
    - d. Annual ryegrass
    - e. Barley
    - f. Oats
    - g. Wheat
    - h. Rapeseed
    - i. Berseem clover
3. Good N scavengers
    - j. Mustards
    - k. Crimson clover
    - l. Red clover
    - m. Woollypod vetch

If the objective is to best synchronize the use of a cover crop to cycle nutrients, factors such as the carbon:nitrogen ratio (C:N) should be considered to determine the kill date to match the release of nutrients with uptake by a following cash crop. Killing or plowing down the cover crop when the crop is still relatively young is important for N availability because decomposition will be slower when the plant is in boot stage or later (Bosworth 2006). If the C:N ratio is over 30:1, N will generally be immobilized during the early stages of the decomposition process (SAN 2007). The C:N ratio of small grain residues is generally lower in young plant tissue, but if the cover crop is killed too early, this lower C:N ratio results in rapid decomposition of a smaller amount of residue, reducing ground coverage. The wide C:N ratio of small grain residues, therefore, must be taken into account for best nutrient management.

In their study of Brassica cover crops Dean and Weil (2009) recommend that the choice of cover crop should take into consideration both the timing of N release in relation to the N demands of the subsequent crop and the impact of soil texture on the susceptibility of NO_3-N to leaching in fall and spring. The forage radish, a cover crop that freeze-kills in the mid-Atlantic region, releases N from plant tissues early in spring. Although this early N availability can provide an agronomic advantage for the summer crop, significant amounts of NO_3-N can be lost to leaching if a main crop is not planted early enough to recapture this N. Early planting of a subsequent summer crop is especially important to minimize spring leaching losses in coarse-textured, well- to excessively drained soils. Rape, which continues to capture soil NO_3-N until terminated in spring, could be a more appropriate choice of cover crop on coarse-textured soils when the summer crop will not be planted until late spring.

Practice Effectiveness

Staver and Brinsfield (1998) investigated the effects of cereal grain winter cover crops on NO_3 leaching rates, profile NO_3 storage, and NO_3 concentrations in shallow groundwater in two Chesapeake Bay field-scale watersheds planted continuously in corn from 1984 through 1996. Rye winter cover crops planted after corn harvest consistently reduced NO_3-N concentrations in root zone leachate to less than 1 mg/L during most of the groundwater recharge period and reduced annual nitrate leaching losses by approximately 80 percent relative to winter-fallow treatments. Shallow groundwater NO_3-N concentrations under long-term continuous corn production decreased from the 10 to 20 mg/L range to less than 5 mg/L after 7 years of cover crop use.

In a Maryland study comparing N uptake ability and potential to reduce N leaching, three Brassica cover crops (forage radish, oilseed radish, and rape) and rye all decreased soil mineral N losses compared with winter weed control plots by storage of N in plant tissues throughout the fall and early winter (Dean and Weil 2009). Averaged across three site-years, forage radish and rape shoots had greater dry matter production and captured more N in fall than rye shoots. Compared with a weedy fallow control, rape and rye caused similar decreases in soil NO_3-N in fall and spring throughout the sampled profile. During the spring on coarse-textured soil, pore water NO_3-N concentrations in freeze-killed radish plots were greater than in control and overwintering rape and rye plots. On fine-textured soil, all cover crops provided a similar decrease in pore water NO_3-N concentration compared with the control. The authors conclude that on coarse-textured soils, freeze-killed Brassica cover crops should be followed by an early planted spring main crop but that additional research is needed to determine the optimal agronomic management of the new cover crops in various types of cropping systems in the region.

A 2-year study comparing sediment, N, and P runoff losses for cotton managed with winter fallow and conventional tillage versus cotton managed with a winter wheat cover crop and strip-tillage, found that the cover crop/strip-till treatment reduced sediment loss for all sampling dates, especially in 2000 when sediment losses were less than half of those with conventional tillage. Sediment loss was also reduced with cover crop/strip-till during the early growing season, before crop canopy closure, and vegetative field borders further reduced runoff of sediment and sediment-attached P (Hoyt 2005).

Hairy vetch, a legume, was shown to not be effective in reducing NO_3 losses on tomato lands in a study conducted on a Norfolk sandy loam in central Georgia (Sainju 1999). Although hairy vetch increased tomato N uptake and recovery, it was not effective in reducing NO_3-N content and movement compared with N fertilizer.

In a field study to determine the potential of a Bermuda grass/ryegrass combination to reduce the level of Mehlich 3 P that had accumulated in a Savannah soil from broiler litter application over 30 years, coupled with antecedent litter rates of 0, 4.48, 8.96, 17.9, and 35.8 Mg/ha, Read et al. (2009) found that annual dry matter (DM) yield and P uptake generally increased as litter rate increased up to 17.9 Mg/ha. Analysis of Mehlich 3 P in surface soil (0–15 cm depth) at four sampling dates over 19 months showed reductions of 25, 27, 22, 26, and 29 percent at the five antecedent litter rates, respectively. Ryegrass-Bermuda grass significantly increased DM yield and P uptake but did not increase reductions in Mehlich 3 P, as compared to Bermuda grass winter fallow, and both forage systems removed about 49 kg/ha P and reduced Mehlich 3 P by about 26 mg/kg annually via five harvests per year.

Sharma and Sahi (2005) examined the phytoremediation potential of Gulf and Marshall ryegrass grown in a greenhouse under varying conditions of soil P concentration, pH, and temperature, finding that an increase in plant biomass was proportional to the increasing concentrations of P up to a level of 10 g of P/kg of soil. Significant effects of both soil pH and temperature on plant uptake of P were measured, and the researchers concluded that Gulf and Marshall ryegrass can accumulate high P under optimal conditions and thus reduce soil P concentrations in successive cropping.

A 3-year field experiment was conducted on sandy loam soils in southwestern Michigan to investigate the combined effects of N fertilization rates and rye cover crops on NO_3 leaching in inbred maize fields (Rasse et al. 2000). Annual NO_3 leaching losses to groundwater in lysimeters fertilized at 202 kg N/ha averaged 88 kg NO_3-N/ha, but rye interseeded with inbred maize fertilized at 202 kg N/ha sequestered from 46 to 56 kg/ha of excess fertilizer N. Well-established rye cover crops reduced NO_3 leaching by as much as 65 kg N/ha when sediment losses were less than half of those with conventional tillage. Sediment loss was also reduced with cover crop/strip-till during the early growing season, before crop canopy closure, and corn yield. Although fall (but not spring) cover crop DM was 26 percent lower with manure than without manure, no difference was detected for N (9.4 kg/ha) or P (1.4 kg/ha) uptake. Shoot DM and N, P, and K uptake increased 29, 41, 31, and 25 percent, respectively, from the cover crop manure 112 kg N/ha treatment to the cover crop manure 224 kg N/ha treatment, with no increase above the cover crop manure 224 kg N/ha treatment. Cover crop N, P, and K uptake were all higher in cover crop manure versus no manure (60.1 versus 35.6 kg N/ha, 9.2 versus 6.6 kg P/ha and 41.3 versus 30.0 kg K/ha, respectively), while corn yield was unaffected by cover crop and responded positively to manure application (11,022 with manure versus 9,845 kg/ha without manure).

A comparison of a rye winter cover crop and strips of gamagrass (3.05-m wide) placed above subsurface tiles under a no-till corn and soybean management system on drained fields in Iowa showed that rye winter cover crops have the potential to reduce the NO_3 concentrations and loads delivered to surface waters by subsurface drainage systems (Kaspar et al. 2007). Averaged over 4 years, the rye cover crop treatment reduced flow-weighted NO_3-N concentrations by 59 percent and loads by 61 percent, with no significant reduction in cumulative drainage. The gamagrass strips did not significantly reduce cumulative drainage, the average annual flow-weighted NO_3 concentrations, or cumulative NO_3 loads averaged over the 4-year period.

A winter rye cover crop following corn in Minnesota did not affect subsequent soybean yield but reduced subsurface tile drainage discharge, flow-weighted mean NO_3 concentration, and NO_3-N loss relative to winter fallow, with the magnitude of the effect varying considerably with annual precipitation (Strock et al. 2004). Over 3 years, subsurface tile-drainage discharge was reduced 11 percent and NO_3-N loss was reduced 13 percent for a corn-soybean cropping system with a rye cover crop following corn versus no rye cover crop.

An incubation experiment designed to assess the effect of freeze-thaw-cycle duration and frequency on the release of P from catch crop biomass (ryegrass), illustrated the trade-offs of establishing catch crops in frigid climates, which can enhance P uptake by biomass and reduce erosion potential but increase dissolved P runoff (Bechmann et al. 2005). Before freezing and thawing, TP in runoff from catch-cropped soils was lower than from manured and bare soils because of lower erosion. Repeated freezing and thawing significantly increased WEP from catch crop biomass and resulted in significantly elevated concentrations of dissolved P in runoff (9.7 mg/L) compared with manured (0.18 mg/L) and bare soils (0.14 mg/L). Catch crop WEP was strongly correlated with the number of freeze-thaw cycles. Freezing and thawing did not change the WEP of soils mixed with manures, nor were differences observed in subsurface losses of P between catch-cropped and bare soils before or after manure application.

A 2-year field lysimeter study was established in Uppsala, Sweden, to evaluate the effect of a perennial ryegrass cover crop interseeded in barley on NO_3-N leaching and availability of N to the main crop (Bergström and Jokela 2001). Barley yields and total fertilizer N uptake in year one (1992) were unaffected by cover crop. Study results clearly show that a ryegrass cover crop, interseeded in spring barley for one season, substantially reduced NO_3-N leaching. In that case, leaching was reduced by two-thirds in the first year and by more than 50 percent over a 2-year period. The cover crop reduced NO_3-N concentration in the leachate to levels (about 3 mg/L) well below the U.S. and European drinking water standards, compared with approximately 15 mg/L without a cover crop. Barley yield was not significantly affected by the presence of the interseeded ryegrass cover crop during the first year, although it was reduced somewhat during the residual year.

In a 2-year lysimeter study in Switzerland, three non-winter hardy catch crops (sunflower, yellow mustard, and phacelia) were compared with fallow at low (4 g $N/m^2/yr$) and high (29 g $N/m^2/yr$)

N input levels in a spring wheat-catch crop succession (Herrera and Liedgens 2009). Catch crops reduced N leaching by 31–36 percent and by 16–24 percent versus fallow at the low-N and high-N input levels, respectively, but the capacity of the catch crop for recycling N in situ and to increase grain yield and N uptake of the successive spring wheat varied among catch crop species and depended on the level of N input. Although the catch crops reduced N leaching for the entire crop succession, it was mostly from reductions during the periods when water percolation and NO_3 concentration in the soil solution were high (i.e., winter and autumn). A significant amount of the N saved from leaching during autumn and winter was lost during the spring wheat season.

Brandi-Dohrn et al. (1997) used a randomized complete-block split plot design with three N application rates (0 to 280 kg N/ha/yr) to compare winter NO_3-N leaching losses under winter-fallow and a winter cereal rye cover crop following the harvest of sweet corn or broccoli. At the recommended N rate for the summer crops, NO_3 leaching losses were 48 kg N/ha under sweet corn-winter-fallow for winter 1992-1993, 55 kg N/ha under broccoli-winter-fallow for winter 1993–1994, and 103 kg N/ha under sweet corn-winter-fallow for winter 1994–1995, which were reduced to 32, 21, and 69 kg N/ha, respectively, under winter cereal rye. For the first two winters, most of the variation (61 percent) in NO_3 leaching was explained by N rate (29 percent), cereal rye N uptake (17 percent), and volume of leachate (15 percent). Seasonal, flow-weighted concentrations at the recommended N rate were 13.4 mg N/L under sweet corn-winter-fallow (1992–1993), 21.9 mg N/L under broccoli-winter-fallow, and 17.8 mg N/L under sweet corn-winter-fallow (1994–1995), which were reduced by 39, 58, and 22 percent, respectively, under winter cereal rye.

In Denmark, a 24-year-old permanent field trial on coarse sand with spring-sown crops (wheat) was used in a NO_3 leaching study to determine both the effect of long-term cover crop use compared with the introduction of perennial ryegrass as a cover crop on plots with a history of no previous cover crop use as well as the effect of discontinuing long-term use of ryegrass as a cover crop compared with no previous cover crop use (Hansen et al. 2000). From the 4-year average for two N rates (60 and 120 kg/N ha/yr), it was found that leaching was 14 kg/N ha/yr or 29 percent higher in plots with long-term previous cover crop use than in plots without. The effect of previous long-term use of ryegrass as a cover crop lasted at least 4 years, and the authors concluded that if the higher N mineralization from long-term use of a cover crop is not taken into consideration by adjusting the cropping system, the reduction in NO_3 leaching caused by the cover crop might not be as significant in the long term.

Van Vliet et al. (2002) compared different fall-manure application strategies on runoff and contaminant transport from silage corn land in the Lower Fraser Valley of British Columbia. They had three treatments: a control that did not receive manure in the fall, manure broadcast in the fall on corn stubble, and manure broadcast in the fall on corn stubble with an established relay crop. Runoff, solids, and nutrients loads from natural precipitation were measured on replicated experimental plots (0.0125 ha) from 1996 to 1998. Fall-applied manure on 3–5 percent sloping silage corn without a relay crop yielded high suspended solids export of between 7 and 14 Mg/ha/yr and high nutrient transport with mean annual TKN, P, and K losses of 98, 21, and 63 kg/ha respectively. Compared with no relay crop, intercropping silage corn with a relay crop of Italian ryegrass reduced the mean annual runoff and suspended solid load by 53 and 74 percent, respectively, TKN load by 56 percent, P load by 42 percent, K load by 31 percent, and Cu load by 57 percent. Even though total nutrient loads were lower with the relay crop treatment, all fall manure treatments including the relay crop resulted in nutrient loads above local guidelines for the first three runoff events immediately following application.

Practice Costs

The Chesapeake Bay Commission (2004) evaluated 34 nutrient and sediment-reduction practices representing a wide range of specific actions associated with wastewater treatment plants, agriculture, urban stormwater, land preservation, forestry, and air pollution. The analysis resulted in identifying six measures that could achieve a substantial portion of the N, P, and sediment-reduction goals set for the period 2002–2010 in the Chesapeake 2000 agreement. One of those practices is enhanced adoption of late cover crops and use of early cover crops to absorb excess nutrients in the soil. The report estimates that implementing fall cover crops at the maximum extent feasible (0.83 million hectares) in the watershed could achieve annual N reductions of 6,893 Mg of N at $9.54/kg (2010 dollars), 99.8 Mg of P, and 49.9 Mg of sediment at no additional cost. Maximum feasible implementation of early cover crops could provide annual reductions of 3,673 Mg of N at $5.90/kg and 99.8 Mg of P and 049.9 Mg of sediment at no additional cost.

Factors affecting the economics of cover crop use consist of the following (SAN 2007):

- The cash crop grown
- The cover crop selected
- Time and method of establishment
- Method of termination
- The cash value applied to the environment, soil productivity, and soil protection benefits derived from the cover crop
- The cost of N fertilizer and the fertilizer value of the cover crop
- The cost of fuel

The economic picture is most affected by seed costs, energy costs and N fertility dynamics in cover crop systems (SAN 2007). Cover crop seed costs vary considerably from year to year and from region to region, but historically, legume cover crops cost about twice as much to establish as small grain covers. The increased cost of the legume cover crop seed can be offset by the value of N that legumes can replace. Depending on the system in place on a farm, legume cover crops can replace 50 to 112 kg N/ha. On the other hand, a rye cover crop terminated at a late stage of growth might require an additional 22–34 kg N/ha because of N immobilization by the wide C:N ratio rye residue. Thus, the difference in cost between a rye cover crop and a legume cover crop would be offset by the value of 73 to 140 kg N/ha. At a price of $0.21/kg N (2010 dollars), it would be worth $75/ha to $145/ha.

The highest cost for annual cover crops is for the seed, with hairy vetch and crimson clover typically ranging from $1.30 to $3.90/kg (2010 dollars) (Sullivan 2003). With a 22.4-kg/ha seeding rate, seed costs range from $30 to $86/ha. With a 28-kg/ha seeding rate at $2.22/kg and a $7.69 no-till drilling cost, it would cost $82/ha to plant this cover crop.

Saleh et al. (2005) used the modified SWAT (SWAT-M) and FEM (Farm-level Economic Model) models to evaluate the environmental and economic impacts of various BMP scenarios often adopted by local farmers to reduce sediment and nutrient loadings (in particular NO_3-N). Measured values of water quality indicators from the Walnut Creek watershed in central Iowa were used to verify the capability of SWAT-M to predict the impact of late-spring NO_3 test (LSNT) and rye cover crop management on NO_3-N reduction at the subbasin level. The results obtained from SWAT-M simulation results, similar to field measurement data, indicated a 25 percent reduction in NO_3-N under the LSNT scenario. FEM results indicated a corresponding increased annual cost of $6.69/ha (2010 dollars) across all farms in the watershed. Simulating other scenarios, including winter cover cropping and a combination of LSNT and cover cropping at different adoption rates within WCW, resulted in a progressive reduction in sediment and nutrient losses as adoption rates increased. Using the rye cover crop added about $28/ha to $39/ha to the annual cost of the average farm, indicating that some cost-share support might be necessary to encourage farmers to use winter cover crops.

In an application of the Annualized Agricultural Nonpoint Source pollutant loading model (AnnAGNPS 2.1) to a 12-ha Mississippi Delta Management System Evaluation Area (MDMSEA) subwatershed, cover crops, filter strips, grade control pipes, and impoundments were modeled in combination with three tillage systems: conventional tillage, reduced tillage, and no-till (Yuan et al. 2002). Costs of management practices were estimated using 2001 state average prices for Mississippi, and amortized fixed costs—using a 25-year planning horizon and interest rates of both 5 percent and 10 percent—were combined with direct annual costs into total annual cost estimates. AnnAGNPS predicted that no-till alone, reduced tillage with winter cover and an edge-of-field pipe, or conventional tillage with a small permanent impoundment (covering less than 3 percent of the watershed) would all reduce sediment yield by at least 50 percent. The most cost-effective BMPs were managing volunteer winter weeds as cover crops and various types of edge-of-field grade-control pipes. The average marginal cost using BMPs for sediment yield reduction was about $9.84/MT ($8.98/t) (2010 dollars) for conventional and reduced tillage. The cost was higher, about $13.16/MT ($11.93/t), for no-till because the practice of no-till alone reduced sediment yield by half, and further marginal reductions were more expensive.

An assessment of options to address NO_3 problems in the Neuse River Basin of North Carolina concluded that cover crops can reduce N loading to shallow groundwater by 5 to 15 percent (Wossink 2001). Conservation tillage, including cover crops, is identified as one of the three best options for N reduction in the Piedmont region, and the cost of a wheat cover crop is estimated at $230/ha with $0 in net receipts, for a net revenue of -$230/ha.

Franzluebbers (2005) summarizes research on some of the key components that could produce viable integrated crop-livestock production systems in the Southeast: sod-based crop rotation, cover cropping, intercropping, and conservation tillage. Despite its agronomic benefits, adopting cover cropping appears to be limited because of cost without immediate economic benefit, but the author suggests that grazing of cover crops could provide such an immediate economic benefit to producers. On the basis of the research reviewed, barriers to adopting integrated crop–livestock systems include lack of experience or time to manage both the crops and livestock. Franzluebbers reviewed several studies regarding economic returns from grazing livestock and found the following:

- Livestock increased labor required on an average North Dakota farm by about 50 percent, but only about 30 percent of the additional time competed directly during critical crop management. Net economic return attributed to livestock increased whole farm income by about 20 percent.
- Ten steers and heifers were grazed on a 4-ha area of rye or ryegrass cover crop at the Sunbelt Agricultural Exposition near Moultrie, Georgia. The equivalent of $346 ±$69/ha (2010 dollars) greater gross income was generated in the value of animal gain (assuming $1.95/kg animal gain).
- A 3-year experiment was conducted at Headland, Alabama, to compare the effect of oat and ryegrass winter cover crops under cattle grazing on cotton and peanut production managed under different tillage systems. Net return from winter grazing of cover crops (5 head/ha for 80 d) was $206 to $223/ha/yr.
- Using an economic model comparing a conventional system (53 ha cotton, 27 ha peanut) with a sod-based rotation system (20 ha cotton, 20 ha peanut, 40 ha bahiagrass) on a typical small farm in Florida, net profit was expected to be $17,483/year on a conventional farm and $49,967/year on a sod-based farm with cattle grazing the second year bahiagrass.

3.4 Pasture Land Management

Implementation Measure A-14:

Minimize nutrient and soil loss from pasture land by maintaining uniform livestock distribution, keeping livestock away from riparian areas, and managing stocking rates and vegetation to prevent pollutant losses through erosion and runoff.

Livestock can obtain their nutrients through feed supplied to them in a confined livestock facility, through forage, or through a combination of forage and feed supplements. Forage systems can be pasture-based or rangeland-based.

There are important differences between rangeland and pasture. *Rangeland* refers to those lands on which the native or introduced vegetation (climax or natural potential plant community) is predominantly grasses, grass-like plants, forbs, or shrubs suitable for grazing or browsing. Rangeland includes natural grassland, savannas, many wetlands, some deserts, tundra, and certain forb and shrub communities. *Pastures* are those improved lands that have been seeded, irrigated, and fertilized and are primarily used for producing adapted, domesticated forage plants for livestock. Other grazing lands include grazable forests, native pastures, and crop lands producing forage.

The major differences between rangeland and pasture are the kind of vegetation and level of management that each land area receives. In most cases, range supports native vegetation that is extensively managed through the control of livestock rather than by agronomy practices, such as fertilization, mowing, or irrigation. Rangeland also includes areas that have been seeded with introduced species (e.g., clover or crested wheatgrass) but are managed with the same methods as native range. For both rangeland and pasture, the key to good grazing practice is vegetative management, i.e., timing of grazing should be managed to ensure adequate vegetative regrowth and soil stability.

Pastures are represented by those lands that have been seeded, usually with introduced species (e.g., legumes or tall fescue) or in some cases with native plants (e.g., switchgrass or needle grass), and that are intensively managed using agronomy practices and control of livestock. Permanent pastures are typically based on perennial, warm-season (e.g., Bermuda grass) or cool-season (e.g., tall fescue) grasses and legumes (e.g., warm-season alfalfa, cool-season red clover), while temporary pastures are generally plowed and seeded each year with annual legumes (e.g., warm-season lespedezas, cool-season crimson clover) and grasses such as warm-season pearl millet and cool-season rye (Johnson et al. 1997). Plants for pastures should be selected on the basis of climate, soil type, soil condition, drainage, livestock type and expected forage intake rates, and the type of pasture management to be used. Management of pH and soil fertility is essential to both establishing and maintaining pastures (Johnson et al. 1997). In some climates (e.g., Georgia), overseeding of summer perennials with winter annuals is done to provide adequate forage for the period from mid-winter to the following summer.

Pollutant runoff from pasture land can be controlled by managing animal stocking rates and maintaining vigorous vegetation to provide for soil stability and nutrient recycling. Osmond et al. (2007) recommend using those practices that encourage more uniform livestock distribution over the pasture; riparian areas should not be used as shade paddocks, holding areas, or feeding areas; and access to riparian areas should be limited and should not occur when soils are wet or boggy and when acceptable forage is available on non-riparian sites within the same grazing unit. Good pasture management maintains stocking rates and vegetation to prevent pollutant losses through erosion and runoff, and silvopasture techniques integrate trees into pastures to improve nutrient uptake and vegetation stability. Forestry practices and methodologies that can be incorporated into silvopasture are described in Chapter 4.

Practice Effectiveness

Pasture management

In a Georgia plot study, Butler et al. (2008b) compared runoff and sediment and nutrient export from poorly drained and well-drained riparian soils where heavy or light grazing pressure by cattle was simulated. Runoff volume was generally greater from heavily grazed areas than from lightly grazed areas. Light-use plots were effective at minimizing export of TSS on both soils (less than 30 kg/ha). Mean TP export was fourfold greater from heavy-use plots than from light-use plots on both soils. While export of NO_3-N was unaffected by grazing pressure and soil drainage, mean NH_4-N and TN export from poorly drained heavy-use plots was greater than fivefold that from well-drained light-use plots. Results indicate that livestock heavy-use areas in the riparian zone can export substantial TSS and nutrients, especially on poorly drained soils. However, when full ground cover is maintained on well-drained soils, TSS and nutrient losses can be limited.

Sistani et al. (2008) investigated the effect of pasture management and broiler litter application rate on nutrient runoff from Bermuda grass pasture plots in Kentucky. Runoff was 29 percent greater from grazed than hayed pastures regardless of the litter application rate. There was greater inorganic N in the runoff from grazed paddocks when litter rate was based on N rather than P. The mean TP loss per runoff event for all treatments ranged from 7 to 45 g/ha, and the grazed treatment with litter applied on an N basis had the greatest TP loss. The SRP was greater for treatments with litter applied on an N basis regardless of pasture management. Litter can be applied on an N basis if the pasture is hayed and the soil P is low. In contrast, litter rates should be applied on a P-basis if the pasture is grazed.

Cattle did not cause substantial damage to the soil when they were put on fields to graze cover crops in Georgia (Franzluebbers and Stuedemann 2008). The grazing had little effect on soil bulk density or the stability of macroaggregates in. There was a slight tendency for water infiltration rate to be lower with grazing of cover crops (5.6 mm/min) than when ungrazed (6.9 mm/min).

In New Zealand, McDowell and Houlbrooke (2009) assessed restricted grazing and applying alum for their potential to decrease contaminant loss from winter grazing of forage crops. Volumes of surface runoff and loss of P and sediment showed significant differences between the control treatments (i.e., no mitigation) with cattle crop (88 mm surface runoff) greater than sheep crop (67 mm) and greater than sheep pasture (33 mm). Restricted winter grazing and alum application after grazing significantly decreased P losses in surface runoff under cattle (from 1.4 to 0.9 kg P/ha, 36 percent) and sheep (from 1.0 to 0.7 kg/P/ha, 30 percent). In cattle-grazed plots, restricted grazing also decreased suspended sediments by 60 percent.

Owens and Shipitalo (2009) evaluated two systems of over-wintering cattle in Ohio. Vegetative cover in the continuous wintering area frequently decreased to less than 50 percent by late winter/early spring while it remained at or near 100 percent in the rotational system. Annual runoff from the rotational wintering system was 69 percent lower than from the continuous wintering system; sediment loss was also reduced by 91 percent under the rotational system compared to continuous wintering. Surface runoff losses of N from the continuous system were double those from the rotational system during the dormant season. Some of the differences could be attributed to higher cattle occupancy rate in the continuous wintering system.

In North Carolina, Butler et al. (2007) reported that mean NO_{3-} export was greatest from bare ground and was reduced by 31 percent at 45 percent cover. Mean TN export was greatest from bare ground and was reduced by at least 85 percent at cover levels from 45 to 95 percent. Whereas site did not affect N export, results indicate that cover and time of rainfall following manure deposition are important determinants of the effect of riparian grazing.

In a review of experimental data from the Northeast United States, Stout et al. (2000) assessed the relationships between stocking rate and NO_3-N leaching losses beneath an intensively grazed pasture. A relatively low cumulative seasonal stocking rate of about 200 mature Holstein per hectare could result in a 10 mg/L NO_3-N concentration in the leachate beneath a fertilized, intensively grazed pasture. That means that while management intensive grazing can improve farm profitability and help control erosion, it can have a significant negative effect on water quality beneath pastures.

Lyons et al. (2000) compared bank erosion, fish habitat characteristics, trout abundance, and a fish-based index of biotic integrity (IBI) among stations with riparian continuous grazing, intensive rotational grazing, grassy buffers, or woody buffers along 23 trout stream reaches in Wisconsin. After statistically factoring out watershed effects, stations with intensive rotational grazing or grassy buffers had the least bank erosion and fine substrate in the channel. Continuous grazing stations had significantly more erosion and, with woody buffers, more fine substrate. Station riparian land use had no significant effect on width/depth ratio, cover, percent pools, habitat quality index, trout abundance, or IBI score.

From Minnesota, Magner et al. (2008) reported that low IBI scores were associated with streams draining continuously grazed pasture, while higher IBI scores occurred on ungrazed sites. Ungrazed sites were associated with reduced soil compaction and higher bank stability, whereas continuously grazed sites showed increased soil compaction and lower bank stability. Short-duration grazing sites were intermediate.

Table 2-21. Summary of reported practice effects resulting from pasture management

Location	Study type	Practice	Practice effects	Source
Georgia	Plots	Stocking rate	Runoff volume was greater from heavy use than from light use. Light-use plots were effective at minimizing export of TSS. Mean TP export was fourfold greater from heavy-use plots than from light-use plots. While export of NO_3-N was unaffected by grazing pressure and soil drainage, mean NH_4-N and TN export from poorly drained heavy-use plots was greater than fivefold that from well-drained light-use plots.	Butler et al. 2008b
Kentucky	Plots	Pasture management, litter application rate	Runoff was 29% greater from grazed than hayed pastures regardless of litter application rate. There was greater inorganic N in the runoff from grazed paddocks when litter rate was based on N rather than P. The mean TP loss per runoff event for all treatments ranged from 7 to 45 g/ha and the grazed treatment with litter applied on N basis had the greatest TP loss.	Sistani et al. 2008
Georgia	Field	Grazing cover crops	Grazing of cover crops had little effect on soil bulk density; stability of macroaggregates in water was unaffected by grazing of cover crops.	Franzluebbers & Stuedemann 2008
New Zealand	Field	Restricted grazing, alum	Restricted winter grazing and alum application after grazing significantly decreased P losses in surface runoff under cattle (from 1.4 to 0.9 kg P/ha, 36%) and sheep (from 1.0 to 0.7 kg/P/ha, 30%). In cattle grazed plots, restricted grazing also decreased suspended sediments by 60%.	McDowell and Houlbrooke 2009

Table 2-21. Summary of reported practice effects resulting from pasture management *(continued)*

Location	Study type	Practice	Practice effects	Source
Ohio	Field	Cattle wintering systems	Annual runoff from the rotational wintering system was 69% lower than from the continuous wintering system; sediment loss was also reduced by 91% under the rotational system vs. continuous wintering. Surface runoff losses of N from the continuous system were double those from the rotational system during the dormant season.[a]	Owens and Shipitalo 2009
North Carolina	Plots	Vegetative cover	Mean NO_3-N export from bare ground plots was greatest from bare ground and was reduced by 31% at 45% cover. Mean TN export was greatest from bare ground and was reduced by at least 85% at cover levels from 45%–95%.	Butler et al. 2007
Northeast U.S.	Review	Intensive grazing	A relatively low cumulative seasonal stocking rate of about 200 mature Holstein/ha could result in a 10 mg/L NO_3-N concentration in the leachate beneath a fertilized, intensively grazed pasture.	Stout et al. 2000
Wisconsin	Field	Rotational grazing	Stations with intensive rotational grazing or grassy buffers had the least bank erosion and fine substrate in the channel. Continuous grazing stations had significantly more erosion and more fine substrate. Station riparian land use had no significant effect on width/depth ratio, cover, percent pools, habitat quality index, trout abundance, or IBI score.	Lyons et al. 2000
Minnesota	Field	Short-duration grazing	Low IBI scores associated with streams draining continuously grazed pasture; higher IBM scores occurred on ungrazed sites. Ungrazed sites associated with reduced soil compaction and higher bank stability; continuously grazed sites showed increased soil compaction and lower bank stability. Short-duration grazing sites were intermediate.	Magner et al. 2008

Note:

a. Some of the differences could be attributed to higher cattle occupancy rate in the continuous wintering system

Silvopasture

In Missouri, Garrett et al. (2004) reported that many cool-season forages benefit from 40 percent to 60 percent shade, and grazing trials in such conditions have proven to be successful. Also in Missouri, Kallenbach et al. (2006) reported that cumulative forage production in annual ryegrass/cereal rye planted into a 6- to 7-year-old forested stand was reduced by approximately 20 percent compared to the same forages planted in open pasture. However, beef heifer average daily gain and gain/ha were equal for both treatments, suggesting that a silvopasture system likely would not sacrifice livestock production in the system. In Florida, Bambo et al. (2009) documented 56 percent reduction in NO_3 concentrations under silvopasture compared to conventional open pasture.

Blazier et al. (2008) evaluated soil nutrient dynamics, loblolly pine nutrient composition, and loblolly pine growth of an annually fertilized silvopasture on a well-drained soil in Louisiana in response to fertilizer type, litter application rate, and subterranean clover. Litter stimulated loblolly pine growth, and neither litter treatment produced soil test P concentrations above runoff potential threshold ranges. However, both litter treatments led to accumulation of P in upper soil horizons relative to inorganic fertilizer and unfertilized control treatments. Subterranean clover kept more P sequestered in the upper soil horizon and conferred some growth benefits to loblolly pine. The authors concluded that although the silvopasture systems had a high capacity for nutrient use and retention, litter should be applied less frequently than in their study to reduce environmental risks.

In Florida, Michel et al. (2007) reported that water-soluble P concentrations in the upper soil layer ranged from 4 to 11 mg/kg for the silvopasture sites and 10 to 23 mg/kg in the treeless pasture sites, with higher P concentrations in the treeless pasture at each location. TP storage capacity in the upper 1-m depth ranged from 342 to 657 kg/ha in the silvopasture sites and –60 to 926 kg/ha in the treeless pasture sites (a negative value indicates that the soil is a P source). The results suggest that P builds up within the soil profile (P-sat increases) and therefore the chances for loss of P from soil to waterbodies were less from silvopastures than from treeless pastures.

Nair et al. (2007) monitored soil N and P concentrations under a treeless pasture, a pasture under 20-year-old trees, and a pasture of native vegetation under pine trees in Florida. P concentrations were higher in treeless pasture (mean: 9.11 mg/kg in the surface) compared to silvopastures (mean: 2.51 mg/kg), and ammonium-N and NO_3-N concentrations were higher in the surface horizon of treeless pasture. The more extensive rooting zones of the combined stand of tree + forage might have caused higher nutrient uptake from silvopastures than treeless system. Further, compared to treeless system, soils under silvopasture showed higher P storage capacity.

Table 2-22. Summary of reported practice effects resulting from silvopasture

State	Study type	Practice	Practice effects	Source
Missouri	Field	Forage planted in forest stand	Cool-season forages benefit from 40% to 60% shade and grazing trials in such conditions have proven to be successful	Garrett et al. 2004
Missouri	Field	Forage planted in forest stand	Cumulative forage production in annual ryegrass/cereal rye planted into a 6-7 year-old forested stand was reduced by about 20% vs. the same forages planted in open pasture. However, beef heifer average daily gain and gain/ha were equal for both treatments.	Kallenbach et al. 2006
Florida	Field	Silvopasture	56% reduction in NO_3 concentrations under silvopasture compared to conventional open pasture	Bambo et al. 2009
Louisiana	Field	Silvopasture fertilized with poultry litter	Litter stimulated tree growth, and did not produce soil test P concentrations above runoff potential threshold ranges. However, litter treatments led to accumulation of P in upper soil horizons vs. inorganic fertilizer and unfertilized control treatments. Subterranean clover kept more P sequestered in the upper soil horizon and conferred some growth benefits to loblolly pine.	Blazier et al. 2008
Florida	Field	Silvopasture	Water-soluble P concentrations in the upper soil layer on treeless sites (10 to 23 mg/kg) exceeded those on silvopasture sites (4 to 11 mg/kg) at each location. TP storage capacity in the upper 1-m depth was 342 to 657 kg/ha in the silvopasture sites and -60 to 926 kg/ha in the treeless pasture sites (a negative value indicates that the soil is a P source).	Michel et al. 2007
Florida	Field	Silvopasture	Surface soil P concentrations were higher in treeless pasture (mean: 9.11 mg/kg) compared to silvopastures (mean: 2.51 mg/kg), and ammonium-N and NO_3-N concentrations were higher in the surface horizon of treeless pasture. The more extensive rooting zones of the combined stand of tree + forage might have caused higher nutrient uptake from silvopastures than treeless system. Further, compared to treeless system, soils under silvopasture showed higher P storage capacity.	Nair et al. 2007

Practice Costs

Giasson et al. (2003) examined the cost-effectiveness and the risk of P loss associated with various combinations of manure management options for a typical mid-sized dairy farm in New York using mathematical programming techniques and utility functions to select optimum management practices. Compared with current practices, the recommended combination of practices resulted in an approximate 45 percent reduction in the mean area-weighted P index (64.2 versus 36.1) for a cost (2008 dollars) increase of less than 2 percent ($173,086 versus $175,740) (2010 dollars).

Prescribed grazing plan development costs about $7.50/ac in Virginia, with typical total costs of about $900 (USDA-NRCS 2010). Implementing the plan runs about $70/ac with total costs typically in the neighborhood of $8,300. Forage harvest management costs are about $28/ac for record keeping and forage tissue testing ($421 typical total cost), and about $17/ac for record keeping and monitoring only ($260 typical total cost). Grass establishment for pasture and hay land costs are approximately $260/ac for native warm season grass and $330/ac for cool season grass, with typical total costs of about $2,600 for warm-season grass and $3,300 for cool-season grass. Renovating pasture and hay land with legumes costs nearly $30/ac for broadcast and $40/ac for drilling; typical total costs in Virginia are just under $300 for broadcast and $400 for drilling.

3.5 Drainage System Design

Reduction of nutrient loads from agricultural drainage water has elements of source control (e.g., nutrient management, crop rotations), in-field control (e.g., the drainage system), and edge-of-field control (e.g., controlled drainage, bioreactors). Basic subsurface drainage system design consists of field or lateral drains to collect drainage from the fields, collectors or mains to collect the water from the lateral drains, and a ditch or other conveyance to convey the collected water away from the field. The size, depth, and spacing of the drains are key determinants of the drainage rate or drainage intensity.

Implementation Measure A-15:

Where drainage is added to an agricultural field, design the system to minimize the discharge of N.

Practice Effectiveness

Several studies performed under different conditions document significant reductions in both discharge volume and NO_3 loads for shallower and more widely spaced drains compared to deeper and more closely spaced drains (Table 2-23). However, other studies show no significant effect or increases in NO_3 loads.

Table 2-23. Measured effects of changes in drain depth and spacing

			Practice			Reference practice			Reduction vs. reference practice			
State	**Soils and crops**	**Study type**	**Depth (m)**	**Spacing (m)**	**Drainage Intensity (mm/d)**	**Depth (m)**	**Spacing (m)**	**Drainage Intensity (mm/d)**	**Q**	**NO_3-N Conc.**	**NO_3-N Load**	**Source**
North Carolina	Swine wastewater applied	Plot	0.75	12.5		1.5	25		42%	-217%[a]	26%[b]	Burchell et al. 2005
Minnesota	Poorly drained soils; corn-soybean[c]	Plot	0.9			1.2			20%[d]	N/S	18%[d]	Sands et al. 2008
					13			51	24%[d]	N/S	23%[d]	
			0.9		13	0.9		51	N/S	19%[e]	48%	
			1.2		13	1.2		51	N/S	-15%[e]	-1%	
Illinois[f]	Poorly drained soils; soybeans-corn	Plot	0.61	15.24		0.91	30.48		43%[g]	N/S[e]	37%[h]	Cooke, et al. 2002
			0.61	15.24		1.22	30.48		62%[g]	N/S[e]	51%[h]	
			0.91	30.48		1.22	30.48		33%[g]	N/S[e]	22%[h]	
Indiana	Clermont silt loam, corn for 9 yr, then 6 yr corn-soybean	Plot	0.75	20		0.75	5		42%[i]	N/S	44%[i]	Kladivko et al. 2004
			0.75	20		0.75	10		19%[i]	N/S	21%[i]	
			0.75	10		0.75	5		28%[i]	N/S	28%[i]	
KEY: Q=drainage water discharge, N/S=no significant change												

Notes:

a. Significant increase in 2001 (7.6 mg/L shallow vs. 2.4 mg/L deep), but not significant in 2002 (15.7 mg/L vs. 12.8 mg/L).
b. Significant decrease in 2002 (27.3 kg NO_3-N/ha shallow vs. 36.9 kg NO_3-N/ha deep) but N/S over a 21-month period.
c. NO_3 concentration (4.4 mg/L greater for corn) and load (45% greater for corn) were significantly affected by crop type.
d. Using adjusted means.
e. Flow-weighted concentrations.
f. Findings based on only 1 year of monitoring data.
g. Changes in cumulative flow were greater than changes in flow for discrete events.
h. Similar load reductions were achieved for discrete events.
i. Average of two blocks over 15 years.

A detailed analysis of published field data and simulation results demonstrated that N losses increase with drainage rates or drainage intensity because of lowered water tables, increased mineralization of organic matter, reduced denitrification, and increased rates of subsurface water movement to surface waters (Skaggs et al. 2005). Factors affecting drainage rates include drain depth, drain spacing, soil properties, hydraulic conductivity, drainable porosity, the depth of the profile through which water moves to the drains, surface depressional storage, drain diameter, drain envelopes, the size and configuration of openings in the drain tube walls, the hydraulic capacity of the drainage network to remove water from the field, and management (e.g., controlled drainage) of the drainage outlet. Additional factors affecting NO_3 losses through drain tiles include climate, fertilization rate, and crop rotations.

In a North Carolina study of the effect of subsurface drain depth on NO_3 losses from plots receiving swine wastewater applications, the shallow drainage system (0.75 m deep and 12.5 m apart) had 42 percent less outflow than the deeper drainage system (1.5 m deep and 25 m apart), and NO_3 export from the shallow drains (8 kg/ha in 2001 and 27 kg/ha in 2002) was significantly ($p = 0.10$) lower than from the deeper drains (6 kg/ha in 2001 and 37 kg/ha in 2002) in 2002, but not for the entire 21-month period (Burchell et al. 2005). Lower NO_3 concentrations were observed in the shallow groundwater beneath the shallow drainage plots because of higher water tables and likely increased denitrification, but NO_3 concentrations in the drainage water from the shallow drains increased, possibly because of preferential flow paths to the drains from the surface (hence, shorter retention times) and soil pore flushing near the shallow drains.

Nine subsurface drainage plots in Minnesota were monitored for 5 years to investigate the role of subsurface drainage depth and drainage intensity on NO_3 loads to subsurface drains (Sands et al. 2008). Three plots had a depth of 120 cm (conventional depth) and a spacing of 24 m, resulting in a calculated drainage intensity of 13 mm/d (conventional rate), while two plots had a depth of 90 cm and a spacing of 18 m that was calculated to also achieve the conventional drainage intensity of 13 mm/d. Two plots each had depth/spacing combinations of 120 cm/12 m and 90 cm/9 m, designed to simulate the intensification of drainage systems experienced in the area. Analysis of aggregated data showed that both shallower and less intense drain systems reduced both discharge (20 percent and 24 percent, respectively) and NO_3 loading (18 percent and 23 percent, respectively), but not flow-weighted NO_3-N concentration. Interaction effects, however, indicated that intense drainage increased NO_3 concentration for shallow drainage but diluted NO_3 concentrations for drains at conventional depth. Because of that, NO_3 loads increased significantly for shallow drainage when combined with increased drainage intensity, while NO_3 loads for conventional drainage depth remained at a similar level despite increased drainage intensity.

In a one-year study of tile effluent from drainage tiles installed at different depths in a 16-ha field in Illinois, Cooke et al. (2002) found that tile discharge decreased with decreasing tile depth for tiles at 0.61 m, 0.91 m, and 1.22 m depth. Cumulative discharge from the monitored tile lines at 0.61 m and 0.91m depth were 43 percent and 33 percent less, respectively, than discharge from the tile line at 1.22 m. Average NO_3 load reductions for the 0.61 m and 0.91 m tile lines, when compared to the tile line at 1.22 m, were 51 percent and 22 percent, respectively. There was no relationship between flow-weighted NO_3 concentration and tile depth, and the authors noted a need for more data to validate the findings.

A 15-year drainage study in Indiana to evaluate three drain spacings (5, 10, and 20 m) installed at a depth of 0.75 m showed that both discharge and NO_3 load were reduced significantly as drain spacing increased but that flow-weighted NO_3 concentration did not vary with drain spacing (Kladivko et al. 2004). Differences in NO_3 loads with spacing occurred primarily during the years with continuous corn, high fertilizer N rates, and no cover crop.

Drury et al. (2009) concluded that the lower flow volumes measured for controlled drainage systems were due to the shallower effective tile depth (0.3 m) relative to uncontrolled drainage (0.6 m) because the water level in the soil must reach the 0.3-m level before any water would drain from the tiles. Hence, there is additional storage capacity for water in the soil from the 0.6-m depth to the 0.3-m effective depth with controlled drainage.

4 Implementation Measures and Practices for Cropland Edge-of-Field Trapping and Treatment

Edge-of-field practices remediate or intercept the pollutant before or after it is delivered to the water resource if the pollutants have not been effectively controlled at the source or in the field. Buffers and setbacks, soil amendments, wetlands, drainage water management, and controls in animal agriculture are examples of important *edge-of-field* or *end-of-pipe* measures to prevent nutrient loads to the Chesapeake Bay.

4.1 Buffers and Minimum Setbacks

Buffers are the areas between the cropland or other agricultural land use and the adjacent waterbodies. Buffers are described in detail in Chapter 5 of this document.

Implementation Measure A-16:

Establish manure and chemical fertilizer application buffers or minimum setbacks from in-field ditches, intermittent streams, tributaries, surface waters, open tile line intake structures, sinkholes, agricultural well heads or other conduits to surface waters.

Practice Effectiveness

Merriman et al. (2009) developed a compilation of BMP effectiveness results. Table 2-24 presents a listing of individual results for conservation buffer practices along with percent reductions for TP, TN, and sediment. Additional data on reductions for particulate P, dissolved P, NO_3-N, and ammonium are also available in the document.

Liu et al. (2008) performed an extensive review of sediment trapping efficiencies from more than 80 representative BMP experiments. A summary of their data is presented in Table 2-25. Their analysis of the data indicate that regardless of the area ratio of buffer to agricultural field, a 10-m buffer and a 9 percent slope optimize the sediment-trapping capability of vegetated buffers.

Table 2-24. TP, TN, and sediment reductions for various conservation buffer practices

Reference (as cited by Merriman et al. 1980	State	BMP name	Field plot	3-8	B	TP %	TN %	Total sediment
Bingham et al. 1980	NC	Contour Buffer Strip (3 m)	Field plot	3-8	B	52.77%	18.6%	
Bingham et al. 1980	MO	Contour Buffer Strip (3 m)	Field plot	3	B	7.91%	14.53%	
Udawatta et al. 2002	MO	Contour Buffer Strip (4.5 m)	Small watershed	3	D	26%	20%	19%
Udawatta et al. 2002	MO	Hedgerow Planting	Field plot	3-8	D	26%	20%	19%
Meyer et al. 1999	MS	Hedgerow Planting	Lab plot	3-8	C			76%
Meyer et al. 1995	GA	Hedgerow Planting	Field	3	B			80%
Sheridan et al. 1999	GA	Riparian Forest Buffer	Field	0-3	N/A			95%
Sheridan et al. 1999	GA	Riparian Forest Buffer	Field	0-3	N/A			74%
Sheridan 2005	GA	Riparian Forest Buffer	Farm	0-3	N/A			68%
Blanco-Canqui et al. 2004	GA	Riparian Forest Buffer	Farm	3	D	56%	37%	
Dillaha et al. 2004	MO	Vegetated Filter Strip (VFS)	Field plot	3-8	D			95%
Dillaha et al. 1988	VA	VFS	Field plot	3-8	C	2%	1%	31%
Srivastava et al. 1996	AR	VFS	Field plot	3-8	C	65.5%	67.2%	
Dillaha et al. 1996	AR	VFS	Field plot	8	C	36%	43.9%	
Dillaha et al. 1988	VA	VFS	Field plot	8-15	C	63%	64%	87%
Feagley et al. 1992	AR	VFS	Field plot	N/A	D			78.49%
Chaubey et al. 1995	TX	VFS (15.2 m)	Field plot	3-8	C	86.8%	75.7%	
Sanderson et al. 2001	TX	VFS (16.4 m)	Field plot	N/A	C	47%		
Chaubey et al. 2001	TX	VFS (16.4 m)	Field plot	N/A	C	76%		
Chaubey et al. 1995	AR	VFS (21.4 m)	Field	3-8	C	91.2%	80.5%	
Daniels and Gilliam. 1996	MO	VFS (3 m)	Field	3-8	B	55%	40%	53%
Chaubey et al. 2004	MO	VFS (4 m)	Field plot	3-8	D		77%	91%
Chaubey et al. 1995	AR	VFS (4 m)	Field plot	3-8	C	39.6%	39.2%	
Mendez et al. 2001	VA	VFS (4 m)	Field plot	N/A	N/A	50%	50%	
Mendez et al. 1999	VA	VFS (4.3 m)	Field plot	3-8	C		55.6%	81.9%
Dillaha et al. 1989	VA	VFS (4.6 m)	Field plot	8	C	85%	84%	83%
Dillaha et al. 1989	VA	VFS (4.6 m)	Field plot	15	C	73%	73%	86%
Dillaha et al. 1988	VA	VFS (4.6 m)	Field plot	15-25	C	52%	69%	76%
Dillaha et al. 1989	VA	VFS (4.6 m)	Field	3-8	C	49%	47%	53%
Chaubey et al. 1995	AR	VFS (6 m)	Field	3-8	B	65%	48%	68%
Chaubey et al. 1995	AR	VFS (6.1 m)	Field plot	3-8	C	58.4%	53.5%	

Table 2-24. TP, TN, and sediment reductions for various conservation buffer practices *(continued)*

Reference (as cited by Merriman et al. 1980	State	BMP name	Field plot	3-8	B	TP %	TN %	Total sediment
Mendez et al. 1996	AR	VFS (6.1 m)	Field plot	3-8	C	25.5%	21.4%	
Coyne et al. 1999	VA	VFS (8.5 m)	Field plot	15	C		81.5%	90.2%
Coyne et al. 1995	KY	VFS (9 m)	Field plot	8	B			99%
Dillaha et al. 1988	VA	VFS (9.1m)	Field plot	3-8	C	19%	9%	58%
Dillaha et al. 1989	VA	VFS (9.1m)	Field plot	8	C	87	81%	93%
Dillaha et al. 1988	VA	VFS (9.1m)	Field plot	8-15	C	80%	80%	95%
Dillaha et al. 1989	VA	VFS (9.1m)	Field plot	15	C	93%	93%	98%
Dillaha et al. 1988	VA	VFS (9.1m)	Field plot	15-25	C	57%	72%	88%
Dillaha et al. 1989	VA	VFS (9.1m)	Field plot	3-8	C	65%	59%	70%
Chaubey et al. 1995	AR	VFS (9.2 m)	Field plot	3-8	C	74%	66.6%	

Source: Merriman et al. 2009

Table 2-25. Summary of Vegetated Filter Strip (VFS) characteristics and corresponding sediment-trapping efficiencies

Paper source	BMP	Location	Buffer width	Area ratio	Slope	Sediment trapping efficacy	Inflow	Outflow	Mass sediment reduction
			m	buffer/plot	------------%-----------		--------------------------kg-------------------------		
Young et al. (1980)	VFS†		4.06	0.028	4	79	35.37	6.4	28.97
Hall et al. (1983)	VFS	Pennsylvania	6	0.27	14	76	0.000008	0.000002	0.000006
Hayes and Hairston (1983)	VFS	Mississippi	2.6		2.35	60			
Dillaha et al. (1989)	VFS	Virginia	9.1	0.5	11	97.5			
	VFS	Virginia	4.6	0.25	11	86			
	VFS	Virginia	9.1	0.5	16	70.5			
	VFS	Virginia	4.6	0.25	16	53.5			
	VFS	Virginia	9.1	0.5	5	93			
	VFS	Virginia	4.6	0.25	5	83.5			
Magette et al. (1989)	VFS	Maryland	9.2	0.42	2.7	92.4	70.8	5.4	65.4
	VFS	Maryland	4.6	0.21	2.7	82.8	70.8	12.2	58.6
	VFS	Maryland	9.2	0.42	2.7	88.3	16.2	1.9	14.3
	VFS	Maryland	4.6	0.21	2.7	64.3	13.6	4.97	11.23
	VFS	Maryland	9.2	0.42	4.1	80.3	13.6	2.68	10.92
	VFS	Maryland	4.6	0.21	4.1	65.8		4.65	8.95
Partons et al. (1990)	VFS	North Carolina	4.3	0.12	3.25	75			
	VFS	North Carolina	8.5	0.23	3.25	85			
Parsons et al. (1994)	VFS	North Carolina	4.3	0.12	1.9	78			
	VFS	North Carolina	8.5	0.23	1.9	81			
Coyne et al. (1995)	VFS	Kentucky	4.6	0.4	9	99	0.014	0.002	0.012
Arora et al. (1996)	VFS	Iowa	20.12	0.033	3	83.6			
	VFS	Iowa	20.12	0.067	3	87.6			

Table 2-25. Summary of Vegetated Filter Strip (VFS) characteristics and corresponding sediment-trapping efficiencies *(continued)*

Paper source	BMP	Location	Buffer width	Area ratio	Slope	Sediment trapping efficacy	Inflow	Outflow	Mass sediment reduction
			m	buffer/plot	-----------%----------		-------------------------kg------------------------		
Daniels and Gilliam (1996)	VFS	North Carolina	3	0.034	4.9	59			
	VFS	North Carolina	6	0.071	4.9	61			
	VFS	North Carolina	3	0.034	2.1	45			
	VFS	North Carolina	6	0.071	2.1	57			
Robinson et al. (1996)	VFS	Iowa	3	0.05	7	70			
	VFS	Iowa	3	0.05	12	80			
	VFS	Iowa	9.1	0.15	12	85			
	VFS	Iowa	9.1	0.15	7	85			
Van Dijk et al. (1996)	VFS	Netherlands	1		5.2	49.5			
	VFS	Netherlands	4		5.2	78.5			
	VFS	Netherlands	5		2.3	73			
	VFS	Netherlands	10		2.3	94			
	VFS	Netherlands	5		2.5	64.5			
	VFS	Netherlands	10		2.5	99			
	VFS	Netherlands	5		8.5	92			
	VFS	Netherlands	10		8.5	97.5			
Patty et al. (1997)	VFS	Brittan, France	6	0.12	7	98.9	493.2	5.44	487.76
	VFS	Brittan, France	12	0.24	7	99	493.2	3.7	489.5
	VFS	Brittan, France	18	0.36	7	99.9	493.2	0.37	492.83
	VFS	Brittan, France	6	0.12	10	87	20.4	2.53	17.87
	VFS	Brittan, France	12	0.24	10	100	20.4	0	20.4
	VFS	Brittan, France	18	0.36	10	100	20.4	0	20.4
	VFS	Brittan, France	6	0.12	15	91	309.16	28.71	280.45
	VFS	Brittan, France	12	0.24	15	97	309.16	8.21	300.95
	VFS	Brittan, France	18	0.36	10	98	309.16	4.8	304.36
Barfield et al. (1998)	VFS	Kentucky	4.57	0.21	9	97	258	8.44	249.56
	VFS	Kentucky	9.14	0.41	9	99.9	212	1.1	210.9
	VFS	Kentucky	13.72	0.62	9	99.7	361	2.06	358.94
Coyne et al. (1998)	VFS	Kentucky	9	0.41	9	99			
	VFS	Kentucky	4.5	0.24	9	95			
	VFS	Kentucky	9	0.67	9	98			
Tingle et al. 1998)	VFS	Mississippi	0.5	0.018	3	88	0.018	0.0022	0.0158
	VFS	Mississippi	1	0.045	3	93	0.036	0.0024	0.0336
	VFS	Mississippi	2	0.09	3	94	0.072	0.004	0.068
	VFS	Mississippi	3	0.14	3	96	0.108	0.0048	0.1032
	VFS	Mississippi	4	0.18	3	98	0.144	0.0032	0.1408
Munoz-Carpena et al. (1999)	VFS	North Carolina	4.3	0.11	6	86	64.76	1.74	63.02
	VFS	North Carolina	8.5	0.22	6	93	54.88	3.99	50.89
Schmitt et al. (1999)	VFS	Nebraska	7.5	0.093	6.5	85	3.99	1.3	2.69
	VFS	Nebraska	15	0.19	6.5	96	3.01	0.84	2.17

Table 2-25. Summary of Vegetated Filter Strip (VFS) characteristics and corresponding sediment-trapping efficiencies *(continued)*

Paper source	BMP	Location	Buffer width	Area ratio	Slope	Sediment trapping efficacy	Inflow	Outflow	Mass sediment reduction
			m	buffer/plot	------------%----------		--------------------------kg-------------------------		
Sheridan et al. (1999)	VFS	Georgia	8	0.03	2.5	81			
Lee et al. (2000)	VFS	Iowa	7.1	0.32	5	70	2.82	0.85	1.97
Abu-Zreig et al. (2004)	VFS	Canada	2	0.2	2.3	68	5887	1876	4011
	VFS	Canada	15	0.025	2.3	98	9324	219	9105
Blanco-Canqui et al. (2004)	VFS	Columbia, MIssouri	8	0.09	5	90	$1.6*10^{-8}$	$1.3*10^{-10}$	$1.58*10^{-8}$
Borin et al. (2005)	VFS	Northeast Italy	6		1.8	94	3450	200	3250
Helmers et al. (2005)	VFS	Nebraska	13	0.06	1	80	147	29	118
Gharabaghi et al. (2006)	VFS	Ontario, Canada	2.5			50			
	VFS	Ontario, Canada	20			98			
Young et al. (1980)	Riparian buffer		21.3		4	78			
	Riparian buffer		27.4		4	79			
Peterjohn and Correll (1984)	Riparian buffer	Maryland	19		5	90			
	Riparian buffer	Maryland	60		5	94	3.99	1.3	2.69
Dillaha et al. (1988)	Riparian buffer		4.6		11	87			
	Riparian buffer		4.6		16	76			
	Riparian buffer		9.1		11	95			
	Riparian buffer		9.1		16	88			
Dillha et al. (1989)	Riparian buffer		4.6		11	86	$0.1*10^{-6}$	$0.2*10^{-7}$	$0.8*10^{-7}$
	Riparian buffer		4.6		16	53	$2.3*10^{-7}$	$1.1*10^{-7}$	$1.2*10^{-7}$
	Riparian buffer		9.1		11	98	$2*10^{-7}$	$0.1*10^{-7}$	$1.9*10^{-7}$
	Riparian buffer		9.1		16	70	$4.5*10^{-7}$	$1.4*10^{-7}$	$3.1*10^{-7}$
Fiener and Auerswald (2003)	Grassed waterways	Munich	35	0.16	9.3	97	330.72	7.42	323.3
	Grassed waterways	Munich	17.5	0.12	9	77	175.74	40.02	135.72
Fiener and Auerswald (2005)	Grassed waterways	Central Europe	18.5	0.076	3.6	93			

† VFS represents vegetated filter strips.

Source: Liu et al. 2008

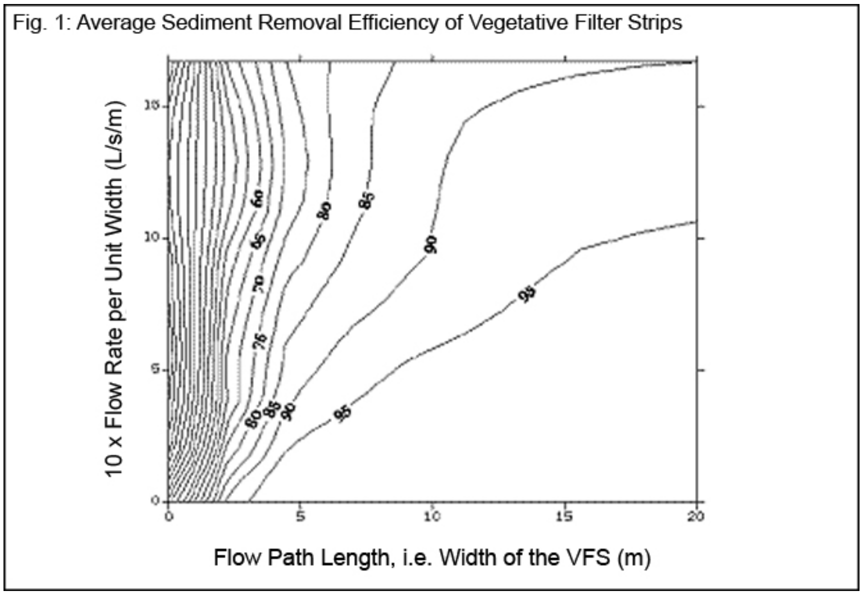
Ghadiri et al. (2001) developed a set of laboratory experiments with a tilting flume to investigate the effects of buffer strips on flow hydrology and sediment transport/deposition in and around the strips. The investigators found that flow retardation initiates above the strip and can begin to remove sediment. The results summarized in Table 2-26 show sediment deposition ranging from 18 to 77 percent, but caution is advised when applying those laboratory results to field conditions. In a study of simulated filter strips, Jin et al. (2002) found that adding a mulch barrier increased the sediment trapping efficiency of filter strips by 10–60 percent compared with the same flow, slope, and filter strip conditions without mulch. The observed interactions of crop residue mulches and filter strips suggest that combining residue management systems with vegetative buffer strips containing an upslope edge of strong vegetation offer potential synergies for increased conservation effectiveness. Jin and Romkens (2001) found that over 80 percent of the sediment trapped by a vegetative (or vegetated) filter strip (VFS) was deposited in the approach channel to the VFS and in the upper half of the VFS. As the slope increased, deposition moved downstream and deposited sediment became larger.

Table 2-26. Effect of high-density grass strip on sediment concentration on different slopes

	Sediment concentration (g/L)			Sediment deposited (%)	
Slope (%)	**Unaffected flow**	**In the backwater**	**After grass strip**	**In the backwater**	**Inside grass strip**
1.5	1.25	1.02	1.06	18	– 4
2.0	4.30	3.11	3.20	28	+ 3
3.4	17.44	10.76	11.01	38	– 2
5.2	78.63	18.15	16.81	77	+ 7

Source: Ghadiri et al. 2001

In a field experiment in Ontario, Gharabaghi et al. (2001) compared sediment removal efficiency using a variety of filter widths (2.44, 4.88, 9.67 and 19.52 m), flow rates, and slopes. They found that sediment removal ranged from 50 to 98 percent and generally found little improvement for widths greater than 10 m. Sediment removals are depicted in Figure 2-6.



Source: Gharabaghi et al. 2001

Figure 2-6. Average sediment-removal efficiency of VFS.

In a Raritan Basin (New Jersey) case study, Qiu et al. (2009) compared the placement of fixed-width buffers using regulatory rules, variable-width buffers according to watershed initiatives, and variable source area-based conservation buffer placement strategy derived from an alternative concept of watershed hydrology. The authors showed that there is little difference in cost-effectiveness between fixed- and variable-width buffers but that the variable source area-based buffer placement strategy, which targets the most hydrologically critical source areas in a watershed tier buffer placement, is more cost-effective.

In a riparian buffer in Connecticut, one-half of a 35 m by 250 m riparian buffer cropped in corn was seeded with fine-leaf fescue and allowed to remain idle (Clausen et al. 2000). TKN and TP concentrations significantly (P less than 0.05) increased as groundwater flowed through the restored buffer, while NO_3 concentrations declined significantly with most (52 percent) of the decrease occurring within a 2.5-m wetland adjacent to the stream. An N mass balance for the 2.5-m strip indicated that denitrification accounted for only one percent of the N losses and plant uptake accounted for 7–13 percent of the N losses annually. Groundwater was the dominant source of N to the buffer and also the dominant loss pathway. Restoring the riparian buffer decreased (p less than 0.05) overland flow concentrations of TKN by 70 percent, NO_3-N by 83 percent, TP by 73 percent, and TSS by 92 percent as compared with the control. Restoration reduced (P less than 0.05) NO_3-N concentrations in groundwater by 35 percent as compared with the control. Underestimated denitrification and dilution by upwelling groundwater in the wetland area adjacent to the stream were believed to be primarily responsible for the lower NO_3-N concentrations observed.

In a plot study, Dosskey et al. (2007) examined whether filter strip effectiveness changes over time and if temporal change depends on vegetation type. Plots containing all-grass (New Grass) and grass with trees and shrubs (New Forest) were established in 1995 among plots that contained either grass since 1970 (Old Grass) or were recultivated and replanted annually with grain sorghum (Crop). Once each summer, in 1995, 1996, 1997, 2003, and 2004, identically prepared solutions containing sediment, N and P fertilizer, and bromide tracer were applied to the upper end of each plot during a simulated rainfall event. The authors concluded that filter strip performance improves over time, with most of the change occurring within three growing seasons after establishment. Infiltration characteristics account for most of that change, and grass and forest vegetation are equally effective as filter strips for at least 10 growing seasons after establishment.

Lee et al. (2003) used a field plot study to determine the effectiveness of an established multi-species buffer in trapping sediment, N, and P from cropland runoff during natural rainfall events. A switchgrass buffer removed 95 percent of the sediment, 80 percent of the N, 62 percent of the NO_3-N, 78 percent of the P, and 58 percent of the phosphate-phosphorus (PO_4-P), while a switchgrass/woody buffer removed 97 percent of the sediment, 94 percent of the TN, 85 percent of the NO_3-N, 91 percent of the TP, and 80 percent of the PO_4-P in the runoff. In an earlier study using the same plots, Lee et al. (2000) found generally similar results; during a 2-hour rainfall simulation at 25 mm/h, the switchgrass buffer removed 64, 61, 72, and 44 percent of the incoming TN, NO_3-N, TP, and PO_4-P, respectively. The switchgrass-woody buffer removed 80, 92, 93, and 85 percent of the incoming TN, NO_3-N, TP, and PO_4-P, respectively. During a 1-hour rainfall simulation at 69 mm/h, the switchgrass buffer removed 50, 41, 46, and 28 percent of the incoming TN, NO_3-N, TP, and PO_4-P, respectively, The switchgrass-woody plant buffer removed 73, 68, 81, and 35 percent of the incoming TN, NO_3-N, TP, and PO_4-P, respectively. In both studies, the switchgrass buffer was effective in trapping coarse sediment and sediment-bound nutrients, but the additional buffer width with high infiltration capacity provided by the deep-rooted woody plant zone was effective in trapping the clay and soluble nutrients.

Using a set of 36 field lysimeters with six different ground covers (bare ground, orchardgrass, tall fescue, smooth bromegrass, timothy, and switchgrass), Lin et al. (2007) evaluated the ability of grasses to reduce nutrient levels in soils and shallow groundwater. The leachate from each lysimeter was collected after major rainfall events during a 25-day period, and soil was collected from each lysimeter at the end of the 25-day period. Grass treatments reduced NO_3-N levels in leachate by 74.5 to 99.7 percent compared to the bare ground control, but timothy was significantly less effective at reducing NO_3-N leaching than the other grasses. Switchgrass decreased PO_4-P leaching to the greatest extent, reducing it by 60.0 to 74.2 percent compared to the control. In a separate study, Bedard-Haughn et al. (2005) found that cutting vegetative buffers increased the uptake of NO_3-N 2.3 times that of uncut buffers.

The influence of vegetation characteristics, buffer width, slope, and stubble height on sediment retention was evaluated in a Montana study using three vegetation types (sedge wetland, rush transition, bunchgrass upland) on plots spanning 2 to 20 percent slopes (Hook 2003). Sediment retention was affected strongly by buffer width and moderately by vegetation type and slope, but it was not affected by stubble height. Mean sediment retention ranged from 63 to greater than 99 percent for different combinations of buffer width and vegetation type, with 94 to 99 percent retention in 6-m-wide buffers regardless of vegetation type or slope. Results suggest that rangeland riparian buffers should be at least 6 m wide, with dense vegetation, to be effective and reliable.

Mankin et al. (2007) studied the effectiveness of established grass-shrub riparian buffer systems in reducing TSS, P, and N using simulated runoff on nine plots with buffer widths ranging from 8.3 to 16.1 m. Vegetation types were all natural selection grasses (control), a 2-segment buffer with native grasses and plum shrub, and a 2-segment buffer with natural selection grasses and plum shrub. Removal efficiencies were strongly linked to infiltration, with TSS mass and concentration reductions averaging 99.7 percent and 97.9 percent, TP reductions of

91.8 percent and 42.9 percent, and TN reductions at 92.1 percent and 44.4 percent. Mankin et al. (2007) concluded that adequately designed and implemented grass-shrub buffers with widths of 8 m provide for water quality improvement, particularly if adequate infiltration is achieved.

Hoffman et al. (2009) examined the main hydrological pathways for P losses from and P retention in riparian buffers. They determined that P retention rates of up to 128 kg P/ha-yr can be accounted for by sedimentation, while plant uptake can temporarily immobilize up to 15 kg P/ha-yr. Dissolved P retention is often below 0.5 kg P/ha-yr, and the authors note that several studies have shown significant release of dissolved P up to 8 kg P/ha-yr.

In Finland, the effects of 10-m–wide, annually cut grass buffer zones and vegetated buffer zones under natural vegetation were compared on 70-m-long by 18-m-wide plots with no buffer zone (Uusi-Kamppa 2006). Retention of TS, TP, and PP was greater than 50, 40, and greater than 45 percent, respectively, for both treatments.

In northeast Italy, a 5-m-wide grass strip and a 1-m-wide row of trees were evaluated with corn and wheat from 1997 to 1999 (Borin and Bigon 2002). Under a variety of fertilization levels and tree sizes, water discharged from the strip was always below 2 mg/L NO_3-N. Tree size showed no evident effect on the reduction of the concentration. In a companion study from 1998 to 2001, Borin et al. (2005) evaluated 6-m buffer strips with adjoining fields of corn-wheat-soybeans. The buffer strip was composed of two rows of regularly alternating trees and shrubs, with grass in the inter-rows. Total runoff was reduced by 78 percent. TSS concentrations at the control was 2–7 times greater than the TSS of 0.14 mg/L from the buffer strip. N concentrations through the buffer strip were higher than control, but mass export was reduced from 17.3 to 4.5 kg/ha.

Practice Costs

Contour buffer strips cost about $270/ac in Virginia, and typical total costs are about $2,700 (USDA-NRCS 2010). Filter strips cost about $262 and $322 per acre for warm-season and cool-season grasses, respectively. Total costs are typically $524 for warm-season grasses and $645 for cool-season grasses.

Field borders using grasses cost about $210/ac for warm-season grasses and $330/ac for cool-season grasses, with typical total costs of about $420 and $650, respectively (USDA-NRCS 2010). Various mixtures of peas, mixed shrubs, and Indian grass cost about $300/ac to $400/ac, with total costs of $600 to $800. High-end mixtures including wildflowers can cost $1,300/ac, for a typical total cost of about $2,600. Hedgerow planting with hardwoods costs are approximately $910/ac ($455 total), whereas hedgerow planting with mixed shrub seedlings can range from

$951 to $1,419 per acre ($476 to $709 total cost) depending on the shrubs used (USDA-NRCS 2010).

Riparian forest buffers incorporating hardwoods generally cost around $900 to $1500 per acre in Virginia, with typical total costs ranging from $6,400 to $10,600 (USDA-NRCS 2010).

4.2 Soil Amendment

Implementation Measure A-17:

Treat buffer or riparian soils with alum, WTR, gypsum, or other materials to adsorb P before field runoff enters receiving waters.

It has been widely observed that adding materials like alum, alum-based residuals, gypsum, and other materials to soils can be effective in reducing water-soluble P concentrations in manure-treated soils. Some researchers have evaluated the ability of such soil amendment—either as area-wide applications or as buffer strips—to reduce or intercept nutrient runoff before delivery from upland fields into adjacent waterways.

Gallimore et al. (1999) reported that dissolved P in runoff was reduced by 46 percent by a buffer strip treated with WTR on the lower 25 percent of plots. Soluble NH_4-N was also reduced significantly. Dayton and Basta (2005b) found that adding alum-based residuals to soils as an enhanced buffer strip reduced mean dissolved P in runoff water by 3–38 percent for a 5 Mg/ha application, by 25–50 percent for a 10 Mg/ha addition, and by 67–86 percent for a 20 Mg/ha addition.

DeWolfe (2006) reported that surface application of WTR to soils (previously amended with poultry litter) at 10 Mg/ha decreased runoff P from 53–69 percent; application at 20 Mg/ha decreased runoff P from 68–87 percent. Penn and Bryant (2006) tested several sorbing materials including alum, gypsum, and fly ash to reduce P losses from streamside cattle loafing areas. All amendments reduced runoff dissolved P concentrations initially—alum (98–99 percent), WTR (81 percent), gypsum (74–88 percent) and fly ash (60 percent); however, after 28 days, runoff P concentrations were not significantly different from untreated plots.

Promising research is underway on using materials such as gypsum (Feyeriesen et al. 2008) and steel slag (Weber et al. 2007) for sorption of P in field runoff.

4.3 Wetlands

Implementation Measure A-18:

Restore wetlands and riparian areas from adverse effects. Maintain nonpoint source abatement function while protecting other existing functions of the wetlands and riparian areas such as vegetative composition and cover, hydrology of surface water and groundwater, geochemistry of the substrate, and species composition.

Properly functioning natural wetlands and riparian areas (discussed in Chapter 5) can significantly reduce nonpoint source pollution by intercepting surface runoff and subsurface flow and by settling, filtering, or storing sediment and associated pollutants. Wetlands and riparian areas typically occur as natural buffers between uplands and adjacent waterbodies. Loss of natural wetlands and riparian areas allows a more direct contribution of nonpoint source pollutants to receiving waters. Degraded wetlands and riparian areas can even become pollutant sources. Thus, natural wetlands and riparian areas should be protected and should not be used as designated erosion control practices. Their nonpoint source control functions are most effective as part of an integrated land management system focusing on nutrient, sediment, and erosion control practices applied to upland areas.

Protection of the full range of functions for wetlands and riparian areas are discussed in *National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source Pollution* (USEPA 2005). Protection of wetlands and riparian areas should allow for both nonpoint source pollution control and maintenance of other benefits of other ecosystem services such as wildlife habitat, flood mitigation, and water storage.

The following practices can protect wetlands and riparian areas:

- Identify existing functions of those wetlands and riparian areas with significant nonpoint source control potential when implementing management practices.
- Do not alter wetlands or riparian areas to improve their water quality functions at the expense of their other functions.
- Use appropriate preliminary treatment practices such as erosion control, vegetated treatment systems or detention, or retention basins to prevent adverse effects on wetland functions that affect nonpoint source pollutant abatement from hydrologic changes, sedimentation, or contaminants.

Wetlands and Acreman (2004) gathered data from 57 wetlands from around the world to evaluate nutrient removal efficacy. Table 2-27 displays a list of those wetlands, and Figure 2-7 displays the removal efficiencies for N and P as a function of loading. The correlation for N is statistically significant while the regression line for P is not.

Table 2-27. Summary of wetlands evaluated

Summary of references studied showing wetland name, wetland type and country of location. References are split into those showing an increase in nutrient loading, decrease in nutrient loading and those showing no change.

Author(s)	Date	N or P	Wetland name	Wetland type	Country
Nutrient Retention					
Raisin and Mitchell	1995	TPN	Humphrey's wetland	Mash/swamp	Australia
Raisin and Mitchell	1995	TP	Reid's wetland	Mash/swamp	Australia
Jacobs and Gilliam	1985	NO_3	Unknown	Riparian	USA
Cooper and Gilliam	1987	P	Unknown	Riparian	USA
Lowrance et al.	1984	NO_3	Unknown	Riparian	USA
Cooke	1994	P, NO_3	Unknown	Mash/swamp	New Zealand
Bugenyi	1993	N, P	Unknown	Riparian	Uganda
Patruno and Russell	1994	N, P	Yamba wetland	Marsh/swamp	Australia
Baker and Maltby	1995	NO_3, NO_4	Kismeldon Meadows and Bradford Mill	Riparian	UK
Peterjohn and Correll	1984	sol P	Rhode River drainage basin	Riparian	USA
Jordan et al.	1993	NO_3, TP	Chester River catchment	Floodplain	USA
Gehrels and Mulamootth	1989	TP	Unknown	Marsh/swamp	USA
Burt et al.	1998	NO_3	R. Leach floodplain	Floodplain	UK
Haycock and Burt	1993	NO_3	R. Leach floodplain	Floodplain	UK
Cooper	1994	NO_3	Unknown	Swamp	NZ
Prior	1998	N, P	R. Lambourn floodplain	Floodplain	UK
Haycock and Pinay	1993	NO_3	R. Leach floodplain	Riparian	UK
Chauvelon	1998	N, P	Rhone river delta	Riverine delta	France
Maltby et al.	1995	N	Floodplains in Devon	Floodplain	UK
Osborne and Totome	1994	TP, SRP, NH_4	Waigani	Marsh/swamp	Papua N. Guinea
Cooper	1990	NO_3	Scotsman Valley, NZ	Riparian	New Zealand
Lindkvist and Hakansson	1993	TP	Unknown	Unknown	Sweden
Lindkvist	1992	TP	Unknown	Unknown	Sweden
Mander et al.	1991	TP	Unknown	Various	Estonia
Nunez Delgado et al.	1997	NO_3	Unknown	Riparian	Spain
Mander et al.	1997	N, P	Porijogi River catchment	Riparian	Estonia
Downes et al.	1997	NO_3	Whangamata Stream	Riparian	New Zealand
Brinson et al.	1984	N, P	Tar River floodplain	Riparian	USA
Brunet	1994	PN	Adour River floodplain	Floodplain	France
Tilton and Kadlec	1979	N, P	Unknown	Fen	USA
Burke	1975	N, P	Unknown	Peat land	Ireland
Boyt et al.	1977	P	Unknown	Marsh/swamp	USA
Spangler	1977	P	Unknown	Marsh/swamp	USA
Yonika and Lowry	1979	N	Unknown	Marsh/swamp	USA

Table 2-27. Summary of wetlands evaluated *(continued)*

Author(s)	Date	N or P	Wetland name	Wetland type	Country
Semkin et al.	1976	N, P	Unknown	Marsh/swamp	USA
Semkin et al.	1976	N, P	Unknown	Marsh/swamp	USA
Johnston et al.	1984	N, P	nr White Clay Lake	Marsh/swamp	USA
Johnston et al.	1984	N, P	nr White Clay Lake	Riparian	USA
Pinay and Decamps	1988	N	Garonne Valley	Riparian	France
Jordon et al.	2003	TN, TP	Kent Island	Marsh/swamp	USA
Mwanuzi et al.	2003	$P0_4$	Unknown	Riparian	Tanzania
Rzepecki	2002	sol P	Unknown	Riparian	Poland
Zhang et al.	2000	TN, TP	Unknown	Marsh/swamp	USA
Bratli et al.	1999	N, P	Unknown	Marsh/swamp	Norway
Kellog and Bridgeham	2003	$P0_4$	Unknown	Peat land	USA
Kansiime and Nalubega	1999	N	Unknown	Marsh/swamp	Uganda
Kansiime and Nalubega	1999	N	Unknown	Marsh/swamp	Uganda
Chescheir et al.	1991	TP, NO_3	Unknown	Riparian	USA
Dorge	1994	NO_3	Rabis Baek	Peat land	Denmark
Dorge	1994	NO_3	Syvbaek	Riparian	Denmark
Dorge	1994	NO_3	Glumso	Marsh/swamp	Denmark
Schlosser and Karr	1981	TP	Champaign-Urbana	Riparian	USA
Hanson et al.	1994	NO_3	nr Kingston	Riparian	USA
Schwer and Clausen	1989	TP, TN	nr Charlotte	Riparian	USA
Daniels and Gilliam	1996	N, P	Cecil soil area	Riparian	USA
Nutrient Addition					
Cook	1994	NO_3	Unknown		New Zealand
Peterjohn and Correll	1984	sol P	Unknown	Riparian	USA
Jordan et al.	1993	N, P	Chester River catchment	Floodplain	USA
Gehrels and Mulamootth	1989	sol P	Unknown	Marsh/swamp	USA
Prior	1998	TDN, TDP	R. Lambourne floodplain	Floodplain	UK
Osborne and Totome	1994	NO_2, NO_3	Waigani	Marsh/swamp	Papua N. Guinea
Downes et al.	1997	NO_3, SRP	Whangamata Stream	Riparian	New Zealand
Clausen et al.	1993	TN	Unknown	Riparian	USA
Daniels and Gilliam	1996	N, P	Georgeville soil area	Riparian	USA
No Nutrient Retention/Addition					
Raisin and Mitchell	1995	TPN	Reid's wetland	Marsh/swamp	Australia
Kadlec	1985	P	Unknown	Marsh/swamp	USA
Elder	1985	N	Apalachicola River floodplain	Floodplain	USA
Ontkean et al.	2003	N, P	Hilton Wetland	Pond	Canada
Daniels and Gilliam	1996	TP, PO_4	Georgeville soil area	Riparian	USA

Source: Adapted from Fisher and Acreman 2004

Notes: N = several N species, P = several P species, TP = total phosphorus, TN = total or Kjeldahl N, sol = soluble N or P, SRP = soluble reactive P, TPN = total particulate N, PN = particulate N, PO_4 = orthophosphate, NO_3 = nitrate, NO_2 = nitrate and NH_4 = ammonium, including ammonium-N.

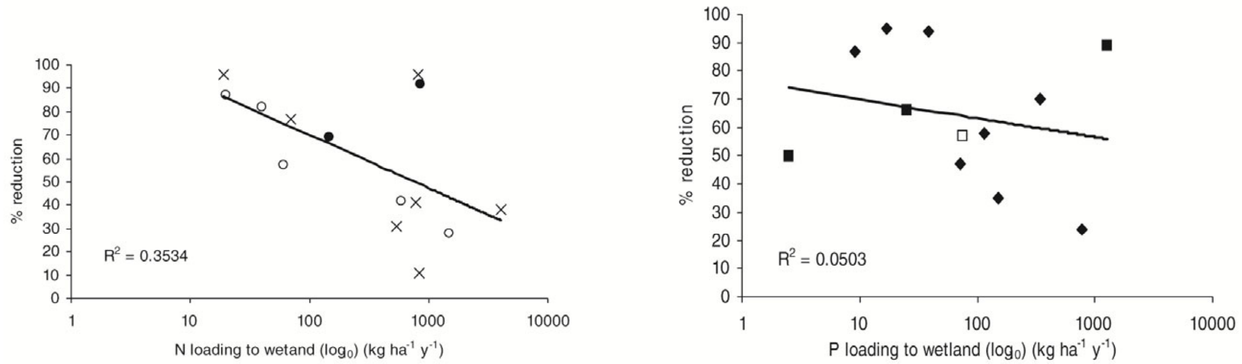


Fig. 4. *Relationship between nutrient reduction within wetlands and the amount of a) N loading to wetlands and b) P loading to wetlands reported in a study. (● = TN, O = nitrate and × = several N species and b) P loading to wetlands, ■ =TP, □ = orthophosphate and ♦ = several P species).*

Source: Fisher and Acreman 2004

Figure 2-7. Percent nutrient reduction as a function of loading.

On Kent Island, Maryland, a 1.3-ha restored wetland received the unregulated inflows from a 14-ha agricultural watershed (Jordan et al. 2003), and the ability of the wetland to remove nutrients was examined over 2 years after its restoration. Most nutrient removal occurred in the first year, which included a 3-month period of decreasing water level in the wetland. In that year, the wetland removed 59 percent of the TP, 38 percent of the TN, and 41 percent of the TOC it received. However, in the second year, which lacked a drying period, there was no significant (P greater than 0.05) net removal of TN or P, although 30 percent of the TOC input was removed. For the entire 2-year period, the wetland removed 25 percent of the ammonium, 52 percent of the NO_3, and 34 percent of the organic carbon it received, but there was no significant net removal of TSS or other forms of N and P.

A wetland mesocosm experiment was conducted in eastern North Carolina to determine if organic matter (OM) addition to soils used for in-stream constructed wetlands would increase NO_3-N treatment (Burchell et al. 2007). Four batch studies, with initial NO_3-N concentrations ranging from 30 to 120 mg/L, were conducted in 2002 in 21 surface-flow wetland mesocosms. The results indicated that increasing the OM content of a Cape Fear loam soil from 50 g/kg to 110 g/kg enhanced NO_3-N wetland treatment efficiency in spring and summer batch studies, but increases to 160 g/kg OM did not. Increased OM addition and biosolids to the Cape Fear loam significantly increased biomass growth in the second growing season when compared to no OM addition. Those findings indicate that increased OM in the substrate will reduce the area required for in-stream constructed wetlands to treat drainage water in humid regions.

A small-scale wetland system was constructed and monitored for several years to quantify nutrient removal near Steamboat Creek, a tributary of the Truckee River in Nevada (Chavan et al. 2007). Results indicated seasonal variations in nutrient removal with 40–75 percent of TN and 30–60 percent of TP being removed, with highest removals during summer and lowest removals during winter. In a following study to evaluate the effectiveness of a large-scale wetland, 10 parallel pilot-scale wetland mesocosms were used to test the effects of drying and rewetting, hydraulic retention time, and high N loading on the efficiency of nutrient and TSS removal (Chavan et al. 2008). During increased influent N loading (9.5 +/- 2.4 mg/L), manipulated mesocosms functioned as sinks for TN with removal efficiency increasing from 45 +/- 13 percent to 87 +/- 9 percent. The average change in TN concentration was 9.1 +/- 2.2 mg/L. TP removal was associated with TSS removal.

Wetlands dominated by submerged aquatic vegetations (SAVs) can take up nutrients, particularly P, from surface flow with high efficiency. In a 1999–2001 study in South Florida, samples were collected from four small constructed test cells (wetlands) (Gu 2008). Test cells receiving higher TP (average = 75 µg/L) displayed a removal efficiency of 60 percent while test cells receiving lower TP (average = 23 µg/L) had a 20 percent removal efficiency. In a similar study, Gu and Dreschel (2008) evaluated the effectiveness of constructed wetlands from 2002–2004. Test cells receiving higher TP (average = 72 µg/L) displayed a removal efficiency of 56–65 percent while test cells receiving lower TP (average = 43 µg/L) had a 35–62 percent removal efficiency with a hydraulic loading rate of 9.27 in/yr.

The restoration plan for the Everglades includes construction of large stormwater treatment areas (STAs) to intercept and treat relatively high nutrient water down to very low TP concentrations (White et al. 2006). One such STA has been in operation for approximately 10 years and contains both emergent aquatic vegetation (EAV) and SAV communities. The authors investigated the interaction of vegetation type (EAV or SAV) and hydrology (continuously flooded or periodic drawdown) on the P removal capacity in mesocosms packed with peat soil obtained from the STA. The surface water had low TP concentrations with an annual mean of 23 µg/L. For SRP and TP, hydrologic fluctuations had no discernable effect on P treatment while vegetation type showed a significant effect. Influent SRP decreased by 49 percent for the SAV treatments compared with 41 percent for the EAV treatments, irrespective of hydrology treatment. The reduction of dissolved organic P was also higher for the SAV treatment, averaging 33 percent, while showing a reduction of 11 percent for the EAV treatments. There was no significant difference in the treatment efficiency of particulate P across the treatments. The SAV treatments removed 45 percent of TP while EAV removed significantly less at 34 percent of TP. By mass calculations, the EAV required 85 percent more P for plant growth than was removed from the water column in one year compared with only 47 percent for the SAV. Therefore, the EAV *mined* substantially more P from the relatively stable peat soil, translocating it into the detrital pool.

In an examination of benefits to water quality provided by a natural, flow-through wetland and a degraded, channelized wetland within the flood-irrigation agricultural landscape of the Sierra

Nevada foothills of northern California, Knox et al. (2008) found that the nondegraded, reference wetland significantly improved water quality by reducing loads of TSS, NO_3, and *E. coli* on average by 77, 60, and 68 percent, respectively. Retention of TN, TP, and SRP was between 35 and 42 percent of loads entering the reference wetland. Retention of pollutant loads by the channelized wetland was significantly lower than by the reference wetland for all pollutants except SRP. A net export of sediment and NO_3 was observed from the channelized wetland. Decreased irrigation inflow rates significantly improved retention efficiencies for NO_3, *E. coli*, and sediments in the reference wetland. It is suggested that maintaining such natural wetlands and regulating inflow rates can be important aspects of a BMP to improve water quality in runoff from irrigated pastures.

Practice Costs

Wetland enhancements costs in Virginia include $0.47/ft^2 ($2,575 typical total cost) for excavated seasonal pools in hydric soil sites, $0.026/ft^2 ($145 total) for broadcasting a wetland plant seed mixture, and $0.98/ac ($5,370 total) for wetland plant plugs (USDA-NRCS 2010).

4.4 Drainage Water Management

Subsurface drainage is a water management practice that is commonly used on many highly productive fields in areas such as the Atlantic Coastal Plain and the Midwest, but because NO_3 carried in drainage water contributes to water quality problems in the Chesapeake Bay (as well as some other waterbodies such as the Gulf of Mexico), strategies are needed to reduce the NO_3 loads while maintaining adequate drainage for crop production (Frankenberger et al. 2006). Drainage is generally achieved with open ditches or buried pipe accompanied by either gravity-based or pumped outlets. Practices that can reduce NO_3 loads on tile-drained soils include the following (Frankenberger et al. 2006):

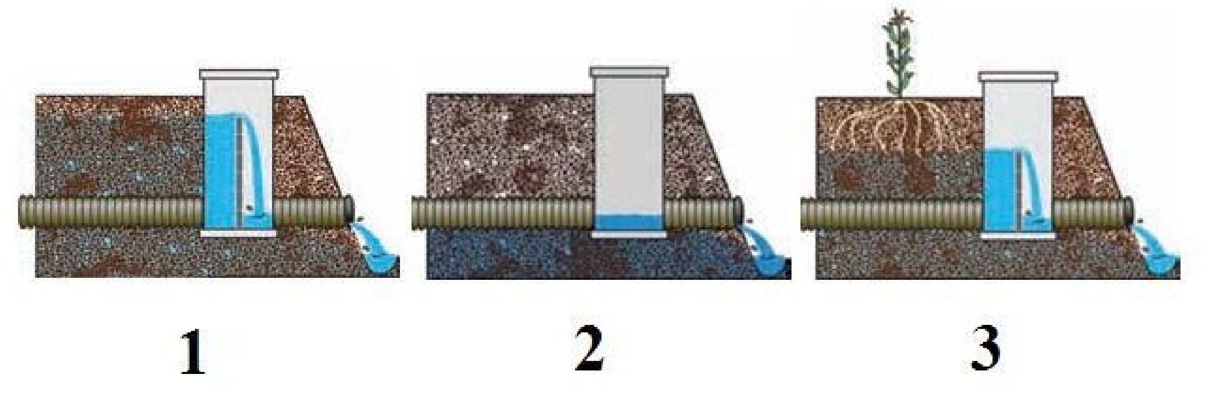
- Fine-tuned fertilizer application rates and timing
- Winter forage or cover crops
- Controlled drainage and water table management
- Ditch management
- Bioreactors to treat drainage water
- Constructed wetlands

Fertilizer management and cover crops are addressed in this document in Sections 2.1 and 3.3 respectively, whereas the other practices are addressed here. In addition, irrigation tailwater recovery systems are not included in this document.

Controlled drainage is the control of surface and subsurface water through use of drainage facilities and water control structures. Water table management is any combination of management, control, or regulation of soil-water conditions in the profile of agricultural soils through the use of water management structures (e.g., subsurface drains, water control structures, and water conveyance facilities) and strategies designed specifically for the given site conditions (Brown 1997) (NRCS Practice Code 554). Graded ditches are used to collect or intercept excess surface or subsurface water and convey it to an outlet (USDA-NRCS 2008). Ditch management includes managing cleanouts and vegetation within the ditch. Bioreactors are one form of edge-of-field treatment of drainage water in which the drainage is diverted into a trench filled with wood chips (Minnesota Department of Agriculture No date). Constructed wetlands are constructed, shallow, earthen impoundments containing hydrophytic vegetation designed to treat both point and nonpoint sources of water (USDA-NRCS 2002).

In drainage water management, a water control structure in a main, sub-main, or lateral drain is used to manipulate the depth of the drainage outlet (Frankenberger et al. 2006). The water table must rise above the outlet depth for drainage to occur, as illustrated in Figure 2-8. The outlet depth, as determined by the control structure, is

- Raised after harvest to limit drainage outflow and reduce the delivery of NO_3 to ditches and streams during the off-season (1 in Figure 2-8)
- Lowered in early spring and again in the fall so the drain can flow freely before field operations such as planting or harvest (2 in Figure 2-8)
- Raised again after planting and spring field operations to create a potential to store water for the crop to use in midsummer (3 in Figure 2-8)



Source: Frankenberger et al. 2006; used with permission

Figure 2-8. Drainage control structure.

Implementation Measure A-19:

For both new and existing surface (ditch) and subsurface (pipe) drainage systems, use controlled drainage, ditch management, and bioreactors as necessary to minimize off-farm transport of nutrients.

Practice Effectiveness

Controlled drainage and water table management practice effectiveness

Numerous studies of the effects of controlled drainage have been conducted in North Carolina, the Midwest, and Canada (Table 2-28). The studies have shown that controlled drainage can significantly reduce discharge volume and NO_3 concentrations.

Table 2-28. Measured effectiveness of controlled drainage

Location	Soils and crops	Study type	Practice	Reference practice	Reduction vs. reference practice			Source
					Discharge	NO_3-N conc.	NO_3-N load	
North Carolina	Moderately well drained soils	Field	CD-flashboard riser	UD	85%		85%[a]	Gilliam et al. 1979
North Carolina	Poorly drained soils	Field	CD-flashboard riser	UD	50%		50%[b]	Gilliam et al. 1979
Illinois		Field	CD	UD			≤ 47%[c]	Kalita et al. 2007
Ohio	Corn-soybean, poorly drained	Plot	CD	UD	40%		45%	Fausey 2005
Ontario, Canada	Corn	Field	CDS	UD	24%	25%[d]	43%	Drury et al. 1996
Ontario, Canada	Corn	Field	CDS-CT	UD-MP			49%	Drury et al. 1996
Ontario, Canada	Corn	Plot	CDS	UD	-8%	41%[d]	36%	Ng et al. 2001
Ontario, Canada	Corn, soybeans	Plot	CDS	UD	36%	14%[d]	27%[e]	Tan et al. 2003
Ontario, Canada	Sandy loam	Field	CDS	UD	0%	38%[d]	37%	Tan et al. 2004
Ontario, Canada	Clay loam	Plot	CDS	UD	50%	32%	66%	

Table 2-28. Measured effectiveness of controlled drainage *(continued)*

Location	Soils and crops	Study type	Practice	Reference practice	Reduction vs. reference practice			Source
					Discharge	NO_3-N conc.	NO_3-N load	
Ontario, Canada	Corn (150 kg N/ha)-soybean (no N), clay loam	Field	CD	UD			44%[f]	Drury et al. 2009
	Corn (200 kg N/ha)-soybean (50 kg N/ha), clay loam	Field	CD	UD			31%[f]	
	Corn (150 kg N/ha)-soybean (no N), clay loam	Field	CDS	UD			66%[f]	Drury et al. 2009
	Corn (200 kg N/ha)-soybean (50 kg N/ha), clay loam	Field	CDS	UD			68%[f]	
Ontario, Canada	Silt loam, Corn-soybean strip-cropping	Field	CDS - .05 m	UD	–555% to 58%[g,h]	61%–84%[g]	0%–94%[g,i]	Mejia and Mandramootoo 1998
			CDS - .075m	UD	–583% to –70%[g,h]	52%–77%[g]	0%–30%[g,i]	
North Carolina	Various	Review[j]	CD	UD	30%[k,l]	≤20%[l,m]	45%[l,n]	Evans et al. 1996
Various	Various	Review[j]	CD	UD			50%	Appelboom and Fouss 2006
Various	Various	Review[j]	CD	UD	17%–85%		18%–85%	Skaggs and Youssef 2008

KEY: CD = controlled drainage, UD = Uncontrolled or traditional or free-tile drainage, CDS = controlled drainage-subirrigation, CDS-CT = controlled drainage-subirrigation with conservation tillage, UD-MP = Uncontrolled or traditional drainage with moldboard plowing.

Notes:

a. Load reduction due solely to discharge reduction; no change in NO_3-N concentration.
b. Reductions due to increased penetration to deeper soil horizons where denitrification occurred.
c. NO_3 load reductions due mostly to discharge reductions. Phosphate load reductions of up to 83%
d. Flow-weighted mean
e. Also reduced dissolved organic (47%) and dissolved inorganic (54%) P loads
f. TN
g. Monitoring only during growing season (April/May-November).
h. Increased discharge due to lack of management, subirrigation, and high rainfall, resulting in little storage for rainfall under CDS.
i. No significant difference in 1995 (0%), but significant difference in 1996 (94%, 30%).
j. Reviews include some of the field and plot studies shown.
k. When managed year-around; < 15% reduction during growing season.
l. Varies with soil type, rainfall, type of drainage, and management intensity
m. TKN concentration increases slightly. Decreases P concentration for surface drainage systems, but increases P concentration for subsurface systems.
n. NO_3-N + TKN; TP reduced by 35%

Flashboard riser-type water level control structures installed in tile mains or outlet ditches on moderately well-drained soils in the Coastal Plain of North Carolina reduced NO_3 movement through the ditches by 80–95 percent (from 25–40 kg/ha to 1–7 kg/ha) because of a reduction in effluent volume with no indication of increased denitrification in the field (Gilliam et al. 1979). The authors note that the reduction in transport through ditches does not necessarily prevent runoff from entering surface waters through other pathways, but ditch transport would increase the chance of the NO_3 being lost through denitrification or being absorbed by plants as the groundwater moves toward a seep at a lower elevation. In poorly drained soils, a 50 percent reduction in NO_3 movement through the drainage ditches was attributed to increased water movement into and through deeper soil horizons (below one m) where denitrification occurred. Factors considered to explain the reduction in flow volume through ditches were leaking or bypassing of control structures, evapotranspiration, and deep seepage. The authors conclude that evapotranspiration would likely explain some of the difference during the summer but that most of the difference in flow volume was due to an increase in lateral flow from the controlled fields through the sandy layers below the B horizon and above the aquiclude where essentially all the NO_3 would be denitrified. They therefore conclude that the decreased quantities of NO_3-N moving through the ditches in the poorly drained soils under controlled water conditions represented a real decrease in the amount of N entering surface waters.

Variability in the effectiveness of controlled drainage was reflected in two modeling studies in the coastal plain of North Carolina. In one study, it was assumed that controlled drainage reduced N by 40 percent but only if the slope in the channel is less than one percent and where the water table can be kept within 0.9 m of the soil surface for 50 percent of the field area (Wossink and Osmond 2001). Long-term modeling of Core Creek using the DRAINMOD-N model after calibration on a field-by-field basis with monitoring data from 4.5 years indicated that controlled drainage could reduce NO_3 loads by 10–12 percent, and a combination of controlled drainage and nutrient management could reduce NO_3 loads by 25–33 percent (Smeltz et al. 2005). Modeling predicted that controlled drainage would reduce the drainage outflow by 21.3 percent annually versus conventional drainage (accounting for 11.5 percent of the reduction in NO_3-N leaving the watershed), and that there was a potential for 30 percent and 75 percent NO_3 reductions for cotton or soybeans, respectively, as compared to corn.

Studies in the Midwest measured similar NO_3 load reductions from controlled drainage. A review of subsurface drainage in the Midwest revealed that drainage water management has achieved load reductions of up to 47 percent and 83 percent for NO_3 and phosphate, respectively (Kalita et al. 2007). In a replicated field plot experiment to examine the hydrology, water quality, and crop yield effects of controlled drainage, uncontrolled drainage, and subirrigation drainage on Hoytville silty clay soil in Ohio, it was found that controlled drainage during the non-growing season reduced annual flows by 40 percent, yielding a 45 percent reduction in annual NO_3 loads from a corn-soybean production system (Fausey 2005).

In a 3-year study on Nicollet loam and silt-loam soils in Iowa, water-table depths of 0.3, 0.6, and 0.9 m were maintained in field lysimeters at one site, and water-table depths averaging 0.2, 0.3, 0.6, 0.9, and 1.1 m were maintained at a second site to determine the effects of controlled drainage-subirrigation (CDS) on NO_3 concentrations in groundwater (Kalita and Kanwar 1993). The lowest NO_3 concentrations in groundwater were observed under the shallow water-table depths, with NO_3 concentrations in groundwater generally decreasing with increased depths, but average corn yields were 30 percent lower under the shallow water-table depths of 0.2 to 0.3 m compared to depths of 0.9 to 1.1 m.

A fairly large number of studies were conducted in Ontario, Canada, to determine the water quality and yield benefits of controlled drainage systems. In a 3-year evaluation of CDS, conservation tillage, and corn production practices, annual tile drainage volumes were reduced by 24 percent with CDS compared with traditional drainage (UD) (Drury et al. 1996). Flow-weighted mean NO_3 concentration and average annual NO_3 loss in tile drainage water were reduced by 25 and 43 percent, respectively, when using CDS (7.9 mg/L N, 14.6 kg/ha N) instead of UD. The combination of conservation tillage and CDS reduced annual NO_3 losses by 49 percent (11.6 kg/ha N) when compared with conventional moldboard plow tillage and UD. Most (88-95 percent) of the NO_3 losses from all treatments occurred in the non-cropping period from November through April. The increase in NO_3 loss through surface runoff for CDS (1.9 kg/ha N) compared to UD (1.4 kg/ha N) was less than 5 percent of the decrease in loss through tile drainage.

Measurements from a plot study on a sandy loam soil in southwestern Ontario, Canada, showed an 8 percent greater cumulative drainage water volume from the CDS treatment versus the free-tile drainage (UD) treatment but a 41 percent lower flow-weighted mean NO_3 concentration (11.3 mg/L N versus 19.2 mg/L N), a 36 percent lower NO_3 export coefficient (36.8 kg/ha N versus 57.9 kg/ha N), and a 64 percent greater average corn yield (11.0 Mg/ha versus 6.7 Mg/ha) for CDS versus UD (Ng et al. 2001).

A plot study of a wetland-reservoir system for controlled drainage and subirrigation in southwestern Ontario found that a CDS system reduced drainage volume by 36 percent, flow-weighted mean NO_3 concentration in tile drainage water by 14 percent, total NO_3 loss by 27 percent (46.3 kg N/ha versus 63.6 kg N/ha), dissolved organic P by 47 percent, and dissolved inorganic P by 54 percent compared to a free drainage system (UD) (Tan et al. 2003). Tile drainage water and surface runoff water from agricultural fields were routed into a wetland reservoir and then recycled back through the CDS to provide subsurface irrigation during times of crop water deficit. NO_3 uptake by plants and algae in the reservoir and increased corn (91 percent) and soybean (49 percent) yields contributed to the reductions in NO_3 loss for the CDS system.

In a comparison of CDS and UD on a 4-ha farm-scale field, CDS did not change total discharge but reduced flow-weighted mean NO_3 concentration in tile drainage water by 38 percent, reduced total NO_3 load by 37 percent, and increased both tomato (11 percent) and corn (64 percent) yield compared to UD (Tan et al. 2004). During the same period on a 0.4-ha plot-scale field, CDS reduced total tile drainage volume by 50 percent, reduced flow-weighted mean NO_3 concentration in tile drainage water by 32 percent, reduced total NO_3 load by 66 percent, and increased both soybean (17 percent) and corn (9 percent) yield relative to UD.

A study comparing both CD and CDS versus UD at two fertilization rates (N1: 150 kg N/ha applied to corn, no N applied to soybean; N2: 200 kg N/ha applied to corn, 50 kg N/ha applied to soybean) on a clay loam soil in Ontario, Canada, documented that CD and CDS reduced N loads from tile drainage by 44 and 66 percent, respectively, relative to UD at the N1 rate, and by 31 and 68 percent, respectively, at the N2 rate (Drury et al. 2009). The N concentrations in tile flow events with the UD treatment exceeded Ontario's provisional long-term aquatic life limit for freshwater (4.7 mg N L-1) 72 percent and 78 percent of the time at the N1 and N2 rates, respectively, but only 24 percent and 40 percent, respectively, with CDS. Crop yields from CDS were increased by an average of 2.8 percent relative to UD at the N2 rate, but were reduced by an average of 6.5 percent at the N1 rate.

A CDS system managed at a depth of 0.050 m reduced total drain discharge over two growing seasons by 42 percent versus UD in a field study in eastern Ontario (Mejia and Mandramootoo 1998). Growing-season mean NO_3 concentrations in drainage water were reduced by CDS at both a depth of 0.050 m (61–84 percent) and a depth of 0.075 m (52–75 percent) versus UD. Because of high rainfall and failure to manage the CDS under the wet conditions, discharge was over five times greater in 1995 under CDS at each depth, resulting in no significant change in NO_3 load. In 1996, however, growing-season NO_3 loads were reduced by 94 percent and 30 percent by the 0.050 m and 0.075 m CDS, respectively.

Monitoring over 2 years of four replicate plots each of surface runoff, CD at 1.1m below the soil surface, and CDS at 0.8 m in Baton Rouge showed that 67 percent of the annual NO_3 loss in tile drainage for the CD and CDS systems occurred during the 150-day growing season (Grigg et al. 2003). There were no statistical differences between the surface, subsurface, or total NO_3 loads from the CD and CDS systems.

Compilations and reviews of literature on controlled drainage have yielded largely consistent findings. On the basis of approximately 125 site-years of data collected at 14 locations in eastern North Carolina (Evans et al. 1996):

- Controlled drainage, when managed all year, reduces total outflow by approximately 30 percent compared to uncontrolled systems, although outflows vary widely depending on soil type, rainfall, type of drainage system and management intensity. For example, control during only the growing season typically reduces outflow by less than 15 percent. The effect of controlled drainage on peak outflow rates varies seasonally. Drainage control reduces peak outflow rates during dry periods (summer and fall) but can increase peak outflow rates during wet periods (winter and spring), depending on the control strategy.

- Drainage control has little net effect on TN and P concentrations in drainage outflow. Controlled drainage can reduce NO_3-N concentrations in drainage outflow by up to 20 percent , but TKN concentrations are somewhat increased. Controlled drainage tends to decrease P concentrations on predominately surface systems but has the opposite effect on predominately subsurface systems. Seasonal variations can also occur, depending on rainfall, soil type, and the relative contribution of surface or subsurface drainage to total outflow.
- Controlled drainage reduces N and P transport at the field edge, primarily because of the reduction in outflow volume. In 14 field studies, drainage control reduced the annual transport of TN (NO_3-N and TKN) at the field edge by 10 kg/ha, or 45 percent , and TP by 0.12 kg/ha, or 35 percent. Again, the reductions at individual sites were influenced by rainfall, soil type, type of drainage system, and management intensity.

In a broader review of methods to reduce NO_3 in drainage water, it was estimated that the potential for NO_3 load reduction with controlled drainage is approximately 50 percent (Appelboom and Fouss 2006). Skaggs and Youssef (2008) reported a wide range of discharge reduction (17–85 percent) and NO_3 load reduction (18–85 percent) in a summary of studies conducted in North Carolina, Ohio, Sweden, and Canada. The authors note that controlled drainage increases evapotranspiration, surface runoff, and deep and lateral seepage, with evapotranspiration accounting for only 8–15 percent of the reduction in subsurface drainage compared to conventional drainage and seepage effects dependent on the size and boundary conditions of the fields under controlled drainage. The effects of size and boundary condition on discharge were illustrated by the different findings for field and plot studies in Canada (Tan et al. 2004). Reductions in NO_3 concentration from controlled drainage were minimal in most studies, so it is important to know what happens to the NO_3 in the seepage water. Evidence indicates that in poorly or very poorly drained soils, the NO_3 is reduced at depths greater than 1 m or so, providing effective reduction of N losses to the environment.

Ditch management practice effectiveness

In a 2-year study of two experimental farm drainage ditches serving land planted in a summer row crop/winter fallow sequence in northern Mississippi, monthly baseflow and stormflow (28 storms) regression results indicated that drainage ditches reduced NO_3 and ammonia over the length of the ditch for both growing and dormant seasons (Kroger et al. 2007). Ditches reduced the maximum farm effluent dissolved inorganic N load, defined as the highest load attained spatially within the drainage ditch as a result of the combination of surface and subsurface flow processes, by an average of 57 percent.

Sediment from two similar drainage ditches in the Atlantic coastal plain were sampled (0–5 cm) after one of the ditches had been dredged, removing fine-textured sediments (clay = 41 percent) with high organic matter content (85 g/kg) and exposing coarse-textured sediments (clay = 15 percent) with low organic matter content (2.2 g/kg) (Shigaki et al. 2008). Laboratory testing in a flume revealed that under conditions of low initial P concentrations, sediment from the dredged ditch released 13 times less P to the water than did sediment from the ditch that had not been dredged, but the sediments from the dredged ditch removed 19 percent less P from the flume water when it was spiked with dissolved P to approximate long-term runoff concentrations. Irradiation of sediments to destroy microorganisms revealed that biological processes accounted for up to 30 percent of P uptake in the coarse-textured sediment of the dredged ditch and 18 percent in the fine-textured sediment of the undredged ditch.

Because vegetation in ditches increases sediment retention, cycles nutrients, and promotes the development of soil structure, management procedures that encourage ditch vegetation, such as targeted clean-outs and gradual inundation, can increase the stability and ecosystem services of ditch soils (Needelman et al. 2006). A study in Florida to evaluate P characteristics of agricultural ditch soils in the Lake Okeechobee Basin found that in-ditch management practices, such as using soil amendments or controlled drainage, could be useful to reduce P loss from ditch soils (Dunne et al. 2006).

Bioreactors effectiveness

Several studies have measured the effectiveness of bioreactors in removing NO_3 and other contaminants from agricultural drainage water (Table 2-29).

A review of bioreactors in the Midwest found that they could reduce NO_3 levels by 60–100 percent (Kalita et al. 2007). In addition, the authors identified the following advantages of bioreactors:

- They use proven technology
- They require no modification of current practices
- No land needs to be taken out of production
- There is no decrease in drainage effectiveness over time
- They require little or no maintenance
- They can last for up to 20 years

Table 2-29. Measured NO_3 removal rates for bioreactors

Location	Practice	Flow-through rate (L/min)	Removal (%)		Source
			NO_3-N conc.	NO_3-N load	
Iowa	Wood-chip denitrification walls		65%[a]	61%–68%[a]	Jaynes et al. 2004
Minnesota	Wood chip bioreactor		32%		Thorstensen No date
	Denitrification reactor using wood particles—Upflow Design	7.8	52%		
Ontario, Canada	In-ditch wood chip bioreactor	24	78%		Robertson and Merkley 2009
Ontario, Canada	Subsurface wood mulch bioreactor (pilot scale)	0.6–1.4	58%		Robertson et al. 2000
Ontario, Canada	200-L fixed-bed bioreactors with sand, tree bark, wood chips, leaf compost (pilot scale)	0.007–0.042		99%	Blowes et al. 1994
Various	Constructed bioreactors (review article)[b]		60%–90%		Appelboom and Fouss 2006
Various	Constructed bioreactors (review article)[b]		60%–100%		Kalita et al. 2007

Notes:

a. Reduction compared to uncontrolled drainage.

b. Reviews include some of the other studies shown.

In an Iowa study comparing several tile and cropping modifications for reducing NO_3 in tile drainage versus the NO_3 concentration in drainage from a UD treatment (tile at 1.2 m), it was found that denitrification walls (DW) reduced the NO_3 concentration in tile drainage by an average of 65 percent and the tile drainage N load by 61–68 percent compared to UD (Jaynes et al. 2004).

Two denitrification reactor designs (a lateral flow design and an upflow design) using fine and coarse wood particles were tested under baseflow conditions in southern Ontario; the former over a 26-month period on drainage from a cornfield, and the latter over a 20-month period on drainage from a golf course (van Driel et al. 2006). Removal by the reactor at the cornfield site averaged 3.9 mg N/L at an average flow-through rate of 7.7 L/min and an average influent NO_3 concentration of 11.8 mg N/L. With an average flow-through of 7.8 L/min and influent NO_3 concentration of 3.2 mg N/L, removal by the reactor at the golf course site averaged 1.7 mg N/L. Mass balance calculations indicate that carbon consumption from denitrification was less than 2 percent per year, showing the potential for the reactors to operate for a number of years without the need for media replenishment.

A 40-m^3 woodchip bioreactor was trenched into the bottom of an existing agricultural drainage ditch in Ontario, Canada, with flow induced through the reactor by construction of a gravel riffle in the streambed (Robertson and Merkley 2009). Over the first year and a half of operation, a mean influent NO_3 concentration of 4.8 mg/L was reduced to 1.04 mg/L at a mean reactor flow rate of 24 L/min. A series of flow-step tests, facilitated by an adjustable height outlet pipe, demonstrated that NO_3 mass removal generally increased with increasing flow rate. Silt accumulation reduced reactor flow rates over time, but design modifications were implemented to address the problem.

In a 1-year pilot-scale study, two 200-L fixed-bed bioreactors containing coarse sand and organic carbon (tree bark, wood chips, and leaf compost) were used to treat NO_3 contamination from agricultural runoff (Blowes et al. 1994). At inflow rates of 10–60 L/day, NO_3-N concentrations of 3–6 mg/L in farm-field drainage tiles were reduced by the reactors to less than 0.02 mg/L.

In Ontario, a pilot-scale assessment of a plywood-framed (1.9 m^3) subsurface reactor filled with coarse wood mulch documented a 58 percent removal of NO_3 from farm drainage water influent at hydraulic loading rates ranging from 800 to 2,000 L/day (Robertson et al. 2000). NO_3 consumption rates were temperature dependent, ranging from 5 mg/L N per day at 2–5 °C, to 15–30 mg/L N per day at 10–20 °C but did not deteriorate over the 7-year monitoring period. Mass-balance calculations of carbon consumption indicated that the reactor could perform well for at least a decade without carbon replenishment.

In a review of methods to reduce NO_3 in drainage water, it was estimated that the potential for NO_3 reduction is 60 to 90 percent for constructed bioreactors (Appelboom and Fouss 2006).

Constructed wetlands effectiveness

In a review of methods to reduce NO_3 in drainage water, it was estimated that the potential for NO_3 reduction is 37–65 percent for natural/constructed wetlands, with up to an additional 18 percent if a berm is used in creation of the wetland (Appelboom and Fouss 2006). A combination of controlled-drainage, constructed wetland, and in-stream denitrification could result in more than 75 percent NO_3 removal before release to larger streams or other surface waters.

Measurement over 3 years of N removal rates in three large (0.3 to 0.8 ha, 1,200 to 5,400 m^3 in volume) constructed wetlands treating tile drainage from corn and soybean fields in southern Illinois indicated TN removal of 37 percent in the wetlands (Kovacic et al. 2000). The wetlands also decreased NO_3-N concentrations of inlet water by 28 percent, and coupling the wetlands with a 15.3-m buffer strip between the wetlands and the river removed an additional 9 percent of the tile NO_3-N, increasing the N removal efficiency to 46 percent. TP removal was only 2 percent during the 3-year period, with highly variable results in each wetland and year.

Two agricultural runoff wetlands, W1 (area 0.16 ha, volume 660 m^3) and W2 (area 0.4 ha, volume 1,780 m^3), intercepting surface and tile drainage in the Lake Bloomington, Illinois, watershed, achieved a mass NO_3-N retention of 36 percent (Kovacic et al. 2005). Wetlands W1 and W2 reduced overall volume-weighted NO_3 concentrations by 42 percent and 31 percent, respectively. Combined P mass retention was 53 percent, and combined TOC mass retention was 9 percent.

Practice Costs

Dual-purpose drainage/subirrigation systems provide drainage, controlled drainage, and subirrigation (Evans and Skaggs 1996). Systems designed primarily for drainage might need to be redesigned or managed more intensively to serve as dual-purpose systems. The three major expenses of installing and operating a drainage and subirrigation system are the cost of a water supply, underground tubing installation, and land grading (Evans et al. 1996). If subirrigation is not part of the system, a water supply is not needed, but increased yields realized with subirrigation can contribute to NO_3 reductions because of increased crop uptake. On the basis of estimates for 1996, water supply ponds sufficient to irrigate approximately 40 ha would cost about \$68,735–\$82,381 in 2010 dollars, but other water supplies (e.g., stream) could be much cheaper. Underground tubing installation costs are generally the largest single expense, varying with the total footage, tubing diameter, installation method, and whether filter material is used. The amount of tubing needed depends on the hydraulic conductivity of the soil, with spacing ranging from 40 to 100 feet in North Carolina. The cost of 10-cm tubing ranges from about 76 cents to just over \$1 per m (2010 dollars), with filter material adding another 32 to 54 cents per m. The cost to install underground tubing depends on the specific job, but can range from about \$1.36/m to \$2.27/m for 10-cm tubing. The total cost to install tubing at 10-m spacing is about \$2,688/ha (2010 dollars), whereas the cost for 30-m spacing is about \$890/ha. Land grading could add \$170 to \$860/ha to the cost, and the cost of control structures ranges from about \$400 to more than \$4,000. Finally, installation generally requires field borders to stabilize open ditches at a cost of about \$100 per production hectare.

A cost analysis for controlled drainage in the lower coastal plain of North Carolina assumed the need for a surface drainage system of 0.9- to 1.5-m-deep open ditches, a flashboard riser installed in the collector canal, a corrugated metal pipe culvert for an outlet, and concrete to stabilize the riser (Wossink and Osmond 2001). It was assumed that there would be no installation and maintenance costs for ditches because they were part of the preexisting condition. On the basis of a land slope of 0.1 to 0.4 m/km, it was assumed that there would be one structure per mile in the canal on a 0.6- to 0.75-m contour interval, meaning that one control structure in the main canal would serve 130 ha. It was also assumed that under controlled drainage soybeans and cotton yields would increase by 2 percent or more, corn yields would increase by 5 percent or more, and wheat and tobacco yields would not increase. Installation costs for controlled drainage were estimated to be \$57.80/ha (2008 dollars), while annual maintenance was estimated at $3.80/ha, and benefits from yield increases were estimated at $6.10/ha to $33.50/ha. Assuming cost-share availability of about $45/ha, the authors concluded that cost-shared controlled drainage was financially practical for the lower coastal plain of NC.

In a demonstration plot in Minnesota, the costs associated with controlled drainage included drainage control structures, design, installation, extra pipe and installation, totaling about $35/ha for a 65-ha field (Binstock 2009). Tile spacing was set at 22.8 m, using 10-cm diameter laterals on a slope of just under 1 percent. It has been estimated that drainage management systems cost about $50 to $500/ha more than conventional drainage systems (Newby 2009).

Water control structures for drainage water management cost from about $535 to $2,120 (2010 dollars) depending on height, size of tile, structure design, manufacturer, and whether it is automated (Frankenberger et al. 2006). Installation costs for structures are about $215 for basic structures, increasing with size and complexity. Assuming flat terrain, a single structure could serve eight hectares at a cost of $70 to $270 per ha. Water control structures cost $2,560 each in Virginia (USDA-NRCS 2010).

Both a lateral flow design and an upflow design bioreactor tested in Ontario were successful in achieving maintenance-free operation during all seasonal conditions, including unassisted startup after drought and freeze periods (van Driel et al. 2006). Construction cost per unit N removal for bioreactors designed to manage baseflow conditions are expected to be similar to the cost for constructed wetlands, but less land is required for the bioreactors.

A woodchip bioreactor (38 m long by 1.8 m deep by 0.6–0.9 m wide) in Minnesota cost approximately $3,200 to construct (Minnesota Department of Agriculture No date). Control structures cost $1,500, trenching cost $1,100, and $600 was spent on woodchips. Serving approximately 3.2 ha, the bioreactor cost is about $990/ha and is expected to work for about 20 years. The cost of a 60-m bioreactor ranges from about $2,900 to $4,300 (2010 dollars) depending on materials and design (Morrison 2008).

4.5 Animal Agriculture

AFOs congregate animals and typically maintain feed, wastes, and production operations on a small land area when under pasture or grazing. Animal production can cause water pollution by leaching and runoff of organic matter, N, P, pathogens, and heavy metals from animal congregation areas or other parts of the facility during regular operation of a facility if not properly managed (for further information regarding storage of manure and wastewater, see Section 2). Key strategies for edge of field trapping and treatment of runoff include VFS and other techniques to capture runoff from feedlots, barnyards, pasture and grazing lands, and other facility areas and remove sediment, nutrients, and other pollutants before delivery to surface waters.

AFOs using grazing and pasture land include nutrients and pathogens in runoff from areas of waste deposition and soil loss from areas of degraded vegetation cover. While livestock exclusion (see Section 2) and pasture management (see Section 3.4) are often the main approaches to managing water quality effects from grazing livestock, non-grazed, vegetated buffer strips or other edge-of-field practices are often recommended to protect waterbodies from sediments and nutrients in runoff from grazed pastures.

Implementation Measure A-20:

Manage runoff from livestock production areas under grazing and pasture to minimize off-farm transport of nutrients and sediment.

Practice Effectiveness

Production area effectiveness

Koelsch et al. (2006) presented the following conclusions about the application of vegetative treatment systems (VTS) to manage runoff from open lot livestock production areas:

- The pollutant reduction resulting from a VTS is based on two primary mechanisms: (1) sedimentation, typically occurring within the first few meters of a VTS, and (2) infiltration of runoff into the soil profile. System design based on sedimentation and infiltration is necessary to achieve a required performance level for concentrated AFO (CAFO) application.
- Critical design factors specific to attaining high levels of pollutant reduction within a VTS include pretreatment, sheet flow, discharge control, siting, and sizing. Critical management factors include maintaining a dense vegetation stand and sheet flow of runoff across VTA as well as minimizing nutrient accumulation.

The authors report numerous pollutant removal rates for a variety of VTS under a broad range of circumstances. While the study focused on VTA specifically related to providing an alternative method of manure and wastewater storage for CAFOs, the practice can be applied more broadly in animal agriculture. In general, the literature reports 70–90 percent TS removal, 80 percent N removal, 70 percent P removal, and 77 percent fecal coliform removal from CAFO runoff treated by VTS.

In Nebraska, Woodbury et al. (2000, 2002) tested a flat-bottom terrace to collect runoff from a beef feedlot to provide temporary liquid storage and accumulate settable solids, while distributing the liquid fraction uniformly across a VFS. No runoff left the VFS, indicating that the basin discharge was used for grass production. In a follow-up study, Woodbury et al. (2003)

reported that the system reduced the cumulative mass of TSS (80 percent), VSS (67 percent), and COD (59 percent).

Kim et al. (2003) studied flow and P transport through a VFS receiving milkhouse wastewater and barnyard runoff from two New York dairy farms. Although 33 m–40 m VFS eventually reduced soluble P to less than 0.2 mg/L, P was less effectively removed where soil saturation occurred. Wastewater entering a VFS should be distributed uniformly to avoid soil saturation.

In Montana, Fajardo et al. (2001) reported on the effectiveness of VFS using tall fescue in treating runoff from livestock manure stockpiles. Runoff NO_3-N concentrations were reduced by 97–99 percent by a VFS. Coliform bacteria counts were reduced by 64–87 percent, although bacteria counts in runoff leaving the VFS remained elevated, even for treatments not receiving manure.

VFS were effective in removing a broad range of constituents from a Kansas beef feedlot runoff pretreated by a settling basin (Mankin and Okoren 2003). The first 30 m provided most or all the reductions found within the 150-m VFS studied: reductions averaged 85 percent of inflow water, 85 percent of sediment, 77 percent of N, and 84 percent of P. Fecal bacteria removal by the VFS was on the order of 1-log: reductions at 30 m ranged from 84 percent for fecal coliform and fecal streptococci to 91 percent for *E. coli*.

In Illinois, Trask et al. (2004) reported that a VFS can be a BMP for controlling the pathogen *Cryptosporidium* in runoff from animal production facilities. The vegetative surface was very effective in reducing *C. parvum* in surface runoff; for all slopes and rainfall intensities, recovery of *C. parvum* oocysts was considerably less from a vegetated surface than from the bare-ground conditions. For a 25.4 mm/h rainfall event, recovery of oocysts in overland flow from the VFS varied from 0.6 to 1.7 percent, while those from the bare ground condition varied from 4.4 to 14.5 percent. For the 63.5 mm/h rainfall, the recovery percentages of oocysts varied from 0.8 to 27.2 percent from the VFS, and 5.3 to 59 percent from bare-ground conditions.

Hubbard et al. (2007) tested the performance of grass-forest vegetated buffers in assimilating N from overland flow application of swine lagoon effluent in Georgia. The buffers approximated 60 m in length by 90 m in width. The upper 10 m of each buffer was in grass, while the downslope area was in mature or newly planted pines. Shallow groundwater under the buffers showed NO_3-N concentrations 20–30 m downslope to be less than 10 mg/L. On those buffers, NO_3-N concentrations in shallow groundwater were near background levels 5 years after wastewater application commenced. This study demonstrated that the ratio of buffer area width to wastewater application area width on the landscape should be at least 1:1.

In Kansas, Mankin et al. (2006) quantified beef cattle feedlot runoff quality, particularly during unstocked conditions, and evaluated reductions of fecal bacteria and nutrients in VFS treating feedlot runoff. Events when few or no cattle were present averaged 17 percent of TN (20 mg/L), 14 percent of TP (6 mg/L), and 2 percent of the fecal coliforms (2.1×10^4 colony forming units/100 mL) of events with cattle present. Measured concentration reductions from all events and VFS averaged 77 percent (fecal coliforms), 83 percent (*E. coli*), 83 percent (fecal streptococci), 66 percent (TN), and 66 percent (TP). VFS allowed no discharges for greater than 90 percent of feedlot runoff events at the sites with the ratio of VFS: drainage area greater than 0.5.

Gilley et al. (2008) compared nutrient transport in runoff from beef feedlots in Nebraska with loose manure surfaces versus compacted surfaces. No significant differences in feedlot soil characteristics or nutrient transport in runoff were found between loose and compacted surfaces. However, concentrations of *E. coli* were significantly greater in runoff from the loose surface feedlots.

In Finland, Narvanen et al. (2008) tested a ferric sulfate dosing system to treat runoff from horse paddocks; runoff was then discharged into a sedimentation pond and sand filter. Dissolved P was reduced by 95 percent, TP by 81 percent.

Robertson and Merkley (2009) demonstrated an in-stream bioreactor using woodchips to promote denitrification of agricultural drainage in Ontario, Canada. Over the first 1.5 years of operation, mean influent NO_3-N of 4.8 mg/L was attenuated to 1.04 mg/L (a 78 percent reduction) at a mean reactor flow rate of 24 L/min. When removal rates were not NO_3-limited, areal mass removal ranged from 11 mg N/m^2/h at 3 °C to 220 mg N/m^{2}hr at 14°C, exceeding rates reported for some surface-flow constructed wetlands by a factor of about 40.

Table 2-30. Summary of reported practice effects resulting from VFS treatment of AFO runoff

Location	Study type	Practice	Practice effects	Source
Various	Review	Vegetated treatment systems	Literature reports removals of about 70%–90% TS, about 80% N, about 70% P, and about 77% fecal coliform from CAFO runoff treated by diverse vegetated treatment systems.	Koelsch et al. 2006
Nebraska	BMP	Settling basin/VFS	No runoff left the VFS treating beef feedlot runoff; the system reduced the cumulative mass of TSS (80%), VSS (67%), and COD (59%)	Woodbury et al. 2000 2002, 2003
New York	BMP	VFS	Although 33–40 m VFS treating milkhouse waste and barnyard runoff reduced soluble P to < 0.2mg/L in most cases; P was less effectively removed in the areas where soil saturation occurred.	Kim et al. 2003

Table 2-30. Summary of reported practice effects resulting from VFS treatment of AFO runoff *(continued)*

Location	Study type	Practice	Practice effects	Source
Montana	BMP	VFS	VFS treating runoff from manure stockpiles reduced NO_3-N concentrations by 97%–99% and coliform bacteria counts by 64%–87%[a]	Fajardo et al. 2001
Kansas	BMP	Settling basin, VFS	Reductions averaged 85% of inflow water, 85% of sediment, 77% of N, and 84% of P. Bacteria reductions at 30 m ranged from 84% for fecal coliform and fecal streptococci to 91% for *E. coli*. The first 30 m provided most or all of the reductions.	Mankin and Okoren 2003
Illinois	BMP	VFS vs. bare soil	Fewer *Cryptosporidium* oocysts were passed in overland flow from a vegetated surface than from the bare-ground conditions. For a 25.4 mm/h rainfall event, oocyst recovery from the VFS were 0.6–1.7%, vs. 4.4–14.5% from bare ground. For the 63.5 mm/h rainfall, the recovery percentages of oocysts varied from 0.8%–27.2% from the VFS, and 5.3%–59% from bare ground.	Trask et al. 2004
Georgia	BMP	Grass-forest buffer[b]	Shallow groundwater under the buffers showed NO_3-N concentrations 20–30 m downslope to be <10 mg/L. On these buffers, NO_3-N concentrations in shallow groundwater were near background levels 5 years after wastewater application began.	Hubbard et al. 2007
Kansas	BMP	VFS, feedlot stocking rate	Runoff when few or no cattle were present averaged 17% of the TN, 14% of the TP, and 2% of the fecal coliforms vs. events with cattle present. Concentration reductions averaged 77% (fecal coliforms), 83% (*E. coli*), 83% (fecal streptococci), 66% (TN), and 66% (TP).	Mankin et al. 2006
Nebraska	BMP	Feedlot surface	No significant differences in nutrient transport in runoff were found between loose and compacted feedlot surfaces. *E. coli* counts were significantly greater in runoff from the loose surface feedlots.	Gilley et al. 2008
Finland	BMP	Ferric sulfate, sand filter	Dissolved P was reduced by 95%, TP by 81% using a ferric sulfate dosing system and sand filter to treat runoff from horse paddocks	Narvanen et al. 2008
Ontario, Canada	BMP	Woodchip bioreactor	Treating AFO drainage, NO_3-N was attenuated to 1.04 mg/L (78% reduction); areal mass removal ranged from 11 mg $N/m^2/h$ at 3 °C to 220 mg N/m^2hr at 14 °C, exceeding rates reported for some surface-flow constructed wetlands by a factor of about 40.	Robertson and Merkley 2009

Notes:

a. Bacteria counts in runoff leaving the VFS remained elevated, even for treatments not receiving manure

b. Upper 10 m in grass, 20-30 m downslope in trees

Buffer/filter strips treating pasture runoff

Sotomayor-Ramirez et al. (2008) tested 10- and 20-m grassed filter strips treating runoff from grazed pasture amended with dairy manure sludge in Puerto Rico. Filter strips reduced TP and dissolved P concentrations by 29 percent and 32 percent at 10 m, and by 57 percent and 49 percent at 20 m, respectively. A 27 percent decrease in TKN concentration was observed in one field as a result of the 20-m filter strip.

Tate et al. (2000) evaluated the potential water quality improvements from 10-m buffer strips on irrigated land in California. The 10-m buffer did not significantly reduce concentrations and load of NO_3-N in runoff from sprinkler and flood irrigated pastures. The buffer also failed to reduce TP concentration under either irrigation system, or TP and TSS load under sprinkler irrigation.

The presence of a vegetated buffer of any size (from 1 to 25 m), generally reduced median fecal coliform bacteria concentrations and loads in runoff from Oregon pasture land by more than 99 percent (Sullivan et al. 2007).

Other practices treating pasture runoff

Tanner et al. (2005) reported on the performance of a surface-flow constructed wetland (occupying about 1 percent of the watershed area) treating subsurface drainage from rain-fed, dairy cattle grazed pasture in New Zealand. TN mass removal efficiency was 79 percent (841 g/m^2 per year) the first year but declined to 21 percent (40 g/m^2 per year) in the second year, associated with changes in the magnitude, speciation and seasonal pattern of N export from the watershed. TP export rose by 101 percent (5.0 g/m per year) after passage through the wetland in the first year but decreased by 12 percent (0.2 g/m^2 per year) in the second year. The results show that constructed wetlands composing similar to 1 percent of watershed area can markedly reduce N export via pastoral drainage but could be net sources of NH_4-N, DRP and TP during establishment.

Knox et al. (2008) examined benefits to water quality provided by a natural, flow-through wetland receiving runoff from irrigated pasture in California. The wetland reduced loads of TSS (77 percent), NO_3 (60 percent), and *E. coli* (68 percent). Retention of TN, TP, and SRP was between 35 and 42 percent of loads entering the wetland.

Table 2-31. Summary of reported practice effects resulting from buffer/wetland treatment of pasture runoff

Location	Study type	Practice	Practice effects	Source
Puerto Rico	BMP	Grassed filter strips	Filter strips treating runoff from grazed pasture reduced TP and dissolved P concentrations by 29% and 32% at 10 m, and by 57% and 49% at 20 m, respectively. A 27% decrease in TKN concentration was observed in one field as a result of the 20-m filter strip	Sotomayor-Ramirez et al. 2008
California	BMP	Buffer	10-m buffer did not significantly reduce concentrations and load of NO_3-N in runoff from sprinkler and flood irrigated pastures. The buffer also failed to reduce TP concentration under either irrigation schemes, or TP and TSS load under sprinkler irrigation	Tate et al. 2000
Oregon	BMP plots	Vegetated buffer	The presence of a vegetated buffer of any size (from 1 to 25 m) reduced median fecal coliform bacteria concentrations and loads in runoff by more than 99%.	Sullivan et al. 2007
New Zealand	BMP	Constructed wetland	Surface-flow constructed wetland (occupying about 1% of watershed area) treating subsurface drainage dairy cattle grazed pasture: TN mass removal efficiency was 79% (841 g/m^2 per year) the first year but declined to 21% (40 g/m^2 per year) in the second year. TP export rose by 101% (5.0 g/m per year) after passage through the wetland in the first year but decreased by 12% (0.2 g/m^2 per year) in the second year.	Tanner et al. 2005
California	BMP	Natural wetland	Wetland receiving runoff from irrigated pasture reduced loads of TSS (77%), NO_3 (60%), and *E. coli* (68%). 35% to 42% of TN, TP, and SRP loads entering the wetland were retained.	Knox et al. 2008

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Appendix 1: USDA National Conservation Practice Standards (Practice Codes)

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

WASTE STORAGE FACILITY

(No.)

CODE 313

DEFINITION

A waste storage impoundment made by constructing an embankment and/or excavating a pit or dugout, or by fabricating a structure.

PURPOSE

To temporarily store wastes such as manure, wastewater, and contaminated runoff as a storage function component of an agricultural waste management system.

CONDITIONS WHERE PRACTICE APPLIES

- Where the storage facility is a component of a planned agricultural waste management system
- Where temporary storage is needed for organic wastes generated by agricultural production or processing
- Where the storage facility can be constructed, operated and maintained without polluting air or water resources
- Where site conditions are suitable for construction of the facility
- To facilities utilizing embankments with an effective height of 35 feet or less where damage resulting from failure would be limited to damage of farm buildings, agricultural land, or township and country roads.
- To fabricated structures including tanks, stacking facilities, and pond appurtenances.

CRITERIA

General Criteria Applicable to All Waste Storage Facilities.

Laws and Regulations. Waste storage facilities must be planned, designed, and constructed to meet all federal, state, and local laws and regulations.

Location. To minimize the potential for contamination of streams, waste storage facilities should be located outside of floodplains. However, if site restrictions require location within a floodplain, they shall be protected from inundation or damage from a 25-year flood event, or larger if required by laws, rules, and regulations. Waste storage facilities shall be located so the potential impacts from breach of embankment, accidental release, and liner failure are minimized; and separation distances are such that prevailing winds and landscape elements such as building arrangement, landforms, and vegetation minimize odors and protect aesthetic values.

Storage Period. The storage period is the maximum length of time anticipated between emptying events. The minimum storage period shall be based on the timing required for environmentally safe waste utilization considering the climate, crops, soil, equipment, and local, state, and federal regulations.

Design Storage Volume. The design storage volume equal to the required storage volume, shall consist of the total of the following as appropriate:

(a) Manure, wastewater, and other wastes accumulated during the storage period

(b) Normal precipitation less evaporation on the surface area (at the design storage volume level) of the facility during the storage period

(c) Normal runoff from the facility's drainage area during the storage period

(d) 25-year, 24-hour precipitation on the surface (at the required design storage volume level) of the facility

(e) 25-year, 24-hour runoff from the facility's drainage area

(f) Residual solids after liquids have been removed. A minimum of 6 inches shall be provided for tanks

(g) Additional storage as may be required to meet management goals or regulatory requirements

Inlet. Inlets shall be of any permanent type designed to resist corrosion, plugging, freeze damage and ultraviolet ray deterioration while incorporating erosion protection as necessary.

Emptying Component. Some type of component shall be provided for emptying storage facilities. It may be a facility such as a gate, pipe, dock, wet well, pumping platform, retaining wall, or ramp. Features to protect against erosion, tampering, and accidental release shall be incorporated as necessary.

Accumulated Solids Removal. Provision shall be made for periodic removal of accumulated solids to preserve storage capacity. The anticipated method for doing this must be considered in planning, particularly in determining the configuration of ponds and type of seal, if any.

Safety. Design shall include appropriate safety features to minimize the hazards of the facility. Ramps used to empty liquids shall have a slope of 4 horizontal to 1 vertical or flatter. Those used to empty slurry, semi-solid, or solid waste shall have a slope of 10 horizontal to 1 vertical or flatter unless special traction surfaces are provided. Warning signs, fences, ladders, ropes, bars, rails, and other devices shall be provided, as appropriate, to ensure the safety of humans and livestock. Ventilation and warning signs must be provided for covered waste holding structures, as necessary, to prevent explosion, poisoning, or asphyxiation. Pipelines shall be provided with a water-sealed trap and vent, or similar device, if there is a potential, based on design configuration, for gases to enter buildings or other confined spaces. Ponds and uncovered fabricated structures for liquid or slurry waste with walls less than 5 feet above ground surface shall be fenced and warning signs posted to prevent children and others from using them for other than their intended purpose.

Erosion Protection. Embankments and disturbed areas surrounding the facility shall be treated to control erosion.

Liners. Liners shall meet or exceed the criteria in Pond Sealing or Lining (521).

Additional Criteria for Waste Storage Ponds

Soil and foundation. The pond shall be located in soils with an acceptable permeability that meets all applicable regulation, or the pond shall be lined. Information and guidance on controlling seepage from waste impoundments can be found in the Agricultural Waste Management Field Handbook (AWMFH), Appendix 10D.

The pond shall have a bottom elevation that is a minimum of 2 feet above the seasonal high water table unless features of special design are incorporated that address buoyant forces, pond seepage rate and non-encroachment of the water table by contaminants. The water table may be lowered by use of perimeter drains, if feasible, to meet this requirement.

Maximum Operating Level. The maximum operating level for waste storage ponds shall be the pond level that provides for the required volume less the volume contribution of precipitation and runoff from the 25-year, 24-hour storm event plus the volume allowance for residual solids after liquids have been removed. A permanent marker or recorder shall be installed at this maximum operating level to indicate when drawdown should begin. The marker or recorder shall be referenced and explained in the O&M plan.

Outlet. No outlet shall automatically release storage from the required design volume. Manually operated outlets shall be of permanent type designed to resist corrosion and plugging.

Embankments. The minimum elevation of the top of the settled embankment shall be 1 foot above the waste storage pond's required volume. This height shall be increased by the amount needed to ensure that the top elevation will be maintained after settlement. This increase shall be not less than 5 percent. The minimum top widths are shown in Table 1. The combined side slopes of the settled embankment shall not be less than 5 horizontal to 1 vertical, and neither slope shall be steeper than 2 horizontal to 1 vertical unless provisions are made to provide stability.

Table 1 – Minimum Top Widths

Total embankment Height, ft.	Top Width, ft.
15 or less	8
15 – 20	10
20 – 25	12
25 – 30	14
30 – 35	15

Excavations. Unless supported by a soil investigation, excavated side slopes shall be no steeper than 2 horizontal to 1 vertical.

Additional Criteria for Fabricated Structures

Foundation. The foundations of fabricated waste storage structures shall be proportioned to safely support all superimposed loads without excessive movement or settlement.

Where a non-uniform foundation cannot be avoided or applied loads may create highly variable foundation loads, settlement should be calculated from site-specific soil test data. Index tests of site soil may allow correlation with similar soils for which test data is available. If no test data is available, presumptive bearing strength values for assessing actual bearing pressures may be obtained from Table 2 or another nationally recognized building code. In using presumptive bearing values, adequate detailing and articulation shall be provided to avoid distressing movements in the structure.

Foundations consisting of bedrock with joints, fractures, or solution channels shall be treated or a separation distance provided consisting of a minimum of 1 foot of impermeable soil between the floor slab and the bedrock or an alternative that will achieve equal protection.

Table 2 - Presumptive Allowable Bearing Stress Values[1]

Foundation Description	Allowable Stress
Crystalline Bedrock	12000 psf
Sedimentary Rock	6000 psf
Sandy Gravel or Gravel	5000 psf
Sand, Silty Sand, Clayey Sand, Silty Gravel, Clayey Gravel	3000 psf
Clay, Sandy Clay, Silty Clay, Clayey Silt	2000 psf

[1] Basic Building Code, 12th Edition, 1993, Building Officials and Code Administrators, Inc. (BOCA)

Liquid Tightness. Applications such as tanks, that require liquid tightness shall be designed and constructed in accordance with standard engineering and industry practice appropriate for the construction materials used to achieve this objective.

Structural Loadings. Waste storage structures shall be designed to withstand all anticipated loads including internal and external loads, hydrostatic uplift pressure, concentrated surface and impact loads, water pressure due to seasonal high water table, and frost or ice pressure and load combinations in compliance with this standard and applicable local building codes.

The lateral earth pressures should be calculated from soil strength values determined from the results of appropriate soil tests. Lateral earth pressures can be calculated using the procedures in TR-74. If soil strength tests are not available, the presumptive lateral earth pressure values indicated in Table 3 shall be used.

TABLE 3 - LATERAL EARTH PRESSURE VALUES[1]

		Equivalent fluid pressure (lb/ft^2/ft of depth)			
Soil		Above seasonal high water table[2]		Below seasonal high water table[3]	
Description[4]	Unified Classification[4]	Free-standing walls	Frame tanks	Free-standing walls	Frame tanks
Clean gravel, sand or sand-gravel mixtures (maximum 5% fines)[5]	GP, GW, SP, SW	30	50	80	90
Gravel, sand, silt and clay mixtures (less than 50% fines) Coarse sands with silt and and/or clay (less than 50% fines)	All gravel sand dual symbol classifications and GM, GC, SC, SM, SC-SM	35	60	80	100
Low-plasticity silts and clays with some sand and/or gravel (50% or more fines) Fine sands with silt and/or clay (less than 50% fines)	CL, ML, CL-ML SC, SM, SC-SM	45	75	90	105
Low to medium plasticity silts and clays with little sand and/or gravel (50% or more fines)	CL, ML, CL-ML	65	85	95	110
High plasticity silts and clays (liquid limit more than 50)[6]	CH, MH	-	-	-	-

[1] For lightly-compacted soils (85% to 90% maximum standard density.) Includes compaction by use of typical farm equipment.

[2] Also below seasonal high water table if adequate drainage is provided.

[3] Includes hydrostatic pressure.

[4] All definitions and procedures in accordance with ASTM D 2488 and D 653.

[5] Generally, only washed materials are in this category

[6] Not recommended. Requires special design if used.

Lateral earth pressures based upon equivalent fluid assumptions shall be assigned according to the following conditions:

- **Rigid frame or restrained wall.** Use the values shown in Table 3 under the column “Frame tanks,” which gives pressures comparable to the at-rest condition.
- **Flexible or yielding wall.** Use the values shown in Table 3 under the column “Free-standing walls,” which gives pressures comparable to the active condition. Walls in this category are designed on the basis of gravity for stability or are designed as a cantilever having a base wall thickness to height of backfill ratio not more than 0.085.

Internal lateral pressure used for design shall be 65 lb/ft^2 where the stored waste is not protected from precipitation. A value of 60 lb/ft^2 may be used where the stored waste is protected from precipitation and will not become saturated. Lesser values may be used if supported by measurement of actual pressures of the waste to be stored. If heavy equipment will be operated near the wall, an additional two feet of soil surcharge shall be considered in the wall analysis.

Tank covers shall be designed to withstand both dead and live loads. The live load values for covers contained in ASAE EP378.3, Floor and Suspended Loads on Agricultural Structures Due to Use, and in ASAE EP 393.2, Manure Storages, shall be the minimum used. The actual axle load for tank wagons having more than a 2,000 gallon capacity shall be used.

If the facility is to have a roof, snow and wind loads shall be as specified in ASAE EP288.5, Agricultural Building Snow and Wind Loads. If the facility is to serve as part of a foundation or support for a building, the total load shall be considered in the structural design.

Structural Design. The structural design shall consider all items that will influence the performance of the structure, including loading assumptions, material properties and construction quality. Design assumptions and construction requirements shall be indicated on standard plans.

Tanks may be designed with or without covers. Covers, beams, or braces that are integral to structural performance must be indicated on the construction drawings. The openings in covered tanks shall be designed to accommodate equipment for loading, agitating, and emptying. These openings shall be equipped with grills or secure covers for safety, and for odor and vector control.

All structures shall be underlain by free draining material or shall have a footing located below the anticipated frost depth. Fabricated structures shall be designed according to the criteria in the following references as appropriate:

- Steel: “Manual of Steel Construction”, American Institute of Steel Construction.
- Timber: “National Design Specifications for Wood Construction”, American Forest and Paper Association.
- Concrete: “Building Code Requirements for Reinforced Concrete, ACI 318”, American Concrete Institute.
- Masonry: “Building Code Requirements for Masonry Structures, ACI 530”, American Concrete Institute.

Slabs on Grade. Slab design shall consider the required performance and the critical applied loads along with both the subgrade material and material resistance of the concrete slab. Where applied point loads are minimal and liquid-tightness is not required, such as barnyard and feedlot slabs subject only to precipitation, and the subgrade is uniform and dense, the minimum slab thickness shall be 4 inches with a maximum joint spacing of 10 feet. Joint spacing can be increased if steel reinforcing is added based on subgrade drag theory.

For applications where liquid-tightness is required such as floor slabs of storage tanks, the minimum thickness for uniform foundations shall be 5 inches and shall contain distributed reinforcing steel. The required area of such reinforcing steel shall be based on subgrade drag theory as discussed in industry guidelines such as American Concrete Institute, ACI 360, “Design of Slabs-on-Grade”.

When heavy equipment loads are to be resisted and/or where a non-uniform foundation cannot be avoided, an appropriate design procedure incorporating a subgrade resistance parameter(s) such as ACI 360 shall be used.

CONSIDERATIONS

Waste storage facilities should be located as close to the source of waste and polluted runoff as practicable.

Non-polluted runoff should be excluded from the structure to the fullest extent possible except where its storage is advantageous to the operation of the agricultural waste management system.

Freeboard for waste storage tanks should be considered.

Solid/liquid separation of runoff or wastewater entering pond facilities should be considered to minimize the frequency of accumulated solids removal and to facilitate pumping and application of the stored waste.

Due consideration should be given to environmental concerns, economics, the overall waste management system plan, and safety and health factors.

Considerations for Minimizing the Potential for and Impacts of Sudden Breach of Embankment or Accidental Release from the Required Volume.

Features, safeguards, and/or management measures to minimize the risk of failure or accidental release, or to minimize or mitigate impact of this type of failure should be considered when any of the categories listed in Table 4 might be significantly affected.

The following should be considered either singly or in combination to minimize the potential of or the consequences of sudden breach of embankments when one or more of the potential impact categories listed in Table 4 may be significantly affected:

1. An auxiliary (emergency) spillway
2. Additional freeboard
3. Storage for wet year rather than normal year precipitation
4. Reinforced embankment -- such as, additional top width, flattened and/or armored downstream side slopes
5. Secondary containment

Table 4 - Potential Impact Categories from Breach of Embankment or Accidental Release

1. Surface water bodies -- perennial streams, lakes, wetlands, and estuaries
2. Critical habitat for threatened and endangered species.
3. Riparian areas
4. Farmstead, or other areas of habitation
5. Off-farm property
6. Historical and/or archaeological sites or structures that meet the eligibility criteria for listing in the National Register of Historical Places.

The following options should be considered to minimize the potential for accidental release from the required volume through gravity outlets when one or more of the potential impact categories listed in Table 4 may be significantly affected:

1. Outlet gate locks or locked gate housing
2. Secondary containment
3. Alarm system
4. Another means of emptying the required volume

Considerations for Minimizing the Potential of Waste Storage Pond Liner Failure.

Sites with categories listed in Table 5 should be avoided unless no reasonable alternative exists. Under those circumstances, consideration should be given to providing an additional measure of safety from pond seepage when any of the potential impact categories listed in Table 5 may be significantly affected.

Table 5 - Potential Impact Categories for Liner Failure

1. Any underlying aquifer is at a shallow depth and not confined
2. The vadose zone is rock
3. The aquifer is a domestic water supply or ecologically vital water supply
4. The site is located in an area of solutionized bedrock such as limestone or gypsum.

Should any of the potential impact categories listed in Table 5 be affected, consideration should be given to the following:

1. A clay liner designed in accordance with procedures of AWMFH Appendix 10D with a thickness and coefficient of permeability so that specific discharge is less than 1 x 10^{-6} cm/sec
2. A flexible membrane liner over a clay liner

3. A geosynthetic clay liner (GCL) flexible membrane liner
4. A concrete liner designed in accordance with slabs on grade criteria for fabricated structures requiring water tightness

Considerations for Improving Air Quality

To reduce emissions of greenhouse gases, ammonia, volatile organic compounds, and odor, other practices such as Anaerobic Digester – Ambient Temperature (365), Anaerobic Digester – Controlled Temperature (366), Waste Facility Cover (367), and Composting Facility (317) can be added to the waste management system.

Adjusting pH below 7 may reduce ammonia emissions from the waste storage facility but may increase odor when waste is surface applied (see Waste Utilization, 633).

Some fabric and organic covers have been shown to be effective in reducing odors.

PLANS AND SPECIFICATIONS

Plans and specifications shall be prepared in accordance with the criteria of this standard and shall describe the requirements for applying the practice to achieve its intended use.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be developed that is consistent with the purposes of the practice, its intended life, safety requirements, and the criteria for its design.

The plan shall contain the operational requirements for emptying the storage facility. This shall include the requirement that waste shall be removed from storage and utilized at locations, times, rates, and volume in accordance with the overall waste management system plan.

In addition, for ponds, the plan shall include an explanation of the permanent marker or recorder installed to indicate the maximum operating level.

The plan shall include a strategy for removal and disposition of waste with the least environmental damage during the normal storage period to the extent necessary to insure the pond’s safe operation. This strategy is for the removal of the contribution of unusual storm events that may cause the pond to fill to capacity prematurely with subsequent design inflow and usual precipitation prior to the end of the normal storage period.

Development of an emergency action plan should be considered for waste storage facilities where there is a potential for significant impact from breach or accidental release. The plan shall include site-specific provisions for emergency actions that will minimize these impacts.

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

COVER CROP

(Ac.)

CODE 340

DEFINITION

Crops including grasses, legumes and forbs for seasonal cover and other conservation purposes.

PURPOSE

- Reduce erosion from wind and water.
- Increase soil organic matter content.
- Capture and recycle or redistribute nutrients in the soil profile.
- Promote biological nitrogen fixation.
- Increase biodiversity.
- Weed suppression.
- Provide supplemental forage.
- Soil moisture management.
- Reduce particulate emissions into the atmosphere.
- Minimize and reduce soil compaction.

CONDITIONS WHERE PRACTICE APPLIES

On all lands requiring vegetative cover for natural resource protection and or improvement.

CRITERIA

General Criteria Applicable to All Purposes

Plant species, seedbed preparation, seeding rates, seeding dates, seeding depths, fertility requirements, and planting methods will be consistent with approved local criteria and site conditions.

The species selected will be compatible with other components of the cropping system.

Cover crops will be terminated by harvest, frost, mowing, tillage, crimping, and/or herbicides in preparation for the following crop.

Herbicides used with cover crops will be compatible with the following crop.

Avoid using plants that are on the state's noxious weed or invasive species lists.

Cover crop residue will not be burned.

Additional Criteria to Reduce Erosion from Wind and Water

Cover crop establishment, in conjunction with other practices, will be timed so that the soil will be adequately protected during the critical erosion period(s).

Plants selected for cover crops will have the physical characteristics necessary to provide adequate protection.

The amount of surface and/or canopy cover needed from the cover crop shall be determined using current erosion prediction technology.

Additional Criteria to Increase Soil Organic Matter Content

Cover crop species will be selected on the basis of producing high volumes of organic material and or root mass to maintain or improve soil organic matter.

The NRCS Soil Conditioning Index (SCI) procedure will be used to determine the amount of biomass required to have a positive trend in the soil organic matter subfactor.

The cover crop will be terminated as late as feasible to maximize plant biomass production, considering the time needed to prepare the field for planting the next crop and soil moisture depletion.

Additional Criteria to Capture and Recycle Excess Nutrients in the Soil Profile

Cover crops will be established and actively growing before the expected period(s) of nutrient leaching.

Cover crop species will be selected for their ability to take up large amounts of nutrients from the rooting profile of the soil.

When used to redistribute nutrients from deeper in the profile up to the surface layer, the cover crop will be killed in relation to the planting date of the following crop. If the objective is to best synchronize the use of cover crop as a green manure to cycle nutrients, factors such as the carbon/nitrogen ratios may be considered to kill early and have a faster mineralization of nutrients to match release of nutrient with uptake by following cash crop. A late kill may be used if the objectives are to use as a biocontrol and maximize the addition of organic matter. The right moment to kill the cover crop will depend on the specific rotation, weather and objectives.

Additional Criteria to Promote Biological Nitrogen Fixation

Only legumes or legume-grass mixtures will be established as cover crops.

The specific Rhizobium bacteria for the selected legume will either be present in the soil or the seed will be inoculated at the time of planting.

Additional Criteria to Increase Biodiversity

Cover crop species shall be selected that have different maturity dates, attract beneficial insects, increase soil biological diversity, serve as a trap crop for damaging insects, and/or provide food and cover for wildlife habitat management.

Additional Criteria for Weed Suppression

Species for the cover crop will be selected for their chemical or physical characteristics to suppress or compete with weeds.

Cover crops residues will be left on the soil surface to maximize allelopathic (chemical) and mulching (physical) effects.

For long-term weed suppression, reseeding annuals and/or biennial species can be used.

Additional Criteria to Provide Supplemental Forage

Species selected will have desired forage traits, be palatable to livestock, and not interfere with the production of the subsequent crop.

Forage provided by the cover crop may be hayed or grazed as long as sufficient biomass is left for resource protection.

Additional Criteria for Soil Moisture Management

Terminate growth of the cover crop sufficiently early to conserve soil moisture for the subsequent crop. Cover crops established for moisture conservation shall be left on the soil surface.

In areas of potential excess soil moisture, allow the cover crop to grow as long as possible to maximize soil moisture removal.

Additional Criteria to Reduce Particulate Emissions into the Atmosphere

Manage cover crops and their residues so that at least 80% ground cover is maintained during planting operations for the following crop.

Additional Criteria to Minimize and Reduce Soil Compaction

Select and manage cover crop species that will produce deep roots and large amounts of surface or root biomass to increase soil organic matter, improve soil structure and increase soil moisture through better infiltration.

CONSIDERATIONS

Plant cover crop in a timely matter to establish a good stand.

Maintain an actively growing cover crop as late as feasible to maximize plant growth, allowing time to prepare the field for the next crop and moisture depletion.

Use deep-rooted species to maximize nutrient recovery.

Use grasses to utilize more soil nitrogen, and legumes utilize both nitrogen and phosphorus.

Avoid cover crop species that harbor or carryover potentially damaging diseases or insects.

For most purposes for which cover crops are established, the combined canopy and surface cover is at nearly 90 percent or greater, and the above ground (dry weight) biomass production is at least 4,000 lbs/acre.

Cover crops may be used to improve site conditions for establishment of perennial species.

Use plant species that enhance bio-fuels opportunities.

Use plant species that enhance forage opportunities for pollinators.

PLANS AND SPECIFICATIONS

Plans and specifications will be prepared for the practice site. Plans for the establishment of cover crops shall include:

- Species or species of plants to be established.
- Seeding rates.
- Recommended seeding dates.
- Establishment procedure.
- Planned rates and timing of nutrient application.
- Planned dates for destroying cover crop.
- Other information pertinent to establishing and managing the cover crop.

Plans and specifications for the establishment and management of cover crops may be recorded in narrative form, on job sheets, or on other forms.

OPERATION AND MAINTENANCE

Control growth of the cover crop to reduce competition from volunteer plants and shading.

Control weeds in cover crops by mowing or by using other pest management techniques.

Control soil moisture depletion by selecting water efficient plant species and terminating the cover crop before excessive transpiration.

REFERENCES

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NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

WASTE TREATMENT LAGOON

(No.)

CODE 359

DEFINITION

A waste treatment impoundment made by constructing an embankment and/or excavating a pit or dugout.

PURPOSE

To biologically treat waste, such as manure and wastewater, and thereby reduce pollution potential by serving as a treatment component of a waste management system.

CONDITIONS WHERE PRACTICE APPLIES

- Where the lagoon is a component of a planned agricultural waste management system.
- Where treatment is needed for organic wastes generated by agricultural production or processing.
- On any site where the lagoon can be constructed, operated and maintained without polluting air or water resources.
- To lagoons utilizing embankments with an effective height of 35 feet or less where damage resulting from failure would be limited to damage of farm buildings, agricultural land, or township and country roads.

CRITERIA

General Criteria for All Lagoons

Laws and Regulations. All Federal, state, and local laws, rules, and regulations governing the construction and use of waste treatment lagoons must be followed.

Location. To minimize the potential for contamination of streams, lagoons should be located outside of floodplains. However, if site restrictions require location within a floodplain, they shall be protected from inundation or damage from a 25-year flood event, or larger if required by laws, rules, and regulations. Lagoons shall be located so the potential impacts from breach of embankment, accidental release, and liner failure are minimized; and separation distances are such that prevailing winds and landscape elements such as building arrangement, landforms, and vegetation minimize odors and protect aesthetic values.

Lagoons should be located so they have as little drainage area as possible. If a lagoon has a drainage area, the volume of normal runoff during the treatment period and 25-year, 24-hour storm event runoff shall be included in the required volume of the lagoon.

Soils and Foundation. The lagoon shall be located in soils with an acceptable permeability that meets all applicable regulations, or the lagoon shall be lined. Information and guidance on controlling seepage from waste impoundments can be found in the Agricultural Waste Management Field Handbook (AWMFH), Appendix 10D.

The lagoon shall have a bottom elevation that is a minimum of 2 feet above the seasonal high water table unless special design features are incorporated that address buoyant forces, lagoon seepage rates, and non-encroachment of the water table by contaminants. The water table may be lowered by use of perimeter drains to meet this requirement.

Flexible Membranes. Flexible membrane liners shall meet or exceed the requirements of flexible membrane linings specified in Pond Sealing or Lining, Flexible Membrane (code 521A).

Required Volume. The lagoon shall have the capability of storing the following volumes:

- Volume of accumulated sludge for the period between sludge removal events;
- Minimum treatment volume (anaerobic lagoons only);
- Volume of manure, wastewater, and other wastes accumulated during the treatment period;
- Depth of normal precipitation less evaporation on the surface area (at the required volume level) of the lagoon during the treatment period;
- Depth of the 25-year, 24-hour storm precipitation on the surface area (at the required volume level) of the lagoon.

Treatment Period. The treatment period is the detention time between drawdown events. It shall be the greater of either 60 days; or the time required to provide the storage that allows environmentally safe utilization of waste considering the climate, crops, soil, and equipment requirements; or as required by local, state, and Federal regulations.

Waste Loading. Daily waste loading shall be based on the maximum daily loading considering all waste sources that will be treated by the lagoon. Reliable local information or laboratory test data should be used if available. If local information is not available Chapter 4 of the AWMFH may be used for estimating waste loading.

Embankments. The minimum elevation of the top of the settled embankment shall be 1 foot above the lagoon's required volume. This height shall be increased by the amount needed to ensure that the top elevation will be maintained after settlement. This increase shall be not less than 5 percent. The minimum top widths are shown in Table 1. The combined side slopes of the settled embankment shall not be less than 5 horizontal to 1 vertical, and neither slope shall be steeper than 2 horizontal to 1 vertical unless provisions are made to provide stability.

Table 1 – Minimum Top Widths

Total embankment Height, ft.	Top Width, ft.
15 or less	8
15 – 20	10
20 – 25	12
25 – 30	14
30 – 35	15

Excavations. Unless supported by a soil investigation, excavated side slopes shall be no steeper than 2 horizontal to 1 vertical.

Inlet. Inlets shall be of any permanent type designed to resist corrosion, plugging, freeze damage, and ultraviolet ray deterioration, while incorporating erosion protection as necessary. Inlets shall be provided with a water-sealed trap and vent, or similar device if there is a potential, based on design configuration, for gases to enter buildings or other confined spaces.

Outlet. Outlets from the required volume shall be designed to resist corrosion and plugging. No outlet shall automatically discharge from the required volume of the lagoon.

Facility for Drawdown. Measures that facilitate safe drawdown of the liquid level in the lagoon shall be provided. Access areas and ramps used to withdraw waste shall have slopes that facilitate a safe operating environment. Docks, wells, pumping platforms, retaining walls, etc. shall permit drawdown without causing erosion or damage to liners.

Sludge Removal. Provision shall be made for periodic removal of accumulated sludge to preserve the treatment capacity of the lagoon.

Erosion Protection. Embankments and disturbed areas surrounding the lagoon shall be treated to control erosion. This includes the inside slopes of the lagoon as needed to protect the integrity of the liner.

Safety. Design shall include appropriate safety features to minimize the hazards of the lagoon. The lagoon shall be fenced around the perimeter and warning signs posted to prevent children and others from using it for other than its intended purpose.

Additional Criteria for Anaerobic Lagoons

Loading Rate. Anaerobic lagoons shall be designed to have a minimum treatment volume based on Volatile Solids (VS) loading per unit of volume. The maximum loading rate shall be as indicated in AWMFH Figure 10-22 or according to state regulatory requirements, whichever is more stringent.

Operating Levels. The maximum operating level shall be the lagoon level that provides the required volume less the 25-year, 24-hour storm event precipitation on the surface of the lagoon. The maximum drawdown level shall be the lagoon level that provides volume for the required minimum treatment volume plus the volume of accumulated sludge between sludge removal events. Permanent markers shall be installed at these elevations. The proper operating range of the lagoon is above the maximum drawdown level and below the maximum operating level. These markers shall be referenced and described in the O&M plan.

Depth Requirements. The minimum depth at maximum drawdown shall be 6 feet. If subsurface conditions prevent practicable construction to accommodate the minimum depth at maximum drawdown, a lesser depth may be used, if the volume requirements are met.

Additional Criteria for Naturally Aerobic Lagoons

Loading Rate. Naturally aerobic lagoons shall be designed to have a minimum treatment surface area as determined on the basis of daily BOD_5 loading per unit of lagoon surface. The required minimum treatment surface area shall be the surface area at maximum drawdown. The maximum loading rate shall be as indicated by AWMFH Figure 10-25 or according to state regulatory requirements, whichever is more stringent.

Operating Levels. The maximum operating level shall be the lagoon level that provides the required volume less the 25-year, 24-hour storm event on the lagoon surface. The maximum drawdown level shall be the lagoon level that provides volume for the volume of manure, wastewater, and clean water accumulated during the treatment period plus the volume of accumulated sludge between sludge removal events. Permanent markers shall be installed at these elevations. The proper operating range of the lagoon is above the maximum drawdown level and below the maximum operating level. These markers shall be referenced and described in the O&M plan.

Depth Requirements. The minimum depth at maximum drawdown shall be 2 feet. The maximum liquid level shall be 5 feet.

Additional Criteria for Mechanically Aerated Lagoons

Loading Rate. Mechanically aerated waste treatment lagoons' treatment function shall be designed on the basis of daily BOD_5 loading and aeration equipment manufacturer's performance data for oxygen transfer and mixing. Aeration equipment shall provide a minimum of 1 pound of oxygen for each pound of daily BOD_5 loading.

Operating Levels. The maximum operating level shall be the lagoon level that provides the required lagoon volume less the 25-year, 24-hour storm event precipitation and shall not exceed the site and aeration equipment limitations. A permanent marker or recorder shall be installed at this elevation. The proper operating range of the lagoon is below this elevation and above the minimum treatment elevation established by the manufacturer of the aeration equipment. This marker shall be referenced and described in the O&M plan.

CONSIDERATIONS

General

Lagoons should be located as close to the source of waste as possible.

Solid/liquid separation treatment should be considered between the waste source and the lagoon to reduce loading.

The configuration of the lagoon should be based on the method of sludge removal and method of sealing.

Due consideration should be given to economics, the overall waste management system plan, and safety and health factors.

Considerations for Minimizing the Potential for and Impacts of Sudden Breach of Embankment or Accidental Release from the Required Volume

Features, safeguards, and/or management measures to minimize the risk of embankment failure or accidental release, or to minimize or mitigate impact of this type of failure should be considered when any of the categories listed in Table 2 might be significantly affected.

The following should be considered either singly or in combination to minimize the potential of or the consequences of sudden breach of embankments when one or more of the potential impact categories listed in Table 2 may be significantly affected:

- An auxiliary (emergency) spillway
- Additional freeboard
- Storage volume for the wet year rather than normal year precipitation
- Reinforced embankment -- such as, additional top width, flattened and/or armored downstream side slopes
- Secondary containment
- Water level indicators or recorders

Table 2- Potential Impact Categories from Breach of Embankment or Accidental Release

1. Surface water bodies -- perennial streams, lakes, wetlands, and estuaries
2. Critical habitat for threatened and endangered species
3. Riparian areas
4. Farmstead, or other areas of habitation
5. Off-farm property
6. Historical and/or archaeological sites or structures that meet the eligibility criteria for listing in the National Register of Historical Places

The following should be considered to minimize the potential for accidental release from the required volume through gravity outlets when one or more of the potential impact categories listed in Table 2 may be significantly affected:

- Outlet gate locks or locked gate housing
- Secondary containment
- Alarm system
- Another means of emptying the required volume

Considerations for Minimizing the Potential of Lagoon Liner Seepage

Consideration should be given to providing an additional measure of safety from lagoon seepage when any of the potential impact categories listed in Table 3 may be affected.

Table 3 - Potential Impact Categories for Liner Seepage

1. Any underlying aquifer is at a shallow depth and not confined
2. The vadose zone is rock
3. The aquifer is a domestic water supply or ecologically vital water supply
4. The site is located in an area of carbonate rock (limestone or dolomite)

Should any of the potential impact categories listed in Table 3 be affected, consideration should be given to the following:

- A clay liner designed in accordance with procedures of AWMFH, Appendix 10D with a thickness and coefficient of permeability so that specific discharge is less than 1×10^{-6} cm/sec.
- A flexible membrane liner
- A geosynthetic clay liner (GCL) flexible membrane liner
- A concrete liner designed in accordance with slabs on grade criteria, Waste Storage Facility (313), for fabricated structures requiring water tightness.

Considerations for Improving Air Quality

To reduce emissions of greenhouse gases, ammonia, volatile organic compounds, and odor:

- Reduce the recommended loading rate for anaerobic lagoons to one-half the values given in AWMFH Figure 10-22.

- Use additional practices such as Anaerobic Digester – Ambient Temperature (365), Anaerobic Digester – Controlled Temperature (366), Waste Facility Cover (367) and Composting Facilities (code 317) in the waste management system.
- Liquid/solid separation prior to discharge to lagoon will reduce volatile solids (VS) loading resulting in reduced gaseous emissions and odors. Composting of solids will further reduce emissions.
- Design lagoons to be naturally aerobic or to allow mechanical aeration.

Adjusting pH below 7 may reduce ammonia emissions from the lagoon but may increase odor when waste is surface applied (See Waste Utilization, code 633).

PLANS AND SPECIFICATIONS

Plans and specifications shall be prepared in accordance with the criteria of this standard and shall describe the requirements for applying the practice to achieve its intended use.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be developed that is consistent with the purposes of the practice, its intended life, safety requirements, and the criteria for design. The plan shall contain the operational requirements for drawdown and the role of permanent markers. This shall include the requirement that waste be removed from the lagoon and utilized at locations, times, rates, and volume in accordance with the overall waste management system plan. In addition, the plan shall include a strategy for removal and disposition of waste with least environmental damage during the normal treatment period to the extent necessary to insure the lagoon’s safe operation. This strategy shall also include the removal of unusual storm events.

Development of an emergency action plan should be considered for lagoons where there is a potential for significant impact from breach or accidental release. The plan shall include site-specific provisions for emergency actions that will minimize these impacts.

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

DIVERSION

(Ft.)

CODE 362

DEFINITION

A channel constructed across the slope generally with a supporting ridge on the lower side.

PURPOSE

This practice may be applied as part of a resource management system to support one or more of the following purposes.

- Break up concentrations of water on long slopes, on undulating land surfaces, and on land that is generally considered too flat or irregular for terracing.
- Divert water away from farmsteads, agricultural waste systems, and other improvements.
- Collect or direct water for water-spreading or water-harvesting systems.
- Increase or decrease the drainage area above ponds.
- Protect terrace systems by diverting water from the top terrace where topography, land use, or land ownership prevents terracing the land above.
- Intercept surface and shallow subsurface flow.
- Reduce runoff damages from upland runoff.
- Reduce erosion and runoff on urban or developing areas and at construction or mining sites.
- Divert water away from active gullies or critically eroding areas.
- Supplement water management on conservation cropping or stripcropping systems.

CONDITIONS WHERE PRACTICE APPLIES

This applies to all cropland and other land uses where surface runoff water control and or management is needed. It also applies where soils and topography are such that the diversion can be constructed and a suitable outlet is available or can be provided.

CRITERIA

Capacity. Diversions as temporary measures, with an expected life span of less than 2 years, shall have a minimum capacity for the peak discharge from the 2-year frequency, 24-hour duration storm.

Diversions that protect agricultural land shall have a minimum capacity for the peak discharge from a 10-year frequency, 24 -hour duration storm.

Diversions designed to protect areas such as urban areas, buildings, roads, and animal waste management systems shall have a minimum capacity for the peak discharge from a storm frequency consistent with the hazard involved but not less than a 25-year frequency, 24-hour duration storm. Freeboard shall be not less than 0.3 ft.

Design depth is the channel storm flow depth plus freeboard, where required.

Cross section. The channel may be parabolic, V-shaped, or trapezoidal. The diversion shall be designed to have stable side slopes.

The ridge shall have a minimum top width of 4 feet at the design depth. The ridge height shall include an adequate settlement factor.

The ridge top width may be 3 feet at the design depth for diversions with less than 10 acres drainage area above cropland, pastureland, or woodland.

The top of the constructed ridge at any point shall not be lower than the design depth plus the specified overfill for settlement.

The design depth at culvert crossings shall be the culvert headwater depth for the design storm plus freeboard.

Grade and velocity. Channel grades may be uniform or variable. Channel velocity shall not exceed that considered non-erosive for the soil and planned vegetation or lining.

Maximum channel velocities for permanently vegetated channels shall not exceed those recommended in the NRCS Engineering Field Handbook (EFH) Part 650, Chapter 7, or Agricultural Research Service (ARS) Agricultural Handbook 667, Stability Design of Grass-Lined Open Channels (Sept. 1987).

When the capacity is determined by the formula $Q = A V$ and the V is calculated by using Manning's equation, the highest expected value of "n" shall be used.

Location. The outlet conditions, topography, land use, cultural operations, cultural resources, and soil type shall determine the location of the diversion.

Protection against sedimentation. Diversions normally should not be used below high sediment producing areas. When they are, a practice or combination of practices needed to prevent damaging accumulations of sediment in the channel shall be installed. This may include practices such as land treatment erosion control practices, cultural or tillage practices, vegetated filter strip, or structural measures. Install practices in conjunction with or before the diversion construction.

If movement of sediment into the channel is a problem, the design shall include extra capacity for sediment or periodic removal as outlined in the operation and maintenance plan.

Outlets. Each diversion must have a safe and stable outlet with adequate capacity. The outlet may be a grassed waterway, a lined waterway, a vegetated or paved area, a grade stabilization structure, an underground outlet, a stable watercourse, a sediment basin, or a combination of these practices. The outlet must convey runoff to a point where outflow will not cause damage. Vegetative outlets shall be installed and established before diversion construction to insure establishment of vegetative cover in the outlet channel.

The release rate of an under ground outlet, when combined with storage, shall be such that the design storm runoff will not overtop the diversion ridge.

The design depth of the water surface in the diversion shall not be lower than the design elevation of the water surface in the outlet at their junction when both are operating at design flow.

Vegetation. Disturbed areas that are not to be cultivated shall be seeded as soon as practicable after construction.

Lining. If the soils or climatic conditions preclude the use of vegetation for erosion protection, non-vegetative linings such as gravel, rock riprap, cellular block, or other approved manufactured lining systems may be used.

CONSIDERATIONS

A diversion in a cultivated field should be aligned and spaced from other structures or practices to permit use of modern farming equipment. The side slope lengths should sized to fit equipment widths when cropped.

At non-cropland sites, consider planting native vegetation in areas disturbed due to construction.

Maximize wetland functions and values with the diversion design. Minimize adverse effects to existing functions and values. Diversion of upland water to prevent entry into a wetland may convert a wetland by changing the hydrology. Any construction activities should minimize disturbance to wildlife habitat. Opportunities should be explored to restore and improve wildlife habitat, including habitat for threatened, endangered, and other species of concern.

On landforms where archeological sites are likely to occur, use techniques to maximize identification of such sites prior to planning, design, and construction.

PLANS AND SPECIFICATIONS

Plans and specification for installing diversions shall be in keeping with this standard and shall describe the requirements for applying the practice to achieve its intended purpose.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be prepared for use by the client. The plan shall include specific instructions for maintaining diversion capacity, storage, ridge height, and outlets.

The minimum requirements to be addressed in the operation and maintenance plan are:

1. Provide periodic inspections, especially immediately following significant storms.
2. Promptly repair or replace damaged components of the diversion as necessary.
3. Maintain diversion capacity, ridge height, and outlet elevations especially if high sediment yielding areas are in the drainage area above the diversion. Establish necessary clean-out requirements.
4. Each inlet for underground outlets must be kept clean and sediment buildup redistributed so that the inlet is at the lowest point. Inlets damaged by farm machinery must be replaced or repaired immediately.
5. Redistribute sediment as necessary to maintain the capacity of the diversion.
6. Vegetation shall be maintained and trees and brush controlled by hand, chemical and/or mechanical means.
7. Keep machinery away from steep sloped ridges. Keep equipment operators informed of all potential hazards.

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

FENCE

(Ft.)

CODE 382

DEFINITION

A constructed barrier to animals or people.

PURPOSE

This practice facilitates the accomplishment of conservation objectives by providing a means to control movement of animals and people, including vehicles.

CONDITIONS WHERE PRACTICE APPLIES

This practice may be applied on any area where management of animal or human movement is needed.

CRITERIA

General Criteria Applicable to All Purposes

Fencing materials, type and design of fence installed shall be of a high quality and durability. The type and design of fence installed will meet the management objectives and site challenges. Based on need, fences may be permanent, portable, or temporary.

Fences shall be positioned to facilitate management requirements. Ingress/egress features such as gates and cattle guards shall be planned. The fence design and installation should have the life expectancy appropriate for management objectives and shall follow all federal, state and local laws and regulations.

Height, size, spacing and type of materials used will provide the desired control, life expectancy, and management of animals and people of concern.

CONSIDERATIONS

The fence design and location should consider: topography, soil properties, livestock management and safety, livestock trailing, wildlife class and movement, location and adequacy of water facilities, development of potential grazing systems, human access and safety, landscape aesthetics, erosion problems, moisture conditions, flooding potential, stream crossings, and durability of materials. When appropriate, natural barriers should be utilized instead of fencing.

Where applicable, cleared rights-of-way may be established which would facilitate fence construction and maintenance. Avoid clearing of vegetation during the nesting season for migratory birds.

Fences across gullies, canyons or streams may require special bracing, designs or approaches.

Fence design and location should consider ease of access for construction, repair and maintenance.

Fence construction requiring the removal of existing unusable fence should provide for the proper disposal of scrap materials to prevent harm to animals, people and equipment.

PLANS AND SPECIFICATIONS

Plans and specifications are to be prepared for all fence types, installations and specific sites. Requirements for applying the practice to achieve all of its intended purposes shall be described.

OPERATION AND MAINTENANCE

Regular inspection of fences should be part of an ongoing maintenance program. Inspection of fences after storms and other disturbance events is necessary to insure the continued proper function of the fence. Maintenance and repairs will be performed in a timely manner as needed, including tree/limb removal and water gap replacement.

Remove and properly discard all broken fencing material and hardware. All necessary precautions should be taken to ensure the safety of construction and maintenance crews.

REFERENCES

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NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

ACCESS CONTROL

(Ac.)

CODE 472

DEFINITION

The temporary or permanent exclusion of animals, people, vehicles, and/or equipment from an area.

PURPOSE

Achieve and maintain desired resource conditions by monitoring and managing the intensity of use by animals, people, vehicles, and/or equipment in coordination with the application schedule of practices, measures and activities specified in the conservation plan.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies on all land uses.

CRITERIA

Use-regulating activities (e.g., posting of signs, patrolling, gates, fences and other barriers, permits) shall achieve the intended purpose and include mitigating associated resource concerns to acceptable levels during their installation, operation, and maintenance. Activities will complement the application schedule and life span of other practices specified in the conservation plan.

Each activity or measure will identify the entity to be monitored and regulated (animals, people, vehicles and/or equipment) and specify the intent, intensity, amounts, and timing of exclusion by that entity. Activities may involve temporary to permanent exclusion of one to all entities.

Placement, location, dimensions and materials (e.g., signs, gates), and frequency of use (e.g., continuous, specific season, or specific dates) shall be described for each activity including monitoring frequency.

CONSIDERATIONS

Even though usage of the area is monitored and controlled, the land manager and/or tenant should be advised about emergency preparedness agencies and related information, e.g., the local fire/wildfire control agency and pumper truck water sources on or near the area. Information should be designated initially and re-designated annually.

PLANS AND SPECIFICATIONS

Specifications for applying this practice shall be prepared for each area and recorded using approved specification sheets, job sheets, and narrative statements in the conservation plan, or other acceptable documentation.

OPERATION AND MAINTENANCE

Monitoring of the effectiveness of use-regulating activities will be performed routinely and at least annually with changes made to specifications and operation and maintenance requirements as necessary.

Modifications to activities and use of measures are allowed temporarily to accommodate emergency-level contingencies such as wildfire, hurricane, drought, or flood as long as resource conditions are maintained.

REFERENCES

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NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

DRAINAGE WATER MANAGEMENT

(Ac.)

CODE 554

DEFINITION

The process of managing water discharges from surface and/or subsurface agricultural drainage systems.

PURPOSE

The purpose of this practice is:

- Reduce nutrient, pathogen, and/or pesticide loading from drainage systems into downstream receiving waters
- Improve productivity, health, and vigor of plants
- Reduce oxidation of organic matter in soils
- Reduce wind erosion or particulate matter (dust) emissions
- Provide seasonal wildlife habitat

CONDITIONS WHERE PRACTICE APPLIES

This practice is applicable to agricultural lands with surface or subsurface agricultural drainage systems that are adapted to allow management of drainage discharges.

The practice may not apply where saline or sodic soil conditions require special considerations.

This practice does not apply to the management of irrigation water supplied through a subsurface drainage system. For that purpose, use NRCS Conservation Practice Standard, Irrigation Water Management (449).

CRITERIA

General Criteria Applicable to All Purposes

The management of gravity drained outlets shall be accomplished by adjusting the elevation of the drainage outlet.

The management of pumped drainage outlets shall be accomplished by raising the on-off elevations for pump cycling.

Structures and pumps shall be located where they are convenient to operate and maintain.

Raising the outlet elevation of the flowing drain shall result in an elevated free water surface within the soil profile.

When operated in free drainage mode, water control structures shall not restrict the flow of the drainage system.

Drainage discharges and water levels shall be managed in a manner that does not cause adverse impacts to other properties or drainage systems.

Release of water from control structures shall not allow flow velocities in surface drainage system components to exceed acceptable velocities prescribed by NRCS Conservation Practice Standard, Surface Drainage, Main or Lateral (608).

Release of water from flow control structures shall not allow flow velocities in subsurface drains to exceed velocities prescribed by NRCS Conservation Practice Standard, Subsurface Drain (606).

Additional Criteria to Reduce Nutrient, Pathogen, and/or Pesticide Loading

During non-cropped periods, the system shall be in managed drainage mode within 30 days after the season's final field operation, until at least 30 days before commencement of the next season's field operations, except during system maintenance periods or to provide trafficability when field operations are necessary.

The drain outlet shall be raised prior to and during liquid manure applications to prevent direct leakage of manure into drainage pipes through soil macro pores (cracks, worm holes, root channels).

Manure applications shall be in accordance with NRCS Conservation Practice Standards, Nutrient Management (590) and Waste Utilization (633).

Additional Criteria to Improve Productivity, Health, and Vigor of Plants

When managing drainage outflow to maintain water in the soil profile for use by crops or other vegetation, the elevation at which the outlet is set shall be based on root depth and soil type.

If using this practice to control rodents, apply in conjunction with NRCS Conservation Practice Standard, Pest Management (595).

Additional Criteria to Reduce Oxidation of Organic Matter in Soils

Drainage beyond that necessary to provide an adequate root zone for the crop shall be minimized.

To reduce oxidation of organic matter, the outlet elevation shall be set to enable the water table to rise to the ground surface, or to a designated maximum elevation, for sufficient time to create anaerobic soil conditions. The implementation of this practice must result in a reduced average annual thickness of the aerated layer of the soil.

Additional Criteria to Reduce Wind Erosion or Particulate Matter (Dust) Emissions

When the water table is at the design elevation, the system shall provide a moist field soil surface, either by ponding or through capillary action from the elevated water table.

Additional Criteria to Provide Seasonal Wildlife Habitat

During the non-cropped season, the elevation of the drainage outlet shall be managed in a manner consistent with a habitat evaluation procedure that addresses targeted species.

CONSIDERATIONS

In-field water table elevation monitoring devices can be used to improve water table management.

Reducing mineralization of organic soils may decrease the release of soluble phosphorus, but water table management may increase the release of soluble phosphorus from mineral soils.

Elevated water tables may increase the runoff portion of outflow from fields. Consider conservation measures that control sediment loss and associated nutrient discharge to waterways.

Elevate the drainage outlet for subsurface drains during and after manure applications to decrease potential for nutrient and pathogen loading to receiving waters.

Consider manure application setbacks from streams, flowing drain lines, and sinkholes, to reduce risk of contamination.

To maintain proper root zone development and aeration, downward adjustments of the drainage outlet control elevation may be necessary, especially following significant rainfall events.

Monitoring of root zone development may be necessary if the free water surface in the soil profile is raised during the growing season.

PLANS AND SPECIFICATIONS

Plans and specifications shall be prepared in accordance with the criteria of this standard as necessary and shall describe the requirements for applying the practice to achieve its intended purpose(s).

OPERATION AND MAINTENANCE

An Operation and Maintenance plan shall be provided that identifies the intended purpose of the practice, practice life safety requirements, and water table elevations and periods of operation necessary to meet the intended purpose. If in-field water table observation points are not used, the relationship of the control elevation settings relative to critical field water table depths shall be provided in the operation plan.

The Operation and Maintenance Plan shall include instructions for operation and maintenance of critical components of the drainage management system, including instructions necessary to maintain flow velocities within allowable limits when lowering water tables.

To prevent leakage of liquid manure applications into drain pipes, the plan shall specify the elevation of the raised drainage outlet and the number of days prior to and after the application that a raised outlet elevation is to be maintained.

Replace warped flashboards that cause structure leakage.

REFERENCES

USDA, NRCS. 2001. National Engineering Handbook, Part 624, Sec. 16, Drainage of agricultural land.

USDA, NRCS. 2001. National Engineering Handbook, Part 650, Engineering Field Handbook, Chapter 14, Water management (Drainage).

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

ROOF RUNOFF STRUCTURE

(No.)

CODE 558

DEFINITION

Structures that collect, control, and transport precipitation from roofs.

PURPOSE

To improve water quality, reduce soil erosion, increase infiltration, protect structures, and/or increase water quantity.

CONDITIONS WHERE PRACTICE APPLIES

Where roof runoff from precipitation needs to be:

- diverted away from structures or contaminated areas;
- collected, controlled, and transported to a stable outlet; or
- collected and used for other purposes such as irrigation or animal watering facility.

CRITERIA

General Criteria Applicable to All Purposes

The minimum design capacity for roof runoff structures shall be a 10-year storm frequency, 5-minute rainfall precipitation event, except where excluding roof runoff from manure management facilities. In that case, a 25-year frequency, 5-minute precipitation event shall be used to design roof runoff structures (Refer to Agricultural Waste Management Field Handbook, NEH Part 651 Chapter 10 Appendix 10B). When gutters are used, the capacity of the downspout(s) must equal or exceed the gutter flow rate.

Runoff may empty into surface or underground outlets, or onto the ground surface. Surface and underground outlets shall be sized to ensure adequate design capacity and shall provide for clean-out as appropriate. When runoff from roofs empties onto the ground surface, a stable outlet shall be provided. When runoff is conveyed through a gutter and downspout system, an elbow and energy dissipation device shall be placed at the end of the downspout to provide a stable outlet and direct water away from the building.

Surface or ground outlets such as rock pads, rock filled trenches with subsurface drains, concrete and other erosion-resistant pads, or preformed channels may be used, particularly where snow and ice are a significant load component on roofs.

In regions where snow and ice will accumulate on roofs, guards and sufficient supports to withstand the anticipated design load shall be included.

Roof runoff structures shall be made of durable materials with a minimum design life of ten years. Roof gutters and downspouts may be made of aluminum, galvanized steel, wood, or plastic. Aluminum gutters and downspouts shall have a minimum nominal thickness of 0.027 inches and 0.020 inches, respectively. Galvanized steel gutters and downspouts shall be a minimum 28 gauge. Wood shall be clear and free of knots. Wood may be redwood, cedar, cypress, or other species that has the desired longevity. Plastics shall contain ultraviolet stabilizers. Dissimilar metals shall not be in contact with each other.

Rock-filled trenches and pads shall consist of poorly graded rock (all rock fragments approximately the same size) and be free of appreciable amounts of sand and/or soil particles. Crushed limestone shall not be used for backfill material unless it has been washed. Subsurface drains or outlets shall meet the material requirements of the applicable NRCS conservation practice standard.

Concrete appurtenances used shall meet the requirements of NRCS NEH Part 642, Chapter 2, Construction Specification 32 Structure Concrete.

Roof runoff structures shall be protected from damage by livestock and equipment.

Additional Criteria to Increase Infiltration

Runoff shall be routed onto pervious landscaped areas (e.g., lawns, mass planting areas, infiltration trenches, and natural areas) to increase infiltration of runoff. These areas shall be capable of infiltrating the runoff in such a way that replenishes soil moisture without adversely affecting the desired plant species.

Additional Criteria to Protect Structures

Runoff shall be directed away from structure foundations to avoid wetness and hydraulic loading on the foundation.

On expansive soils or bedrock, downspout extensions shall be used to discharge runoff a minimum of five (5) feet from the structure.

The discharge area for runoff must slope away from the protected structure.

Additional Criteria to Increase Water Quantity

Storage structures for non-potable purposes such as irrigation water shall be designed in accordance with NRCS conservation practice standards, as appropriate.

Potable water storage structures shall be constructed of materials and in a manner that will not increase the contamination of the stored water. Roof runoff collected and stored for potable uses must be treated prior to consumption and shall be tested periodically to assure that adequate quality is maintained for human consumption.

CONSIDERATIONS

Avoid discharging outlets near wells and sinkholes.

Some designs may provide secondary benefits, e.g. rock pads may also reduce rodent problems around livestock and poultry barns.

PLANS AND SPECIFICATIONS

The plans and specifications shall show the location, spacing, size, and grade of all gutters and downspouts and type and quality of material to be used. Plans and specifications for other practices essential to the proper functioning of the roof runoff structure, such as underground outlet, shall be included.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be developed that is consistent with the purposes of the practice, its intended life, safety requirements, and the criteria for the design. The plan shall contain, but not be limited to, the following provisions:

- Keep roof runoff structures clean and free of obstructions that reduce flow.
- Make regular inspections and perform repair maintenance as needed to ensure proper functioning of the roof runoff structures.

REFERENCES

USDA-NRCS. 1999. National Engineering Handbook, Part 651, Agricultural Waste Management Field Handbook.

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

NUTRIENT MANAGEMENT

(Ac.)

CODE 590

DEFINITION

Managing the amount, source, placement, form and timing of the application of plant nutrients and soil amendments.

PURPOSE

- To budget and supply nutrients for plant production.
- To properly utilize manure or organic by-products as a plant nutrient source.
- To minimize agricultural nonpoint source pollution of surface and ground water resources.
- To protect air quality by reducing nitrogen emissions (ammonia and NO_x compounds) and the formation of atmospheric particulates.
- To maintain or improve the physical, chemical and biological condition of soil.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies to all lands where plant nutrients and soil amendments are applied.

CRITERIA

General Criteria Applicable to All Purposes

A nutrient budget for nitrogen, phosphorus, and potassium shall be developed that considers all potential sources of nutrients including, but not limited to animal manure and organic by-products, waste water, commercial fertilizer, crop residues, legume credits, and irrigation water.

Realistic yield goals shall be established based on soil productivity information, historical yield data, climatic conditions, level of management and/or local research on similar soil, cropping systems, and soil and manure/organic by-products tests.

For new crops or varieties, industry yield recommendations may be used until documented yield information is available.

Plans for nutrient management shall specify the source, amount, timing and method of application of nutrients on each field to achieve realistic production goals, while minimizing movement of nutrients and other potential contaminants to surface and/or ground waters.

Areas contained within established minimum application setbacks (e.g., sinkholes, wells, gullies, ditches, surface inlets or rapidly permeable soil areas) shall not receive direct application of nutrients.

The amount of nutrients lost to erosion, runoff, irrigation and drainage, shall be addressed, as needed.

Soil and Tissue Sampling and Laboratory Analyses (Testing). Nutrient planning shall be based on current soil and tissue (where used as a supplement) test results developed in accordance with Land Grant University guidance, or industry practice if recognized by the Land Grant University. Current soil tests are those that are no older than five years.

Soil and tissue samples shall be collected and prepared according to the Land Grant University guidance or standard industry practice. Soil and tissue test analyses shall be performed by laboratories that are accepted in one or more of the following:

- Laboratories successfully meeting the requirements and performance standards of the North American Proficiency Testing Program (NAPT) under the auspices of the Soil Science Society of America, or

- State recognized program that considers laboratory performance and proficiency to assure accuracy of soil test results.

Soil and tissue testing shall include analyses for any nutrients for which specific information is needed to develop the nutrient plan. Request analyses pertinent to monitoring or amending the annual nutrient budget, e.g. pH, electrical conductivity (EC), soil organic matter, nitrogen, phosphorus and potassium.

Nutrient Application Rates. Soil amendments shall be applied, as needed, to adjust soil pH to an adequate level for crop nutrient availability and utilization.

Recommended nutrient application rates shall be based on Land Grant University recommendations (and/or industry practice when recognized by the university) that consider current soil test results, realistic yield goals and management capabilities. If the Land Grant University does not provide specific recommendations, application shall be based on realistic yield goals and associated plant nutrient uptake rates.

The planned rates of nutrient application, as documented in the nutrient budget, shall be determined based on the following guidance:

- Nitrogen Application **-** Planned nitrogen application rates shall match the recommended rates as closely as possible, except when manure or organic by-products are a source of nutrients. When manure or organic by-products are a source of nutrients, see “Additional Criteria” below.

- Phosphorus Application **-** Planned phosphorus application rates shall match the recommended rates as closely as possible, except when manure or organic by-products are sources of nutrients. When manure or organic by-products are a source of nutrients, see “Additional Criteria” below.

- Potassium Application - Potassium shall not be applied in situations in which excess (greater than soil test potassium recommendation) causes unacceptable nutrient imbalances in crops or forages. When forage quality is an issue associated with excess potassium application, state standards shall be used to set forage quality guidelines.

- Other Plant Nutrients - The planned rates of application of other nutrients shall be consistent with Land Grant University guidance or industry practice if recognized by the Land Grant University in the state.

- Starter Fertilizers - When starter fertilizers are used, they shall be included in the overall nutrient budget, and applied in accordance with Land Grant University recommendations, or industry practice if recognized by the Land Grant University within the state.

Nutrient Application Timing. Timing and method of nutrient application (particularly nitrogen) shall correspond as closely as possible with plant nutrient uptake characteristics, while considering cropping system limitations, weather and climatic conditions, risk assessment tools (e.g., leaching index, P index) and field accessibility.

Nutrient Application Methods. Application methods to reduce the risk of nutrient transport to surface and ground water, or into the atmosphere shall be employed.

To minimize nutrient losses:

- Apply nutrient materials uniformly to application area(s).

- Nutrients shall not be applied to frozen, snow-covered or saturated soil if the potential risk for runoff exists.

- Nutrients shall be applied considering the plant growth habits, irrigation practices, and other conditions so as to maximize availability to the plant and minimize the risk of runoff, leaching, and volatilization losses.

- Nutrient applications associated with irrigation systems shall be applied in a manner that prevents or minimizes resource impairment.

Conservation Management Unit (CMU) Risk Assessment. In areas with identified or designated nutrient related water quality impairment, a CMU specific risk assessment of the potential for nutrient transport from the area shall be completed.

States that utilize a threshold prescreening procedure to trigger CMU risk assessment shall follow approved procedures as recommended by the respective state or Land Grant University.

Use an appropriate nutrient risk assessment tool for the nutrient in question (e.g., leaching index, phosphorus index) or other state recognized assessment tool.

Additional Criteria Applicable to Manure and Organic By-Products or Biosolids Applied as a Plant Nutrient Source

When animal manures or organic by-products are applied, a risk assessment of the potential for nutrient transport from the CMU shall be completed to adjust the amount, placement, form and timing of application of nutrient sources, as recommended by the respective state or Land Grant University.

Nutrient values of manure and organic by-products (excluding sewage sludge or biosolids) shall be determined prior to land application. Samples will be taken and analyzed with each hauling/emptying cycle for a storage/treatment facility. Manure sampling frequency may vary based on the operation’s manure handling strategy and spreading schedule. If there is no prior sampling history, the manure shall be analyzed at least annually for a minimum of three consecutive years. A cumulative record shall be developed and maintained until a consistent (maintaining a certain nutrient concentration with minimal variation) level of nutrient values is realized. The average of results contained in the operation’s cumulative manure analyses history shall be used as a basis for nutrient allocation to fields. Samples shall be collected and prepared according to Land Grant University guidance or industry practice.

In planning for new operations, acceptable “book values” recognized by the NRCS and/or the Land Grant University may be used if they accurately estimate nutrient output from the proposed operation (e.g., NRCS Agricultural Waste Management Field Handbook).

Biosolids (sewage sludge) shall be applied in accordance with USEPA regulations. (40 CFR Parts 403 (Pretreatment) and 503 (Biosolids) and other state and/or local regulations regarding the use of biosolids as a nutrient source.

Manure and Organic By-Product Nutrient Application Rates. Manure and organic by-product nutrient application rates shall be based on nutrient analyses procedures recommended by the respective state or Land Grant University. As indicated above, “book values” may be used in planning for new operations. At a minimum, manure analyses shall identify nutrient and specific ion concentrations, percent moisture, and percent organic matter. Salt concentration shall be monitored so that manure applications do not cause plant damage or negatively impact soil quality.

The application rate (in/hr) of liquid materials applied shall not exceed the soil intake/infiltration rate and shall be adjusted to minimize ponding and to avoid runoff. The total application shall not exceed the field capacity of the soil and shall be adjusted, as needed, to minimize loss to subsurface tile drains.

The planned rates of nitrogen and phosphorus application recorded in the plan shall be determined based on the following guidance:

Nitrogen Application Rates

- When manure or organic by-products are used, the nitrogen availability of the planned application rates shall match plant uptake characteristics as closely as possible, taking into consideration the timing of nutrient application(s) in order to minimize leaching and atmospheric losses.
- Management activities and technologies shall be used that effectively utilize mineralized nitrogen and that minimize nitrogen losses through denitrification and ammonia volatilization.

- Manure or organic by-products may be applied on legumes at rates equal to the estimated removal of nitrogen in harvested plant biomass.
- When the nutrient management plan component is being implemented on a phosphorus basis, manure or organic by-products shall be applied at rates consistent with a phosphorus limited application rate. In such situations, an additional nitrogen application, from non-organic sources, may be required to supply, but not exceed, the recommended amounts of nitrogen in any given year.

Phosphorus Application Rates

- When manure or organic by-products are used, the planned rates of phosphorus application shall be consistent with any one of the following options:
  - ◊ Phosphorus Index (PI) Rating. Nitrogen-based manure application on Low or Medium Risk Sites; phosphorus-based or no manure application on High and Very High Risk Sites.**
  - ◊ Soil Phosphorus Threshold Values. Nitrogen-based manure application on sites on which the soil test phosphorus levels are below the threshold values; Phosphorus-based or no manure application on sites on which soil phosphorus levels equal or exceed threshold values.**
  - ◊ Soil Test. Nitrogen-based manure application on sites for which the soil test recommendation calls for phosphorus application; phosphorus-based or no manure application on sites for which the soil test recommendation calls for no phosphorus application. ‡

    ** Acceptable phosphorus-based manure application rates shall be determined as a function of soil test recommendation or estimated phosphorus removal in harvested plant biomass. Guidance for developing these acceptable rates is found in the NRCS General Manual, Title 190, Part 402 (Ecological Sciences, Nutrient Management, Policy), and the National Agronomy Manual, Section 503 (to be developed).
- The application of phosphorus applied as manure may be made at a rate equal to the recommended phosphorus application or estimated phosphorus removal in harvested plant biomass for the crop rotation or multiple years in the crop sequence. When such applications are made, the application rate shall:
  - ◊ Not exceed the recommended nitrogen application rate during the year of application, or
  - ◊ Not exceed the estimated nitrogen removal in harvested plant biomass during the year of application when there is no recommended nitrogen application.
  - ◊ Not be made on sites considered vulnerable to off-site phosphorus transport unless appropriate conservation practices, best management practices or management activities are used to reduce the vulnerability.

Heavy Metal Monitoring. When sewage sludge (biosolids) is applied, the accumulation of potential pollutants (including arsenic, cadmium, copper, lead, mercury, selenium, and zinc) in the soil shall be monitored in accordance with the US Code, Reference 40 CFR, Parts 403 and 503, and/or any applicable state and local laws or regulations.

Additional Criteria to Protect Air Quality by Reducing Nitrogen and/or Particulate Emissions to the Atmosphere

In areas with an identified or designated nutrient management related air quality concern, any component(s) of nutrient management (i.e., amount, source, placement, form, timing of application) identified by risk assessment tools as a potential source of atmospheric pollutants shall be adjusted, as necessary, to minimize the loss(es).

When tillage can be performed, surface applications of manure and fertilizer nitrogen formulations that are subject to volatilization on the soil surface (e.g., urea) shall be incorporated into the soil within 24 hours after application.

When manure or organic by-products are applied to grassland, hayland, pasture or minimum-till areas the rate, form and timing of application(s) shall be managed to minimize volatilization losses.

When liquid forms of manure are applied with irrigation equipment, operators will select weather conditions during application that will minimize volatilization losses.

Operators will handle and apply poultry litter or other dry types of animal manures when the potential for wind-driven loss is low and there is less potential for transport of particulates into the atmosphere.

Weather and climatic conditions during manure or organic by-product application(s) shall be recorded and maintained in accordance with the operation and maintenance section of this standard.

Additional Criteria to Improve the Physical, Chemical and Biological Condition of the Soil

Nutrients shall be applied and managed in a manner that maintains or improves the physical, chemical and biological condition of the soil.

Minimize the use of nutrient sources with high salt content unless provisions are made to leach salts below the crop root zone.

To the extent practicable nutrients shall not be applied when the potential for soil compaction and rutting is high.

CONSIDERATIONS

The use of management activities and technologies listed in this section may improve both the production and environmental performance of nutrient management systems. The addition of these management activities, when applicable, increases the management intensity of the system and is recommended in a nutrient management system.

Action should be taken to protect National Register listed and other eligible cultural resources.

The nutrient budget should be reviewed annually to determine if any changes are needed for the next planned crop.

For sites on which there are special environmental concerns, other sampling techniques may be appropriate. These include soil profile sampling for nitrogen, Pre-Sidedress Nitrogen Test (PSNT), Pre-Plant Soil Nitrate Test (PPSN) or soil surface sampling for phosphorus accumulation or pH changes.

Additional practices to enhance manure management effectively include modification of the animal’s diet to reduce the manure nutrient content, or utilizing manure amendments that stabilize or tie-up nutrients.

Soil test information should be no older than one year when developing new plans, particularly if animal manures are to be used as a nutrient source.

Excessive levels of some nutrients can cause induced deficiencies of other nutrients.

If increases in soil phosphorus levels are expected, consider a more frequent (annual) soil testing interval.

To manage the conversion of nitrogen in manure or fertilizer, use products or materials (e.g. nitrification inhibitors, urease inhibitors and slow or controlled release fertilizers) that more closely match nutrient release and availability for plant uptake. These materials may improve the nitrogen use efficiency (NUE) of the nutrient management system by reducing losses of nitrogen into water and/or air.

Considerations to Minimize Agricultural Nonpoint Source Pollution of Surface and Ground Water.

Erosion control and runoff reduction practices can improve soil nutrient and water storage, infiltration, aeration, tilth, diversity of soil organisms and protect or improve water and air quality (Consider installation of one or more NRCS FOTG, Section IV – Conservation Practice Standards).

Cover crops can effectively utilize and/or recycle residual nitrogen.

Apply nutrient materials uniformly to the application area. Application methods and timing that reduce the risk of nutrients being transported to ground and surface waters, or into the atmosphere include:

- Split applications of nitrogen to provide nutrients at the times of maximum crop utilization,
- Use stalk-test to minimize risk of over applying nitrogen in excess of crop needs.
- Avoid winter nutrient application for spring seeded crops,
- Band applications of phosphorus near the seed row,
- Incorporate surface applied manures or organic by-products as soon as possible after application to minimize nutrient losses,
- Delay field application of animal manures or organic by-products if precipitation capable of producing runoff and erosion is forecast within 24 hours of the time of the planned application.

Considerations to Protect Air Quality by Reducing Nitrogen and/or Particulate Emissions to the Atmosphere.

Odors associated with the land application of manures and organic by-products can be offensive to the occupants of nearby homes. Avoid applying these materials upwind of occupied structures when residents are likely to be home (evenings, weekends and holidays).

When applying manure with irrigation equipment, modifying the equipment can reduce the potential for volatilization of nitrogen from the time the manure leaves the application equipment until it reaches the surface of the soil (e.g., reduced pressure, drop down tubes for center pivots). N volatilization from manure in a surface irrigation system will be reduced when applied under a crop canopy.

When planning nutrient applications and tillage operations, encourage soil carbon buildup while discouraging greenhouse gas emissions (e.g., nitrous oxide N_2O, carbon dioxide CO_2).

Nutrient applications associated with irrigation systems should be applied in accordance with the requirements of Irrigation Water Management (Code 449).

CAFO operations seeking permits under USEPA regulations (40 CFR Parts 122 and 412) should consult with their respective state permitting authority for additional criteria.

PLANS AND SPECIFICATIONS

Plans and specifications for nutrient management shall be in keeping with this standard and shall describe the requirements for applying the practice to achieve its intended purpose(s), using nutrients to achieve production goals and to prevent or minimize resource impairment.

Nutrient management plans shall include a statement that the plan was developed based on requirements of the current standard and any applicable Federal, state, or local regulations, policies, or programs, which may include the implementation of other practices and/or management activities. Changes in any of these requirements may necessitate a revision of the plan.

The following components shall be included in the nutrient management plan:

- aerial site photograph(s) or site map(s), and a soil survey map of the site,
- location of designated sensitive areas or resources and the associated, nutrient management restriction,
- current and/or planned plant production sequence or crop rotation,
- results of soil, water, manure and/or organic by-product sample analyses,
- results of plant tissue analyses, when used for nutrient management,
- realistic yield goals for the crops,

- complete nutrient budget for nitrogen, phosphorus, and potassium for the crop rotation or sequence,
- listing and quantification of all nutrient sources,
- CMU specific recommended nutrient application rates, timing, form, and method of application and incorporation, and
- guidance for implementation, operation, maintenance, and recordkeeping.

If increases in soil phosphorus levels are expected, the nutrient management plan shall document:

- the soil phosphorus levels at which it may be desirable to convert to phosphorus based planning,
- results of appropriate risk assessment tools to document the relationship between soil phosphorus levels and potential for phosphorus transport from the field,
- the potential for soil phosphorus drawdown from the production and harvesting of crops, and
- management activities or techniques used to reduce the potential for phosphorus loss.

OPERATION AND MAINTENANCE

The owner/client is responsible for safe operation and maintenance of this practice including all equipment. Operation and maintenance addresses the following:

- periodic plan review to determine if adjustments or modifications to the plan are needed. As a minimum, plans will be reviewed and revised with each soil test cycle.
- significant changes in animal numbers and/or feed management will necessitate additional manure sampling and analyses to establish a revised average nutrient content.
- protection of fertilizer and organic by-product storage facilities from weather and accidental leakage or spillage.
- calibration of application equipment to ensure uniform distribution of material at planned rates.
- documentation of the actual rate at which nutrients were applied. When the actual rates used differ from the recommended and planned rates, records will indicate the reasons for the differences.
- Maintaining records to document plan implementation. As applicable, records include:
    - Soil, plant tissue, water, manure, and organic by-product analyses resulting in recommendations for nutrient application,
    - quantities, analyses and sources of nutrients applied,
    - dates and method(s) of nutrient applications,
    - weather conditions and soil moisture at the time of application; lapsed time to manure incorporation, rainfall or irrigation event.
    - crops planted, planting and harvest dates, yields, and crop residues removed,
    - dates of plan review, name of reviewer, and recommended changes resulting from the review.

Records should be maintained for five years; or for a period longer than five years if required by other Federal, state or local ordinances, or program or contract requirements.

Workers should be protected from and avoid unnecessary contact with plant nutrient sources. Extra caution must be taken when handling ammoniacal nutrient sources, or when dealing with organic wastes stored in unventilated enclosures.

Material generated from cleaning nutrient application equipment should be utilized in an environmentally safe manner. Excess material should be collected and stored or field applied in an appropriate manner.

Nutrient containers should be recycled in compliance with state and local guidelines or regulations.

REFERENCES

Follett, R.F. 2001. Nitrogen Transformation and Transport Processes. pp. 17-44, In R.F. Follett and J. Hatfield. (eds.). 2001. Nitrogen in the Environment; Sources, Problems, and Solutions. Elsevier Science Publishers. The Netherlands. 520 pp.

Sims, J.T. (ed.) 2005. Phosphorus: Agriculture and the Environment. Agron. Monogr. 46. ASA, CSSA, and SSSA, Madison, WI.

Stevenson, F.J. (ed.) 1982. Nitrogen in Agricultural Soils. Agron. Series 22. ASA, CSSA, and SSSA, Madison, WI.

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

WATERING FACILITY

(No.)

CODE 614

DEFINITION

A permanent or portable device to provide an adequate amount and quality of drinking water for livestock and or wildlife.

PURPOSE

To provide access to drinking water for livestock and/or wildlife in order to:

- Meet daily water requirements
- Improve animal distribution

CONDITIONS WHERE PRACTICE APPLIES

This practice applies to all land uses where there is a need for new or improved watering facilities for livestock and/or wildlife.

CRITERIA

General Criteria Applicable To All Purposes

Design watering facilities with adequate capacity and supply to meet the daily water requirements of the livestock and/or wildlife planned to use the facility. Include the storage volume necessary to provide water between periods of replenishment. Refer to the National Range and Pasture Handbook for guidance on livestock water quantity and quality requirements. For wildlife, base water quantity and quality requirements on targeted species needs.

Locate facilities to promote even grazing distribution and reduce grazing pressure on sensitive areas.

Design the watering facility to provide adequate access to the animals planned to use the facility. Incorporate escape features into the watering facility design where local knowledge and experience indicate that wildlife may be at risk of drowning.

Include design elements to meet the specific needs of the animals that are planned to use the watering facility, both livestock and wildlife.

Protect areas around watering facilities where animal concentrations or overflow from the watering facility will cause resource concerns. Use criteria in NRCS Conservation Practice Standard 561, Heavy Use Area Protection to design the protection.

Install permanent watering facilities on a firm, level, foundation that will not settle differentially. Examples of suitable foundation materials are bedrock, compacted gravel and stable, well compacted soils.

Design and install watering facilities to prevent overturning by wind and animals.

Design watering facilities and all valves and controls to withstand or be protected from damage by livestock, wildlife, freezing and ice damage.

Construct watering facilities from durable materials that have a life expectancy that meets or exceeds the planned useful life of the installation. Follow appropriate NRCS design procedures for the material being used or industry standards where NRCS standards do not exist.

Use the criteria in NRCS Conservation Practice Standard 516, Pipeline to design piping associated with the watering facility. Include backflow prevention devices on facilities connected to wells, domestic or municipal water systems.

CONSIDERATIONS

Design fences associated with the watering facilities to allow safe access and exit for area wildlife species. To protect bats and other species that access water by skimming across the surface, fencing material should not extend across the water surface. If fencing across the water is necessary it should be made highly visible by avoiding the use of single wire fences and using fencing materials such as woven wire or by adding streamers or coverings on the fence.

For watering facilities that will be accessible to wildlife, give consideration to the effects the location of the facility will have on target and non-target species. Also consider the effect of introducing a new water source within the ecosystem in the vicinity of the facility. This should include things such as the concentration of grazing, predation, entrapment, drowning, disease transmission, hunting and expansion of the wildlife populations beyond the carrying capacity of available habitat.

Consider the following guidelines for materials commonly used for watering facilities.

Concrete	3000 psi compressive strength
Galvanized Steel	20 gauge thickness
Plastic	Ultraviolet resistance
Fiberglass	Ultraviolet resistance

Where water is supplied continuously or under pressure to the watering facility consider the use of automatic water level controls to control the flow of water to the facility and to prevent unnecessary overflows.

Watering facilities often collect debris and algae and should be cleaned on a regular basis. Consider increasing the pipe sizes for inlets and outlets to reduce the chances of clogging. Maintenance of a watering facility can be made easier by providing a method to completely drain the watering facility.

Steep slopes leading to watering facilities can cause erosion problems from over use by animals as well as problems with piping and valves from excess pressure. Choose the location of watering facilities to minimize these problems from steep topography.

PLANS AND SPECIFICATIONS

Plans and specifications for watering facilities shall provide the information necessary to install the facility. As a minimum this shall include the following:

- A map or aerial photograph showing the location of the facility
- Detail drawings showing the facility, necessary appurtenances (such as foundations, pipes and valves) and stabilization of any areas disturbed by the installation of the facility
- Construction specifications describing the installation of the facility

OPERATION AND MAINTENANCE

Provide an O&M plan specific to the type of watering facility. to the landowner. As a minimum include the following items in the plan:

- a monitoring schedule to ensure maintenance of adequate inflow and outflow;
- checking for leaks and repair as necessary;
- if present, the checking of the automatic water level device to insure proper operation;
- checking to ensure that adjacent areas are protected against erosion;
- if present, checking to ensure the outlet pipe is freely operating and not causing erosion problems;
- a schedule for periodic cleaning of the facility.

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Yoakum, J. and W.P. Dasmann. 1971. Habitat manipulation practices. Ch. 14 in Wildlife Management Techniques, Third Edition. Ed. Robert H. Giles, Jr. Pub. The Wildlife Society. 633 pp.

National Engineering Handbook, Part 650 Engineering Field Handbook, Chapters 5, 11 & 12, USDA Natural Resources Conservation Service.

National Range and Pasture Handbook, Chapter 6, Page 6-12, Table 6-7 & 6-8, USDA-Natural Resources Conservation Service.

National Research Council, 1996 Nutrient Requirements of Domestic Animals, National Academy Press.

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

WASTE UTILIZATION

(Ac.)

CODE 633

DEFINITION

Using agricultural wastes such as manure and wastewater or other organic residues.

PURPOSE

- Protect water quality
- Protect air quality
- Provide fertility for crop, forage, fiber production and forest products
- Improve or maintain soil structure
- Provide feedstock for livestock
- Provide a source of energy

CONDITIONS WHERE PRACTICE APPLIES

This practice applies where agricultural wastes including animal manure and contaminated water from livestock and poultry operations; solids and wastewater from municipal treatment plants; and agricultural processing residues are generated, and/or utilized

CRITERIA

General Criteria Applicable to All Purposes

All federal, state and local laws, rules and regulations governing waste management, pollution abatement, health and safety shall be strictly adhered to. The owner or operator shall be responsible for securing all required permits or approvals related to waste utilization, and for operating and maintaining any components in accordance with applicable laws and regulations.

Use of agricultural wastes shall be based on at least one analysis of the material during the time it is to be used. In the case of daily spreading, the waste shall be sampled and analyzed at least once each year. As a minimum, the waste analysis should identify nutrient and specific ion concentrations. Where the metal content of municipal wastewater, sludge, septage and other agricultural waste is of a concern, the analysis shall also include determining the concentration of metals in the material.

When agricultural wastes are land applied, application rates shall be consistent with the requirements of the NRCS conservation practice standard for nutrient management (590).

Where agricultural wastes are to be spread on land not owned or controlled by the producer, the waste management plan, as a minimum, shall document the amount of waste to be transferred and who will be responsible for the environmentally acceptable use of the waste.

Records of the use of wastes shall be kept a minimum of five years as discussed in OPERATION AND MAINTENANCE, below.

Additional Criteria to Protect Water Quality

All agricultural waste shall be utilized in a manner that minimizes the opportunity for contamination of surface and ground water supplies.

Agricultural waste shall not be land-applied on soils that are frequently flooded, as defined by the National Cooperative Soil Survey, during the period when flooding is expected.

When liquid wastes are applied, the application rate shall not exceed the infiltration rate of the soil, and the amount of waste applied shall not exceed the moisture holding capacity of the soil profile at the time of application. Wastes shall not be applied to frozen, snow-covered or saturated soil if the potential risk for runoff exists. The basis for the decision to apply waste under these conditions shall be documented in the waste management plan.

Additional Criteria to Protect Air Quality

Incorporate surface applications of solid forms of manure or other organic by-products into the soil within 24 hours of application to minimize emissions and to reduce odors.

When applying liquid forms of manure with irrigation equipment select application conditions where there is high humidity, little/no wind blowing, a forthcoming rainfall event and/or other conditions that will minimize volatilization losses into the atmosphere. The basis for applying manure under these conditions shall be documented in the nutrient management plan.

Handle and apply poultry litter or other dry types of animal manure or other organic by-products when weather conditions are calm and there is less potential for blowing and emission of particulates in the atmosphere. The basis for applying manure under these conditions shall be documented in the nutrient management plan.

When sub-surface applied using an injection system, waste shall be placed at a depth and applied at a rate that minimizes leaks onto the soil surface, while minimizing disturbance to the soil surface and plant community.

All materials shall be handled in a manner to minimize the generation of particulate matter, odors and greenhouse gases.

Additional Criteria for Providing Fertility for Crop, Forage and Fiber Production and Forest Products

Where agricultural wastes are utilized to provide fertility for crop, forage, fiber production and forest products, the practice standard Nutrient Management (590) shall be followed.

Where municipal wastewater and solids are applied to agricultural lands as a nutrient source, the single application or lifetime limits of heavy metals shall not be exceeded. The concentration of salts shall not exceed the level that will impair seed germination or plant growth.

Additional Criteria for Improving or Maintaining Soil Structure

Wastes shall be applied at rates not to exceed the crop nutrient requirements or salt concentrations as stated above.

Residue management practices shall be used for maintenance of soil structure.

Additional Criteria for Providing Feedstock for Livestock

Agricultural wastes to be used for feedstock shall be handled in a manner to minimize contamination and preserve its feed value. Chicken litter stored for this purpose shall be covered. A qualified animal nutritionist shall develop rations that utilize wastes.

Additional Criteria for Providing a Source of Energy

Use of agricultural waste for energy production shall be an integral part of the overall waste management system.

All energy producing components of the system shall be included in the waste management plan and provisions for utilization of residues of energy production identified.

Where the residues of energy production are to be land-applied for crop nutrient use or soil conditioning, the criteria listed above shall apply.

CONSIDERATIONS

The effect of Waste Utilization on the water budget should be considered, particularly where a shallow ground water table is present or in areas prone to runoff. Limit waste application to the volume of liquid that can be stored in the root zone.

Agricultural wastes contain pathogens and other disease-causing organisms. Wastes should be utilized in a manner that minimizes their disease potential.

Priority areas for land application of wastes should be on gentle slopes located as far as possible from waterways. When wastes are applied on more sloping land or land adjacent to waterways, other conservation practices should be installed to reduce the potential for offsite transport of waste.

It is preferable to apply wastes on pastures and hayland soon after cutting or grazing before re-growth has occurred.

Minimize environmental impact of land-applied waste by limiting the quantity of waste applied to the rates determined using the practice standard Nutrient Management (590) for all waste utilization.

Consider the net effect of waste utilization on greenhouse gas emissions and carbon sequestration.

PLANS AND SPECIFICATIONS

Plans and specifications for Waste Utilization shall be in keeping with this standard and shall describe the requirements for applying the practice to achieve its intended purpose. The waste management plan is to account for the utilization or other disposal of all animal wastes produced, and all waste application areas shall be clearly indicated on a plan map.

OPERATION AND MAINTENANCE

Records shall be kept for a period of five years or longer, and include when appropriate:

- Quantity of manure and other agricultural waste produced and their nutrient content.
- Soil test results.
- Dates and amounts of waste application where land applied, and the dates and amounts of waste removed from the system due to feeding, energy production or export from the operation.
- Describe climatic conditions during waste application such as: time of day, temperature, humidity, wind speed, wind direction and other factors as necessary.
- Waste application methods.
- Crops grown and yields (both yield goals and measured yield).
- Other tests, such as determining the nutrient content of the harvested product.
- Calibration of application equipment.

The operation and maintenance plan shall include the dates of periodic inspections and maintenance of equipment and facilities used in waste utilization. The plan should include what is to be inspected or maintained, and a general time frame for making necessary repairs.

Appendix 2: Agricultural Tools in Support of Section 502 Technical Guidance

Included in this appendix are summaries of online tools that can be used to develop plans for these practices.

A range of information and expertise is available to help in developing management plans for agricultural lands, including information derived from USDA, universities, soil and water conservation districts, agricultural producers, and the private sector. A range of tools and resources are summarized in the table below and represent those that are generally used by experts (e.g., USDA field technicians and engineers) to work with clients to design appropriate conservation plans for their lands. Most of the tools listed below are available for free.

#	Tool name and document link	Applicable practices[a]	Source and Web link
I.	**Software and Models**		
1	NuMan Pro	NM	Univ. Maryland
2	Animal Waste Management Software	AWM	USDA-NRCS
3	Manure Management Planner (MMP) Software	AWM, NM	Purdue University
4	National Nutrient Management Data Download	NM, AWM	Univ. Missouri
5	Spatial Nutrient Management Planner	NM, AWM	Univ. Missouri
6	Win Max	NM, AWM	Purdue University
7	MapWindow GIS + MMP Tools	AWM, NM	Purdue University
8	Revised Universal Soil Loss Equation, Version 2 (RUSLE2)	ESC	USDA-NRCS
9	Using RUSLE2 for the Design and Predicted Effectiveness of Vegetative Filter Strips (VFS) for Sediment	ESC	USDA-NRCS
10	Vegetative Filter Strip Modeling System (VFSMOD)	ESC	Univ. Florida
11	Integrated Farm System Model (IFSM)	AWM, NM, ESC, GM	USDA-ARS
12	Dairy Greenhouse Gas Model (DairyGHG)	AWM, NM	USDA-ARS
13	Cropware	NM, AWM	Cornell University
14	Soil Test Conversion Tools	NM	Cornell University
15	Great Plains Framework for Agricultural Resource Management (GPFARM)	AWM, NM, ESC, GM	USDA-ARS

#	Tool name and document link	Applicable practices^a	Source and Web link
16	Soil - Plant - Atmosphere—Water Field & Pond Hydrology (SPAW)	DWM	USDA-ARS
II. Calculators, Spreadsheets, and Graphical Tools			
17	Dairy Cattle N Excretion Calculator	AWM, NM	Cornell University
18	Corn N Calculator	NM	Cornell University
19	Total N Available from Manure Applications	AWM, NM	Cornell University
20	Other Calculators	AWM, NM	Cornell University
21	Nutrient Management Spreadsheets	AWM, NM	Univ. of Delaware
22	Crop Nutrient Tool	NM	USDA-NRCS
23	Crop Fertilizer Recommendation Calculator	NM	Purdue University
24	Manure Nutrient Availability Calculator	AWM, NM	Purdue University
25	Conservation Buffers	ESC	USDA NAC
26	Farm*A*Syst	AWM, NM	Univ. of Wisconsin
27	Virginia Phosphorus Index	NM	Virginia Tech
III. Compilations of Tools			
28	Technical Resources Main Page	AWM, DWM, ESC, GM, NM	USDA NRCS
29	Animal Feeding Operations (AFO) Virtual Information Center	AWM, NM	USEPA
30	Software Products	AWM, DWM, ESC, GM, NM	USDA-ARS
31	Nutrient Management Planning Software and Support	NM, AWM	Univ. Missouri
IV. Guidance and Other Technical Resources			
32	Nutrient and Pest Management Tools and Information	NM	USDA-NRCS
33	Conservation Practices	AWM, DWM, ESC, GM, NM	USDA-NRCS
34	Agronomy and Erosion	ESC	USDA-NRCS
35	Animal Feeding Operations	AWM, NM	USDA-NRCS
36	Nutrient Management Technical Notes	NM, AWM	USDA-NRCS
37	National Range and Pasture Handbook	GM, ESC	USDA-NRCS
38	Phosphorus Index	NM	USDA-NRCS
39	SERA-17 Publications and BMP Fact Sheets	NM	SERA-17
40	Managing Cover Crops Profitably, 3rd Edition	Cover Crops	SARE

#	Tool name and document link	Applicable practices[a]	Source and Web link
41	Precision Feed Management Certification for Dairy Professionals	AWM, NM	Mid-Atlantic Water Program
42	Mid-Atlantic Better Composting School	AWM, NM	Mid-Atlantic Water Program
43	Environmental Management System for Manure	AWM	Mid-Atlantic Water Program
44	Mid-Atlantic Nutrient Management Handbook	NM	Mid-Atlantic Water Program
45	Information on Nutrient and Sediment Best Management Practices	NM, ESC	Chesapeake Bay Program
46	Fact Sheets	NM, AWM	Univ. Delaware
47	Nutrient Management	NM	MD Dept. Agriculture
48	Nutrient Management Program	NM	Univ. Maryland
49	Nutrient Management Plan Writing Tools	NM	Univ. Maryland
50	Phosphorus Site Index	NM	Univ. Maryland
51	Nutrient Management Software and Publications	NM	Univ. Maryland
52	Nutrient Management Spear Program	AWM, NM	Cornell Univ.
53	Manure Management	AWM, NM	Penn State Univ.
54	Pennsylvania Nutrient Management Program	NM	Penn State Univ.
55	Planning Tools and Resources	NM	Penn State Univ.
56	Nutrient Management Technical Manual	NM, AWM	Penn State Univ.
57	Educational Materials	NM, AWM	Penn State Univ.
58	Fact Sheets on Agriculture and Environmental Quality	NM, AWM, GM	Virginia Tech Univ.
59	Virginia Agricultural BMP Cost Share and Tax Credit Programs	AWM, DWM, ESC, GM, NM	Virginia Dept. Conservation and Recreation
60	Nutrient and Waste Management	NM, AWM	Univ. West Virginia
61	Comprehensive Livestock Environmental Assessments and Nutrient (CLEANEast) Management Plan program	NM, AWM	RTI International and North Carolina State Univ.
62	Comprehensive Nutrient Management Planning (CNMP)	NM, AWM	eXtension
63	CNMP Core Curriculum	NM, AWM, ESC, GM	Iowa State Univ.
64	Manure Management Planner Tutorials	AWM, NM	Univ. Missouri

Note:

a. AWM = animal waste management, DWM = drainage water management, ESC = erosion and sediment control, GM = grazing management, NM=nutrient management

I. Software and Models

1. Nutrient Management Planning (NMP) Software for Professionals (NuMan Pro)—Univ. Maryland Extension

Nutrient Management for Maryland Professional Edition (NuMan Pro) is an integrated software program that permits comprehensive NMP. The Maryland Phosphorus Site Index (PSI) has been integrated into the program so that warnings are given when a PSI calculation could be required based on soil test results. A simplified version of the Revised Universal Soil Loss Equation (RUSLE) model to predict soil erosion losses has been included in the program in support of the Maryland PSI assessment. Values for rainfall erosivity (R) and soil erodibility (K) factors are determined from field location and soils information entered in the initial portions of the program. Soil slope/steepness (LS), cropping management (C), and conservation management (P) factors are determined from simplified user inputs. Part A and Part B of the Maryland PSI are presented in a color-code scheme for user ease. Once slopes have been identified in the field, it is estimated that an experienced user can determine the Maryland PSI in less than 10 minutes.

Link: http://anmp.umd.edu/numan/numanpro.htm Accessed January 28, 2010

2. Animal Waste Management Software—USDA-NRCS

AWM 2.4.0, like the previous version, is a planning/design tool for animal feeding operations that can be used to estimate the production of manure, bedding, and process water and determine the size of storage/treatment facilities. The procedures and calculations used in AWM are based on the USDA-NRCS *Agricultural Waste Management Field Handbook.*

The AWM has been upgraded with the capability to evaluate existing facilities. The results from the evaluation are incorporated into the design processes for new facilities. The user can design the new facility either for the *Additional* waste not handled by the existing facility, or for the *Total* waste flowing into the structure.

The evaluation process involves the user entering the basic dimensions of an existing storage facility along with other parameters such as herd size, local climatic condition (monthly rainfall), and details about the additions such as bedding, wash water and flush water. With these inputs, the system estimates the total waste flowing into the structure identified in the management train for the selected storage period and compares it to the available storage volume. It then presents an on-screen color-coded report (red for inadequate and green for the adequate structure.) The report helps recognize if the structure is adequately designed or not easily and quickly. The user can also print a hardcopy of the report.

The AWM process of evaluating existing structures can help producers in deciding if they would like to go for the *No Discharge* declaration within the EPA 2008 CAFO rule. The facility design for the Total waste or for the Additional waste not handled by the existing structure is easily done by selecting the appropriate radio button on the AWM design screen. In addition, several improvements and bug fixes, listed below, have been incorporated to further improve AWM functions and capabilities.

Link: http://www.wsi.nrcs.usda.gov/products/W2Q/AWM/pgrm24.html Accessed January 22, 2010

3. Manure Management Planner (MMP) Software—Purdue University

Manure Management Planner (MMP) is a Windows-based computer program developed at Purdue University that is used to create manure management plans for crop and animal feeding operations. The user enters information about the operation's fields, crops, storage, animals, and application equipment. MMP helps the user allocate manure (where, when and how much) on a monthly basis for the length of the plan (1–10 years). This allocation process helps determine if the current operation has sufficient crop acreage, seasonal land availability, manure storage capacity, and application equipment to manage the manure produced in an environmentally responsible manner. MMP is also useful for identifying changes that could be needed for a non-sustainable operation to become sustainable, and determine what changes might be needed to keep an operation sustainable if the operation expands.

MMP supports 34 states including Delaware, Maryland, and Pennsylvania (support for Virginia is underway), by automatically generating fertilizer recommendations and estimating manure N availability based on each state's Extension and/or NRCS guidelines. It should be noted, however, that MMP is not generally used in Maryland. Questions about MMP can be addressed to the authors using contact information provided at the Web site.

Link: http://www.agry.purdue.edu/mmp/ Accessed January 22, 2010

4. National Nutrient Management Data Download—Univ. of Missouri Extension

The data download Web site helps to address nutrient management software data requirements by providing a way for users to locate the farm of interest, define an area of interest and submit a data request.

- The Spatial Nutrient Management Planner (SNMP) requires geo-referenced aerial photographs, data from the soils survey, a topographic map and state-specific data on manure application setback requirements.

- Manure Management Planner (MMP) needs data from the soils survey and crop and climatology data from Natural Resource Conservation Service (NRCS).
- The data download also includes data needed by the Revised Soil Loss Equation version 2 (RUSLE(2)).

The data-finder packages the data in a compressed file that can be downloaded onto a computer hard drive. The file is then un-compressed in the same folder on the computer the holds the working SNMP and MMP files for that farm. This tool will generate a ZIP file containing the aerial photo image, topographic map image, and soils data needed for SNMP, MMP and RUSLE(2). The data is obtained from various USDA-NRCS data servers for any area with spatial data in the NRCS Soils Data Mart (see Status Map). Google Maps is used to locate farms and define a download area which includes the farm.

Link: http://www.nmplanner.missouri.edu/software/national_data.asp Accessed January 22, 2010

5. Spatial Nutrient Management Planner—Univ. of Missouri Extension

The Spatial Nutrient Management Planner (SNMP) is a decision support tool that facilitates the collection, analysis and presentation of spatial data related to NMP. Capabilities of SNMP include:

- The SNMP interface simplifies the GIS program ArcMap for nutrient management planners.
- With a click of a mouse, data can be imported and exported from Purdue's Manure Management Planner (MMP).
- SNMP simplifies the creation of maps required for NRCS comprehensive nutrient management plans
- Compatibility with NRCS Toolkit 9.x.

Link: http://projects.cares.missouri.edu/snmp/nrcsdata/aoilist.asp Accessed January 22, 2010

6. Win Max—Purdue University

WinMax is a computer program developed at Purdue University to calculate and compare economic returns on crop production. WinMax manages crop input data, calculates crop fertilizer recommendations, generates production cost and nutrient management worksheets, and allows sets of custom input costs to be created and used in all calculations. WinMax supports the import of data from a manure management plan created with MMP, as well as the export of WinMax data to an MMP plan. Various management options, such as tillage, pest control and fertilizer strategies, can be compared to help assess which practices are both economically efficient and environmentally sound.

Link: http://www.agry.purdue.edu/max/ Accessed January 22, 2010

7. MapWindow GIS + MMP Tools—Purdue University

MapWindow GIS + MMP Tools is a free GIS that can be used as a front-end to MMP and WinMax.

Link: http://www.agry.purdue.edu/mmp/mapwindow/ Accessed January 22, 2010

8. Revised Universal Soil Loss Equation, Version 2 (RUSLE2)—USDA-NRCS

This site contains the official NRCS version of RUSLE2. It is the only version of RUSLE2 to be used for official purposes by NRCS field offices. The NRCS developed and maintains the database components on this site.

RUSLE2 is an upgrade of the text-based RUSLE DOS version 1. It is a computer model containing both empirical and process-based science in a Windows environment that predicts rill and interrill erosion by rainfall and runoff. The USDA-Agricultural Research Service (ARS) is the lead agency for developing the RUSLE2 model. The ARS, through university and private contractors, is responsible for developing the science in the model and the model interface.

Link: http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm Accessed January 22, 2010

9. Using RUSLE2 for the Design and Predicted Effectiveness of Vegetative Filter Strips (VFS) for Sediment—USDA-NRCS

The Revised Universal Soil Loss Equation, Version 2, (RUSLE2) can also be used to design and predict the expected lifespan of a VFS designed for the purpose of sediment removal based on the procedures developed by Dillaha and Hayes. The following information is needed:

- Sediment delivery rate at the upper edge of the VFS for the *contributing area* to the VFS—calculated by RUSLE2 using the *overland flow slope length*.
- Sediment Trapping Efficiency—calculated from RUSLE2 results.
- Ratio of Contributing Area to VFS Area.

This publication requires Microsoft Excel® and uses the following spreadsheet:
Filter Strip Life Span Design for Sediment (XLS; 24 KB)

Link: http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=18578.wba
Accessed January 22, 2010

Additional Reference: USDA-NRCS. 2007. Agronomy Technical Note No. 2, Using RUSLE2 for the Design and Predicted Effectiveness of Vegetative Filter Strips (VFS) for Sediment, 8pp.

10. Vegetative Filter Strip Modeling System (VFSMOD)—University of Florida

VFSMOD-W is a design-oriented vegetative filter strip modeling system. The MS-Windows graphical user interface (GUI) integrates the numerical model VFSMOD, a utility to generate source (upslope disturbed area) inputs for the model based on readily available NRCS site characteristics (UH), and advanced uncertainty and sensitivity analysis, inverse calibration and design menu-driven components. VFSMOD, the core of the modeling system, is a computer simulation model created to study hydrology, sediment and pollutant transport through vegetative filter strips (VFS). The model is targeted at studying VFS performance on an event-by-event basis and when combined with the upslope source area input preparation utility (UH or others like PRZM), becomes a powerful and objective VFS design tool. The design paradigm implemented in VFSMOD-W seeks to identify optimal filter constructive characteristics (length, slope, vegetation) to reduce (to a prescribed reduction target like a TMDL) the outflow of pollutants from a given disturbed area (soil, crop, area, management practices, design storm return period).

VFSMOD has been tested in a variety of settings (agroforestry, mining and roads) with good model predictions against measured values of infiltration, outflow, and vegetation trapping efficiency for sediments, P, and pesticides. Although the model was originally developed as research tool, is now widely used by consultants, planners and regulators to design optimal filter strips for specific scenarios or to assess effectiveness of existing VFS.

Link: http://carpena.ifas.ufl.edu/vfsmod/ Accessed January 28, 2010

11. Integrated Farm System Model (IFSM)—USDA-ARS

The Integrated Farm System Model (IFSM) is a process-based simulation of dairy, beef, and crop farming systems. This farm model provides a tool for evaluating the long-term performance, economics, and environmental impacts of production systems over many years of weather. Environmental impacts include volatile N losses, NO_3 loss to groundwater, erosion, soluble and sediment P losses to surface water, and greenhouse gas emissions.

Link: http://www.ars.usda.gov/Main/docs.htm?docid=8519 Accessed January 27, 2010

12. Dairy Greenhouse Gas Model (DairyGHG)—USDA-ARS

The Dairy Greenhouse Gas Model (DairyGHG) is an easy to use software tool that estimates total greenhouse gas emissions and the carbon footprint of a dairy production system. DairyGHG uses a relatively simple process-based model to predict the primary GHG emissions from the production system, which include the net emission of carbon dioxide plus all emissions of methane and nitrous oxide. Emissions are predicted through a daily simulation of feed use and manure handling where daily values of each gas are summed to obtain annual values. A carbon footprint is then calculated as the sum of both primary and secondary emissions in CO_2 equivalent units divided by the milk produced. Secondary emissions are those occurring during the production of resources used including machinery, fuel, electricity, fertilizer, pesticides, and plastic. DairyGHG is available for download from our Internet site (http://ars.usda.gov/naa/pswmru). The model includes a fully integrated help system with a reference manual that documents the relationships used to predict emissions.

Link: http://www.ars.usda.gov/Main/docs.htm?docid=17355 Accessed January 27, 2010

13. Cropware—Cornell University Extension

Cropware is used to develop plans in accordance with the NRCS Nutrient Management Standard (Standard 590), making the output of Cropware a key component of Comprehensive Nutrient Management Plans. Cornell Cropware integrates the following tools for effective nutrient management planning:

- Cornell crop nutrient guidelines for a full range of agronomic and vegetable crops.
- Nutrient credits from many sources, including manure, soil, sod, and fertilizer.
- Equations for the conversion of soil test values from other laboratories into Cornell Morgan equivalents.
- Environmental risk indices, including the New York State Phosphorus Runoff Index and the Nitrate Leaching Index.
- On-farm logistics, such as manure production, storage, and inventories Report generation for guiding on-farm implementation.

Link: http://nmsp.cals.cornell.edu/software/cropware.html Accessed January 27, 2010

14. Soil Test Conversion Tools—Cornell University Extension

This program converts soil test results from Brookside Laboratories Inc. (Mehlich 3 P, K, Ca, Mg), Spectrum Analytic Inc. (Mehlich 3 P, K, Ca, and Mg and Morgan P, K, Ca, and Mg), A&L Laboratories Inc. (Mehlich 3 P, K, Ca, Mg and Modified Morgan P), and the soil testing laboratories from the University of New Hampshire (Mehlich 3 P, K, Ca and Mg), University of Massachusetts (Morgan P, K, Ca, and Mg) and the Universities of Vermont and Maine (Modified Morgan P, K, Ca, Mg) to Cornell University Morgan Equivalents. P conversions from Mehlich 3 data require measured values for soil pH, Mehlich 3 P, Ca, and Al. For each test, the range of valid input data is given by a minimum value (min) and a maximum value (max). Also given are the correlation coefficients (r^2) for each of the conversion models. Conversions with larger r^2 values are more reliable. Models were derived using New York soils. There is uncertainty involved with each of the conversions and we now know there is seasonality in the conversions with the most reliable conversions obtained when samples are taken after harvest and before manure application. The user assumes all risk and it is recommended to submit samples for the Cornell Morgan test to check on the accuracy of the conversion models for your farm or the farm you work with. It is also recommended to take three subsamples per acre if you use conversion models to derive Cornell Morgan soil test equivalents.

Link: http://nmsp.cals.cornell.edu/software/conv-tools.html Accessed January 27, 2010

15. Great Plains Framework for Agricultural Resource Management (GPFARM)—USDA-ARS

Great Plains Framework for Agricultural Resource Management (GPFARM) is a simulation model computer application that incorporates state-of-the-art knowledge of agronomy, animal science, economics, weed science, and risk management into a user-friendly, decision-support tool. Producers and others can use GPFARM to test alternative management strategies with regard to sustainability, pollution reduction, and economic return.

Link: http://www.ars.usda.gov/services/software/download.htm?softwareid=234 Accessed January 27, 2010

16. Soil - Plant - Atmosphere—Water Field & Pond Hydrology (SPAW)—USDA-ARS

SPAW is a daily hydrologic budget model for agricultural fields and ponds (wetlands, lagoons, ponds and reservoirs). Included are irrigation scheduling and soil N. Companion models for soil water characteristics and chemical budgets are included. Data input and results are graphical screens.

Link: http://hydrolab.arsusda.gov/SPAW/Index.htm Accessed January 28, 2010

II. Calculators, Spreadsheets, and Graphical Tools

17. Dairy Cattle N Excretion Calculator—Cornell University Extension

The Dairy Cattle N Excretion Calculator enables users to quickly characterize rations, individual dairy cattle, and groups of dairy cattle to predict the N partitioned to growth, milk production, pregnancy, urine, and feces. From there, N use efficiency and N volatilization from the barn floor are estimated.

Link: http://www.dairyn.cornell.edu/pages/40dairy/420precision/424herdspread.shtml Accessed January 27, 2010

18. Corn N Calculator—Cornell University Extension

This calculator factors in soil type, drainage, and other factors to estimate corn N requirements.

Link: http://www.dairyn.cornell.edu/pages/20cropsoil/240guides/245corn.shtml Accessed January 27, 2010

19. Total N Available from Manure Applications—Cornell University Extension

N from urine (ammonium N) is quickly available for crop uptake, while N from feces (organic N) is more slowly released. Manure represents a mix of both urine and feces, so estimations of the amount of plant available N from manure should be based on both.

The total manure N calculator uses factors such as animal type, percent dry matter, organic N content, and application rate to estimate the combined contributions of organic N and ammonium N to the total pool of plant available N from manure.

Link: http://www.dairyn.cornell.edu/pages/20cropsoil/250credits/256totalN.shtml Accessed January 27, 2010

20. Other Calculators—Cornell University Extension

This page provides links to calculators for corn N needs, manure nutrients, N credits from plowed sods, and whole-farm nutrient balancing.

Link: http://nmsp.cals.cornell.edu/software/calculators.html Accessed January 27, 2010

21. Nutrient Management Spreadsheets—University of Delaware Cooperative Extension

This page includes links to two spreadsheets, one for estimating animal waste quantity, and the other for estimating poultry litter quantity.

Link: http://ag.udel.edu/extension/NutriManage/spreadsheets.htm Accessed January 27, 2010

22. Crop Nutrient Tool—USDA-NRCS

This is a tool for calculating the approximate amount of N, P, and potassium that is removed by the harvest of agricultural crops.

Link: http://plants.usda.gov/npk/main Accessed January 22, 2010

23. Crop Fertilizer Recommendation Calculator—Purdue University

This calculator is supported for Delaware, Maryland, and Pennsylvania.

Link: http://www.agry.purdue.edu/mmp/webcalc/fertRec.asp Accessed January 22, 2010

24. Manure Nutrient Availability Calculator—Purdue University

This calculator is supported for Delaware, Maryland, and Pennsylvania.

Link: http://www.agry.purdue.edu/mmp/webcalc/nutAvail.asp Accessed January 22, 2010

25. Conservation Buffers—USDA National Agroforestry Center

At any given site, the level of pollutant removal from surface runoff depends primarily on buffer width. The graph and tables at this site can be used to estimate a buffer width that will achieve a desired level of pollutant removal. The tool is designed to quickly generate estimates of design width for a broad range of site conditions. Adjustments are made for land slope, soil texture, field size, and soil surface condition. The tool can be used for sediment, sediment-bound pollutants, and dissolved pollutants. The tool was developed for agricultural runoff using VSFMOD (Vegetative Filter Strip Model) but can be applied in a more general way to other land uses as well.

Link: http://www.unl.edu/nac/bufferguidelines/guidelines/1_water_quality/19.html Accessed January 26, 2010

26. Farm*A*Syst—University of Wisconsin Extension

Farm*A*Syst is a partnership between government agencies and private business that enables landowners to prevent pollution on farms, ranches, and in homes using confidential environmental assessments. A system of step-by-step factsheets and worksheets helps landowners identify the behaviors and practices that create risks associated with livestock waste storage, nutrient management, wells, hazardous wastes, and petroleum products.

Link: http://www.uwex.edu/farmasyst/ Accessed January 27, 2010

27. Virginia Phosphorus Index —Virginia Tech

The Virginia Phosphorus Index (P-Index) is a field-level assessment tool that integrates soil, management, environmental, and hydrologic (transport) characteristics to estimate the relative risk of phosphorus (P) losses through erosion, surface runoff and subsurface transport to water bodies.

Link: http://p-index.agecon.vt.edu/ Accessed April 22, 2010

III. Compilations of Tools

28. Technical Resources Main Page—USDA-NRCS

This page serves as the gateway to a wide range of technical resources provided by USDA.

Link: http://www.nrcs.usda.gov/technical/

29. Animal Feeding Operations (AFO) Virtual Information Center—EPA

The AFO Virtual Information Center is a tool to facilitate quick access to livestock agricultural information in the United States. This site is a single point of reference to obtain links to state regulations, Web sites, permits and policies, nutrient management information, livestock and trade associations, federal Web sites, best management practices and controls, cooperative extension and land grant universities, research, funding, and information on environmental issues. The nutrient management information page has links to nutrient management resources for Delaware, Maryland, Pennsylvania, Virginia, and West Virginia.

Link: http://cfpub.epa.gov/npdes/afo/virtualcenter.cfm Accessed January 28, 2010

30. Software Products—USDA-ARS

This page provides updated information on software tools available from USDA-ARS. Additional information on ARS models and projects can be found here.

Link: http://www.ars.usda.gov/Services/software/software.htm Accessed January 27, 2010

31. Nutrient Management Planning Software and Support—Univ. of Missouri Extension

This page provides links to national resources that facilitate writing a nutrient management plan. The listed resources contribute to a unified system for writing a nutrient management plan that meets national standards for NRCS and EPA.

a. Nutrient Management Data Download: Use the Nutrient Management Data Finder to obtain data needed by nutrient management software to complete a plan.

b. Spatial Nutrient Management Planner (SNMP): Use the SNMP to collect and analyze spatial information and create maps needed for completing a nutrient management plan.

c. Purdue's Manure Management Planner (MMP): Use MMP to determine fertilizer and manure application rates and generate the nutrient management plan.

d. Manure Management Planner (MMP) Tutorials: Tutorials on how to use MMP to develop a swine, poultry or fertilizer only plan.

e. National Setbacks Database: Access a database on the Web that reports setback requirements for the 34 states supported by SNMP and MMP.

Link: http://www.nmplanner.missouri.edu/software/ Accessed January 22, 2010

IV. Guidance and Other Technical Resources

32. Nutrient and Pest Management Tools and Information— USDA-NRCS

Users will find fact sheets on practices and links to various tools for nutrient and pest management at this site.

Link: http://www.nrcs.usda.gov/technical/nutrient.html Accessed January 26, 2010

33. Conservation Practices—USDA-NRCS

At this site, users will find links to the Field Office Technical Guide and the National Handbook of Conservation Practices. Links to each state's electronic Field Office Technical Guide (eFOTG) can be found here.

Link: http://www.nrcs.usda.gov/technical/standards/ Accessed January 26, 2010

34. Agronomy and Erosion—USDA-NRCS

This site has links to the *National Agronomy Manual*, a publication on using RUSLE2 to design and predict the effectiveness of vegetative filter strips for sediment control, Core 4 Conservation, and other resources.

http://www.nrcs.usda.gov/technical/agronomy.html Accessed January 27, 2010

35. Animal Feeding Operations—USDA-NRCS

This page provides information on CNMPs and links to the MMP and the CNMP field handbook.

Link: http://www.nrcs.usda.gov/technical/afo/index.html Accessed January 27, 2010

36. Nutrient Management Technical Notes—USDA-NRCS

This page includes links to several fact sheets on diet and feed management for various types of livestock. The page also includes links for National Conservation Practice Standards for nutrient management (NRCS Practice Code 590) and waste utilization (NRCS Practice Code 633).

Link: http://www.nrcs.usda.gov/technical/ECS/nutrient/documents.html Accessed January 22, 2010

37. National Range and Pasture Handbook—USDA-NRCS

This handbook includes chapters on grazing management and conservation planning for grazing lands.

Link: http://www.glti.nrcs.usda.gov/technical/publications/nrph.html Accessed January 27, 2010

38. Phosphorus Index—USDA-NRCS

This page provides background on the Phosphorus Index, which is intended to provide field staffs, watershed planners, and land users with a tool to assess the various landforms and management practices for potential risk of P movement to waterbodies.

USDA is careful to point out,

> The Phosphorus Index is not intended to be an evaluation scale for determining whether land users are abiding within water quality or nutrient management standards that have been established by local, state, or federal agencies. Any attempt to use this index as a regulatory scale would be grossly beyond the intent of the assessment tool and the concept and philosophy of the working group that developed it. The Phosphorus Index is proposed to be adapted to local conditions by a process of regional adaptations of the site characteristic parameters. This local development process must involve those local and state agencies and resource groups that are concerned with the management of phosphorus. After the index is adapted to a locality, it must be tested by the development group to assure that the assessments are giving valid and reasonable results for that region. Field testing of the index is one of the most appropriate methods for assessing the value of the index.

Link: http://www.nrcs.usda.gov/technical/ecs/nutrient/pindex.html Accessed January 29, 2010

39. SERA-17 Publications and BMP Fact Sheets

SERA-17 is an organization of research scientists, policy makers, extension personnel, and educators whose mission is to develop and promote innovative solutions to minimize phosphorus losses from agriculture by supporting

- Information exchange between research, extension, and regulatory communities
- Recommendations for phosphorus management and research
- Initiatives that address phosphorus loss in agriculture

Link: http://www.sera17.ext.vt.edu/SERA_17_Publications.htm Accessed January 22, 2010

40. Managing Cover Crops Profitably, 3rd Edition—SARE

This 2007 update from Sustainable Agriculture Research and Education (SARE) includes information on the benefits of cover crops, selecting cover crops, the use of cover crops with conservation tillage, crop rotations, and a wide range of legume and non-legume cover crops. Appendix E contains contact information for regional cover crop experts

Link: http://www.sare.org/publications/covercrops/index.shtml Accessed January 27, 2010

41. Precision Feed Management Certification for Dairy Professionals—Mid-Atlantic Water Program

To help reduce nutrient pollution and implement the NRCS Feed Management Standard 592, specialists in Pennsylvania, Maryland, and Virginia are working with NRCS and the American Registry of Professional Animal Scientists to develop a process to certify nutritionists as feed management planners. With few areas in the nation working with the dairy industry and NRCS on feed management, the mid-Atlantic is being looked at as a potential standard for how other states can train nutritionists for a feed management certification and meet their post-certification, professional needs. This page provides current information on precision feed management certification, including contact information for leaders from Maryland, Pennsylvania, and Virginia.

Link: http://mawaterquality.org/industry_change/precision_feed_mgmt.html Accessed January 27, 2010

42. Mid-Atlantic Better Composting School—Mid-Atlantic Water Program

Because commercial compost can be manufactured from a variety of waste materials, a variety of standards have been established based on end uses. Managers of composting facilities should be familiar with these standards and with the waste materials and composting systems that can best produce the desired products. Composting to produce a product that is consistent in quality will require good management and quality control.

By enrolling in the Mid-Atlantic Better Composing School, participants will not only learn the basics of making good compost, but they will also have the opportunity to tour commercial operations, perform product sampling, and learn simple procedures for compost testing.

Link: http://mawaterquality.org/industry_change/ma_composting_school.html Accessed January 27, 2010

43. Environmental Management System for Manure—Mid-Atlantic Water Program

Members from the Mid-Atlantic Water Program (MAWP) are collaborating with CLEANeast to assess livestock and poultry operations in sensitive watersheds across PA, MD, and VA using an Environmental Management Systems (EMS) model. An EMS is a voluntary, flexible business management system that helps farmers and managers to develop their own strategies for integrating environmental considerations into the daily operations of a farm.

By implementing pilot assessments across farms in Pennsylvania, Virginia, and Maryland, team members will demonstrate how an EMS can not only reduce pollution from farms, but also increase operating efficiency, achieve public acceptance without regulatory oversight, and elicit confidence in citizens that the wastes are being handled in an environmentally sound manner.

This page also provides state contacts information.

Link: http://mawaterquality.org/industry_change/env_mgmt_system_manure.html Accessed January 27, 2010

44. Mid-Atlantic Nutrient Management Handbook—Mid-Atlantic Water Program

The *Mid-Atlantic Nutrient Management Handbook* was written as a reference text for nutrient management training programs offered by state regulatory agencies. The handbook was based off an earlier nutrient management training manual that was widely used in the Chesapeake Bay watershed but revised to incorporate advances in soil, crop, and nutrient management research and the techniques used to protect surfacewater and groundwater.

Link: http://mawaterquality.org/capacity_building/ma_nutrient_mgmt_handbook.html Accessed January 27, 2010

45. Information on Nutrient and Sediment Best Management Practices—Chesapeake Bay Program

This report led by the University of Maryland Mid-Atlantic Water Program includes nutrient and sediment reduction effectiveness estimates of select agricultural, stormwater and forestry best management practices (BMPs). With funding from the Chesapeake Bay Program Office, the Mid-Atlantic Water Program developed definitions and effectiveness estimates for BMPs that states were implementing or proposing to implement as part of their efforts to meet the nutrient and sediment reduction goals necessary to restore the Bay. The report provides realistic, science-based estimates of expected nutrient and sediment reduction performance from these BMPs and reflects current research and knowledge as well as average operational conditions representative of the entire Chesapeake Bay watershed.

Link: http://www.chesapeakebay.net/marylandbmp.aspx?menuitem=34449 Accessed January 27, 2010

46. Fact Sheets—University of Delaware Cooperative Extension

This page contains links to several fact sheets on nutrient management, poultry litter management, and animal waste management.

Link: http://ag.udel.edu/extension/NutriManage/publications.htm Accessed January 27, 2010

47. Nutrient Management—Maryland Department of L., J. A. Nienaber, et al. (2003). Performance of a passive feedlot runoff control and treatment system. Transactions of the ASAE 46(6):1525–1530.

Ladha, J.K., Pathak, H., Krupnik, T.J., Six, J. and van Kessel, C. 2005. Efficiency of fertilizer nitrogen in cereal production: retrospects and prospects. *Advances in Agronomy* 87:85-156.

Mosier, A.R., J.K. Syers, and J.R. Freney. 2004. Ch. 1-Nitrogen fertilizer: an essential component of increased food, feed, and fiber production. pp. 3-15. *In* A.R. Mosier, J.K. Syers, and J.R. Freney (eds.). Agriculture and the Nitrogen Cycle. Assessing the impacts

This page provides various links to nutrient management fact sheets, recommendations, and training opportunities.

Link: http://www.mda.state.md.us/resource_conservation/nutrient_management/index.php Accessed January 27, 2010

48. Nutrient Management Program—University of Maryland Extension

The Agricultural Nutrient Management Program is a component of the University of Maryland's College of Agriculture and Natural Resources Nutrient Management Programs and focuses on reducing the pollution of the Chesapeake Bay by plant nutrients from cropland. The program provides nutrient planning services to Maryland farmers via a network of nutrient management advisors in all county Extension offices and provides continuing education and technical support to certified nutrient management consultants via state and regional nutrient management specialists.

One of these services is the development of nutrient management plans, which are documents that incorporate soil test results, yield goals, and estimates of residual N to generate field-by-field nutrient recommendations.

Link: http://anmp.umd.edu/ Accessed January 27, 2010

49. Nutrient Management Plan Writing Tools—University of Maryland Extension

A nutrient management plan is a formal document that balances crop nutrient needs with nutrients that are applied in the form of commercial fertilizer, animal manure, or biosolids. The plan contains soil test results, manure and biosolids analyses (where applicable), yield goals, and estimates of residual N to generate field-by-field nutrient recommendations. The following information sheets and work sheets will help producers in the plan writing process.

Link: http://anmp.umd.edu/Plan/Plan_Writing.html Accessed January 27, 2010

50. Phosphorus Site Index—University of Maryland Extension

The Phosphorus Site Index, or PSI, is an integral part of a nutrient management plan. If a producer intends to add P in commercial or organic forms (including starter fertilizer) to a field and the soil test indicates a P fertility index value (FIV-P) of 150 or more for that field, the PSI should be calculated. The PSI takes into consideration P loss potential due to site and transport characteristics and management and source characteristics.

Link: http://anmp.umd.edu/PSI/PSI.html Accessed January 27, 2010

51. Nutrient Management Software and Publications—University of Maryland Extension

This page provides summary information and links to available publications and software for nutrient management in Maryland.

Link: http://anmp.umd.edu/Pubs/Pubs.html Accessed January 27, 2010

52. Nutrient Management Spear Program—Cornell University

The vision of the Cornell University's Nutrient Management Spear Program is to assess current knowledge, identify research and educational needs, conduct applied, field and laboratory-based research, facilitate technology and knowledge transfer, and aid in the on-farm implementation of strategies for field crop nutrient management, including timely application of organic and inorganic nutrient sources to improve profitability and competitiveness of New York State farms while protecting the environment.

This page has links to a variety of nutrient management resources, including nutrient guidelines, N management, and the New York State Phosphorus Runoff Index. These links provide additional links to tools and resources such as Cropware and other nutrient management calculators.

Link: http://nmsp.cals.cornell.edu/index.html Accessed January 27, 2010

53. Manure Management—Penn State College of Agricultural Sciences

This page provides information on manure management at animal operations, including links to information specific to Pennsylvania.

Link: http://www.das.psu.edu/research-extension/nutrient-management/manure Accessed January 27, 2010

54. Pennsylvania Nutrient Management Program—Penn State University

This Web site provides a comprehensive source of information about Pennsylvania's Nutrient Management Act (Act 38, 2005) Program, and associated technical guidance and educational information. It also provides limited information concerning related programs. The Web site has been developed and is maintained through a workgroup representing various partnering agencies actively involved with the Pennsylvania Nutrient Management Act Program. Contributions to this site represent the collective efforts of that workgroup

Link: http://panutrientmgmt.cas.psu.edu/ Accessed January 27, 2010

55. Planning Tools and Resources—Penn State University

This page provides links to the nutrient management plan standard format, a nutrient balance spreadsheet, the Pennsylvania Phosphorus Index spreadsheet, a pasture nutrient calculator, and other resources associated with nutrient management in Pennsylvania. The Phosphorus Index spreadsheet contains contact information for state experts.

Link: http://panutrientmgmt.cas.psu.edu/main_planning_tools.htm Accessed January 27, 2010

56. Nutrient Management Technical Manual—Penn State University

This is the technical manual for Pennsylvania's Nutrient Management Act Program.

Link: http://panutrientmgmt.cas.psu.edu/main_technical_manual.htm Accessed January 27, 2010

57. Educational Materials—Penn State University

This page provides links to fact sheets and publications addressing of wide range of topics associated with nutrient management and manure management in Pennsylvania.

Link: http://panutrientmgmt.cas.psu.edu/em_publications.htm Accessed January 27, 2010

58. Fact Sheets on Agriculture and Environmental Quality—Virginia Tech Extension

The page provides links to fact sheets covering a range of topics including composting, P management, and livestock exclusion.

Link: http://pubs.ext.vt.edu/category/environmental-quality.html Accessed January 27, 2010

59. Virginia Agricultural BMP Cost Share and Tax Credit Programs—Virginia Department of Conservation and Recreation

This page provides information and links associated with agricultural BMPs in Virginia, including the Virginia agricultural BMP manual and BMP cost-sharing.

Link: http://www.dcr.virginia.gov/soil_and_water/costshar.shtml Accessed January 27, 2010

60. Nutrient and Waste Management—West Virginia University Extension Service

This page provides links to nutrient management training courses including the P index, information on nutrient management consultant certification, manure sampling and analysis methods, and related Web sites.

Link: http://www.wvu.edu/~agexten/wastmang/index.html Accessed January 28, 2010

61. Comprehensive Livestock Environmental Assessments and Nutrient (CLEANEast) Management Plan program—RTI International and North Carolina State University

CLEANEast provides confidential, free technical support to farms including beef, dairy, swine, or poultry operations located in 27 eastern states. It helps farm operators identify and implement farm management practices that protect the environment. CLEANEast is a voluntary program to which farm operators can apply for on-site support services from a qualified Technical Assistance Professional to:

- Conduct an Environmental Assessment
- Update an existing Nutrient Management Plan
- Prepare a new Nutrient Management Plan

Link: https://livestock.rti.org/ Accessed January 28, 2010

62. Comprehensive Nutrient Management Planning (CNMP)— eXtension

The details of a Comprehensive Nutrient Management Plan (CNMP) are described at this site, including links to various handbooks and guidance documents important to the development of a CNMP for an AFO. For example, a key objective of a CNMP is to document the plans of an animal feeding operation owner/operator to manage manure and organic by-products in combination with conservation practices and facility management activities to protect or improve water quality. NRCS has listed six elements of a CNMP that should be considered during preparation of the plan, though a CNMP is not required to contain all six elements. The components that should be considered are the following:

- Manure and Wastewater Storage and Handling
- Land Treatment Practices
- Nutrient Management
- Record Keeping
- Feed Management
- Other Utilization Activities

USDA-NRCS provides technical information for Comprehensive Nutrient Management Plans, including a complete description of these elements and what each element specifically covers in National Instruction 190-304. Users should check with their agriculture and natural resources agencies to see if their state has its own specific CNMP requirements and guidance.

Link:
http://www.extension.org/pages/Comprehensive_Nutrient_Management_Planning_%28CNMP%29
Accessed January 22, 2010

63. CNMP Core Curriculum—Iowa State University

There are several sources for additional information about Comprehensive Nutrient Management Plans (CNMPs). Many land grant universities and other commodity/producer organizations provide informational literature and Web sites. Additionally, state NRCS offices often maintain CNMP/TSP informational Web pages. A source of information about CNMPs is the CNMP Core Curriculum training modules maintained by Iowa State University and available through the Midwest Plan Service. The CNMP Core Curriculum is also a good resource for educators interested in providing training on CNMP development. Also, the breadth of information covered in the topic areas make the curriculum a good source of materials for smaller scale trainings, such as shorter, topic specific extension programs. The CNMP Core Curriculum provides a consistent background and framework from which state or regionally specific CNMP courses can be developed. There are ten sections in the CNMP Core Curriculum. The section topics are:

- Introduction to a Comprehensive Nutrient Management Plan
- Conservation Planning

- Land Treatment Practices
- Manure and Wastewater Storage and Handling
- Nutrient Management
- Feed Management
- Record Keeping
- Air Quality
- Alternative Utilization
- TSP Certification

Link: http://www.abe.iastate.edu/wastemgmt/cnmp-curriculum.html Accessed January 26, 2010

64. Manure Management Planner Tutorials—Univ. of Missouri Extension

These tutorials were part of a training program for Missouri nutrient management planners. The tutorials outline many of the steps in developing a nutrient management plan in MMP. Many of the steps in using MMP are universal among all states. These tutorials were developed in 2005 for an earlier version of MMP, but the authors believe that the tutorials are still mostly applicable to the planning process when using MMP. Separate tutorials were developed for a swine operation (liquid manure), poultry operation (solid manure) and fertilizer plan (no manure).

Link: http://www.nmplanner.missouri.edu/software/mmp_tutorial.asp Accessed January 22, 2010