Appendix A

Basic Soil Science and Soil Fertility

Introduction

Understanding the nutritional needs of plants can be quite complex, given the dynamic nature of plant nutrients in the soil. Nutrients can exist in organic or inorganic forms and in various phases. They can exist in solution, on mineral surfaces, or be retained in the structural framework of soils. Environmental conditions affect nutrients' transformations and movement in the soil, which determines their availability for plant uptake. In managed systems, understanding those transformations is essential for maintaining nutrient balances to properly supply a plant's nutritional requirements with minimal effect on the environment.

Soil Formation and Basic Morphology

Soil is the layer of unconsolidated material on the immediate surface of the earth that is capable of supporting plant life. Most soils contain four basic components: mineral particles, water, air, and organic matter. Organic matter can be further subdivided into roots, living organisms, and humus (a dark colored, semi-soluble organic substance formed from decomposition of other soil organic matter). A soil in good condition for plant growth will have a volume composition of approximately 50 percent solid material and 50 percent pore space. Under ideal moisture conditions for plants, the soil pore space would also consist of about half air and half water by volume (Figure A-1).

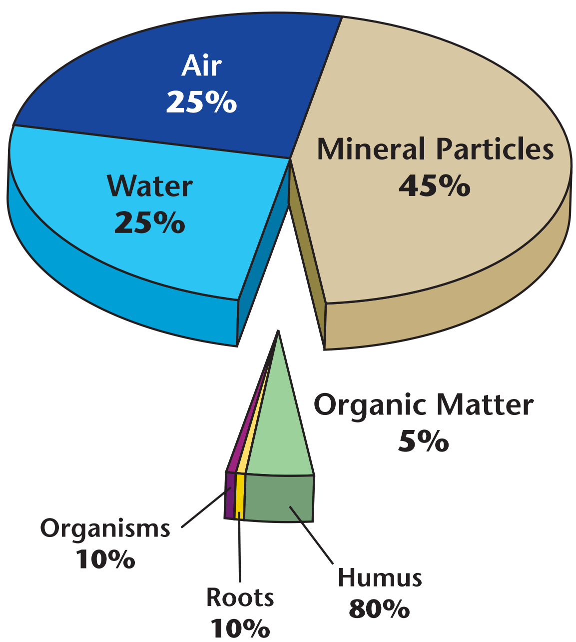


Figure A-1. Average composition of soil.
(Source: Pidwirny, M. J., *Fundamentals of Physical Geography*)

The mass of dry soil per unit of bulk volume, including the airspace, is called the soil bulk density. Bulk density is an indicator of soil quality. Soils with a high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pore space. As bulk density increases, pore space is reduced, which ultimately inhibits root growth. Not only is it more difficult for roots to penetrate through the soil, fewer pores means less aeration and water infiltration both of which also deteriorate the conditions necessary for optimum crop growth. Fine-textured soils such as silt loams, clays, and clay loams generally have lower bulk densities than sandy soils. Sandy soils typically have less total pore space than finer textured soils. Sandy soils lack the micro-pore spaces that exist within soil aggregates, which finer textured soils contain in addition to the macro-pore spaces that exist between soil aggregates (Figure A-2).[1] Although finer textured soils have very low bulk densities, when they become compacted, the bulk density can be quite high.

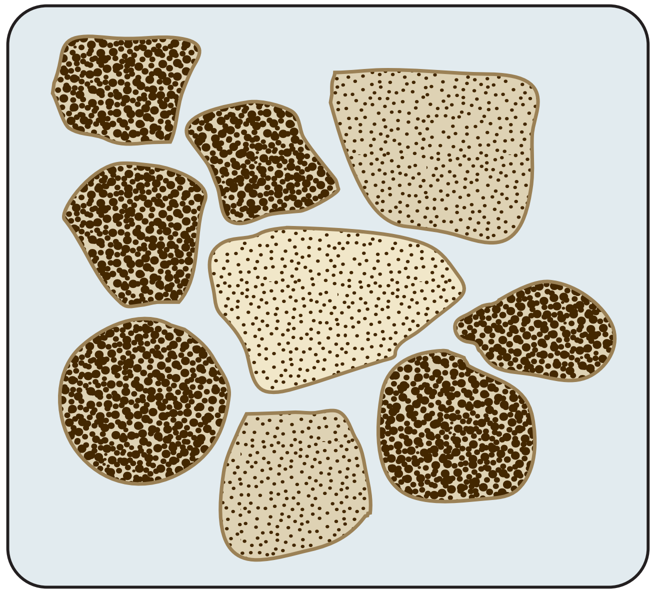


Figure A-2. Soil aggregates, aka micro & macro.

Heavy animal traffic and repeatedly driving farm equipment over fields and can compact soils, increasing the bulk density. Compaction deteriorates plant growth, and increased bulk density means a diminished capacity to infiltrate water and, therefore, greater surface runoff. It is extremely difficult to decrease the bulk density of a soil once it has been compacted. Tillage practices can initially loosen the soil surface and improve aeration and infiltration; however, over long periods those practices also lead to an overall increase in soil bulk density. The effects that different practices can have on increasing soil bulk density should be considered so that they can be minimized to improve the longevity of the soil, reduce surface runoff and help crops reach optimum yield potentials.

Soil is largely made up of mineral material from weathered rock (also called parent material), which is the product of thousands of years of physical processes. Temperature changes, water, ice and wind abrasions, and plants and animals all act to physically wear down rock and minerals. Physical weathering exposes greater amounts of surface area that can simultaneously weather through chemical processes. Many chemical reactions can take place during soil formation. Acid-producing reactions are one example that is enhanced once a soil begins supporting living organisms. Carbon dioxide is emitted through respiration and decomposition. Carbon dioxide dissolves in water held in the soil pore spaces to form carbonic acid, which dissolves minerals. Physical and chemical weathering will occur simultaneously and enhance each other, greatly speeding up the soil-forming process.

The soil-forming process produces distinct visible layers, called horizons, in the soil. The horizons are defined by the soil's color, texture, consistency, and structure. Horizons will also vary in chemical characteristics or composition. Figure A-3 shows the major horizons in a soil profile.

Some soils will have an O (organic) horizon on the surface that consists mainly of plant litter at various levels of decomposition. The O horizon is unlikely to be identified in cultivated fields because the layer is easily lost though erosion that can result from years of plowing and tilling.

Horizon A is the surface soil (also called the topsoil) and is the layer where crops are planted and grown. Typically, the layer contains more organic matter and is coarser than the lower horizons. The humus in the surface soil imparts a distinct grayish to dark-brown to black color to the horizon. Generally, the darker the color of a soil, the more humus is present. Horizon A is the zone of maximum biological activity.

Horizon B is the subsurface soil, which is also called the subsoil. There is generally more clay, which makes the horizon finer-grained than the surface horizon. Horizon B's color is usually brighter, ranging from red to brown to yellow. The layer generally accumulates all or most of the silicates, clay, iron, and aluminum in the soil.

Horizon C is formed in the parent material and has acquired some characteristics of the subsoil. The parent material can be alluvium, loess, colluvium,[2] or bedrock. If formed in bedrock, the layer will sometimes look like weathered rock, but it is soft enough to be dug into and will crumble easily.

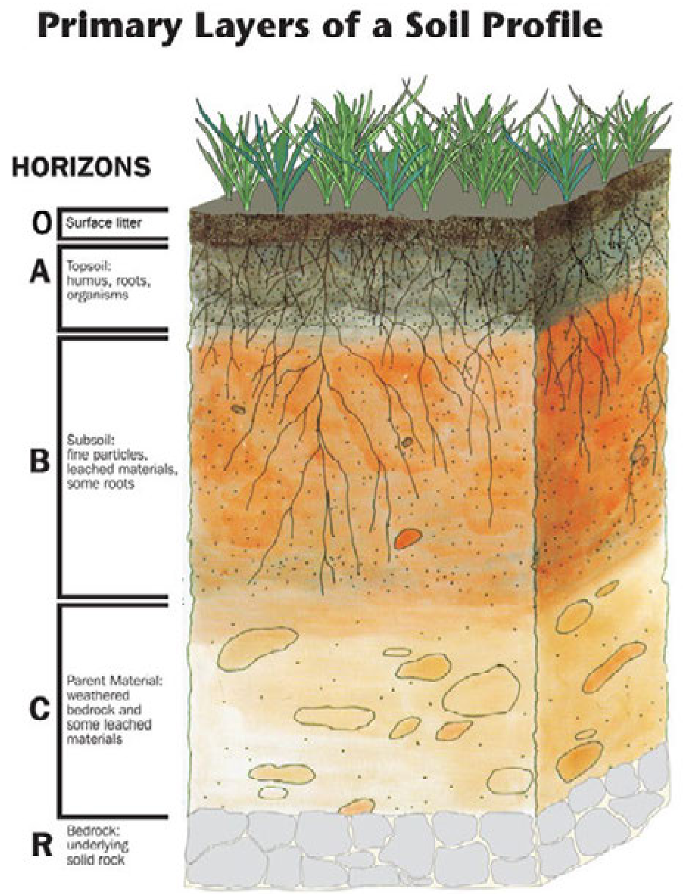


Figure A-3. The major horizons in a soil profile. (Source: Illinois Central Core)

The R horizon, if present, consists of unweathered bedrock.

Soil Properties

The properties of a soil result from the environmental factors and conditions that shaped the soil. The following characteristics are important factors that determine a soil's suitability for use and its management needs.

Organic Matter

Organic matter in soil is derived from decomposed plant and animal material. The amount of organic matter depends on the type of plants that are growing in the soil, how long the plants have been growing, and the water content or moisture in the soil. Humus is the most reactive and important component of soil organic matter.

An adequate level of humus provides soil with a number of benefits:

- Increased ability to hold and store moisture.
- Helps maintain porosity in fine-textured soils.
- Reduces leaching of soluble nutrients to lower soil layers.
- Important source of carbon and nitrogen (N) for plants.
- Improves soil structure for plant growth.
- Decreases erosion losses.

Texture

Texture refers to the fineness or coarseness of the mineral particles in the soil and is determined by the relative amounts of different sized mineral particles in the soil. Particles are normally grouped into three main classes: sand, silt, and clay (Table A-1).

Table A-1. Soil classification by particle size

Classification	Soil particle size
Sand	0.05 to 2 mm
Silt	0.002 to 0.05 mm
Clay	< 0.002 mm

Mineral particles that are larger than 2 mm in diameter are considered coarse fragments. Mineral particles that range from 0.05 mm to 2 mm in diameter are called sand. Sand feels rough when rubbed between the thumb and fingers. Soil particles between 0.002 mm to 0.05 mm in diameter are classified as silt. Dry silt feels smooth and silky and retains an imprint when pressed. Wet silt remains smooth and does not become slick or sticky. Clay is the finest sized particle, with each particle smaller than 0.002 mm in diameter. When dry, clay feels very smooth. When wet, clay becomes slick and sticky and holds its form when shaped.

The proportion of sand, silt, and clay form the basis for 12 primary classes of soil texture (Figure A-4 and Table A-2). The texture of a soil affects the movement of air and water, as well as plant root penetration. However, most importantly, the texture of a soil determines the amount of surface area available. The surface of a mineral is where water, nutrients, chemicals, microorganisms, and charges are held and released. That ultimately determines the soil's water-holding capacity and fertility. Coarse and sandy soils allow for more rapid infiltration rates for water as opposed to more fine-textured or clay soils. Sandy soils are also easier to till. Sandy soils are suited for producing specialty crops such as vegetables, tobacco, and peanuts. Fine-textured soils hold more water and

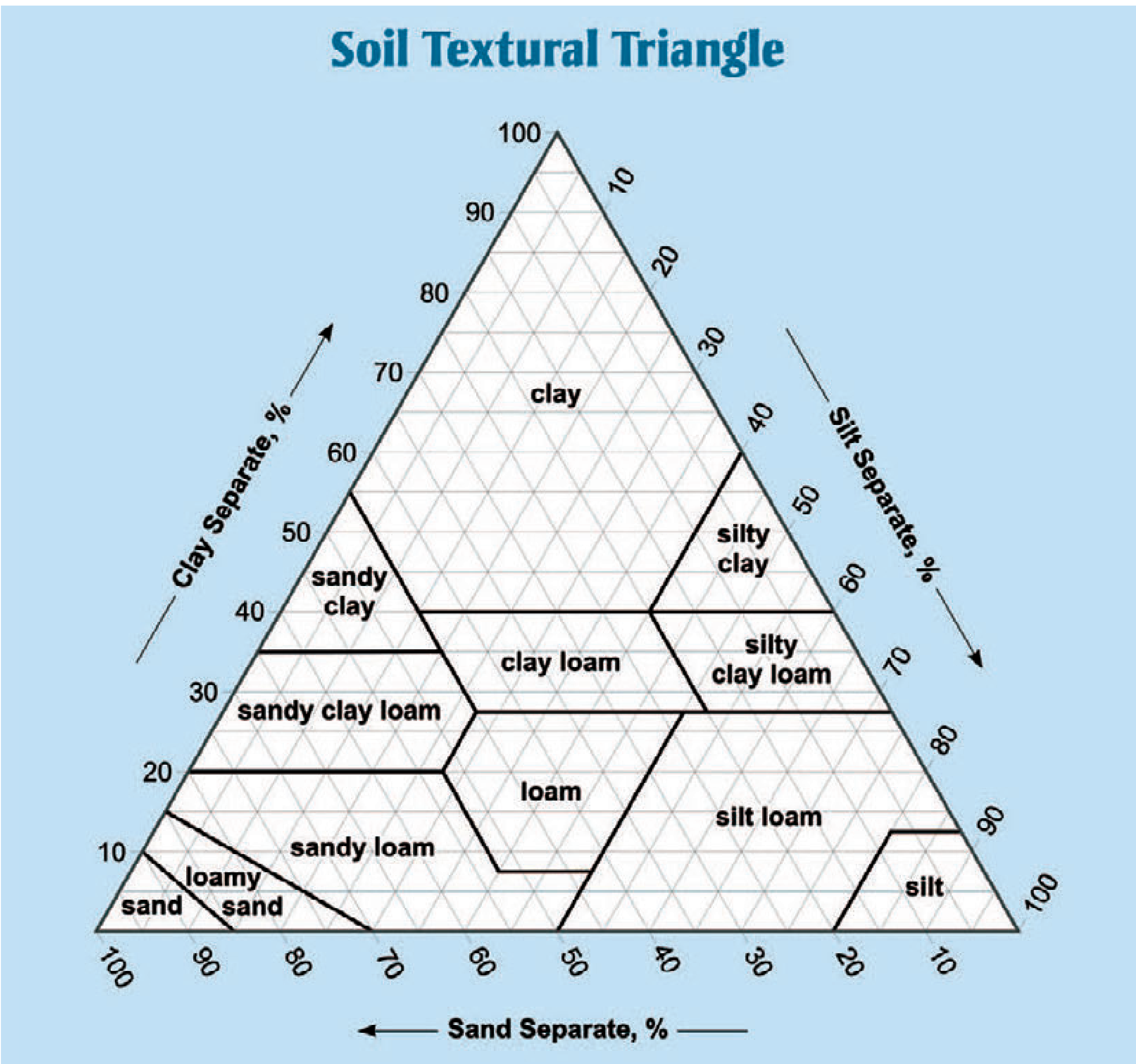


Figure A-4. Soil textural triangle. (Source: USDA/NRCS) plant nutrients and require less frequent nutrient applications. Moisture has a significant effect on the workability of fine soils. Such soils can form puddles after a rain and can develop a crust. Fine-textured soils are best suited for producing corn, small grains, hay, and forages.

Table A-2. Soil texture classes

Texture classes of soils[a]		
Common names	**Texture**	**Class names**
Sandy soils	Coarse	Sandy, loamy sands
Loamy soils	Moderately coarse	Sandy loam, loam
	Medium	Silt loam, silt, clay loam
	Moderately fine	Sandy clay loam, silty clay loam
Clayey soils	Fine	Sandy clay, silty clay, clay

a. Adapted from Smith 1990

Aggregation and Structure

The cementing or binding together of several soil particles into a secondary unit is called soil aggregation. The soil particles are arranged or grouped together to form structural pieces (building blocks) called peds or aggregates, in various shapes and sizes. The arrangement of the aggregates determines the soil's structure (Figure A-5).

Structure is an important soil characteristic because good structure allows favorable movement of air and water and allows and encourages extensive root development.

The formation of aggregates and good structure of the surface soil is promoted by a proper supply of organic matter, adequate lime, and working or tilling the soil during correct moisture conditions. On the other hand, structure is weakened or destroyed when organic matter is depleted, when inadequate lime is used, and when the soil is tilled or worked with too much or too little moisture in the soil.

Color

The color of a soil has little influence on a soil's function; however, it tells a great deal about the soil. Soil colors are often a result of the various oxidation states of the minerals present. Brighter colors such as yellow and reds are an indication of iron oxides. The brighter colors suggest good drainage and aeration. Grayish soils can indicate iron reduction caused by permanently saturated soil. Soils with mottled colors of various shades of yellow, brown, and gray are indicative of a fluctuating aerobic and anaerobic environment. Aside from iron, other minerals that contribute to soil color are manganese oxide, glauconite, and carbonates. Additionally, very dark browns and black soil colors can be an indication of high levels of organic matter.

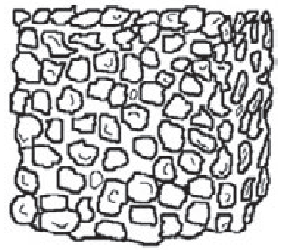
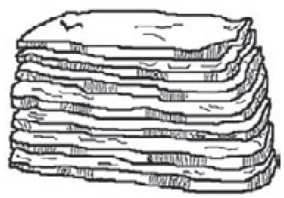
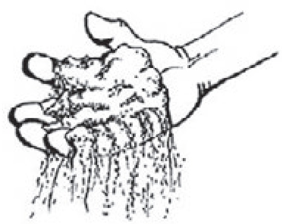
	**Granular:** Resembles cookie crumbs and is usually less than 0.5 cm in diameter. Commonly found in surface horizons where roots have been growing.
	**Platy:** Thin, flat plates of soil that lie horizontally. Usually found in compacted soil.
	**Single Grained:** Soil is broken into individual particles that do not stick together. Always accompanies a loose consistence. Commonly found in sandy soils.

Figure A-5. Examples of soil structure. (Source: Soil Science Education home page)

Retention/Water-Holding Capacity

The amount of water retained in a soil is dependent on the interaction of soil texture, bulk density, and aggregation. The term field capacity defines the amount of water remaining in a soil after downward gravitational flow has stopped, and it is expressed as a percent by weight. The permanent wilting percentage represents the amount of water in soil after plants are permanently wilted. Water is still in the soil, but it is held so tightly that it is unavailable for plant use. The difference between field capacity and the wilting point is the plant-available water (Figure A-6). Irrigation water is generally applied when the soil moisture is depleted by 40 to 60 percent of field capacity. Irrigation water is applied to bring the soil moisture back to near field capacity.

Sandy soils hold little water because their large pore spaces allow water to drain freely. While clay soils have greater water-holding capacities because of their small pore spaces, they also hold water more tightly than sandy soils, making a certain amount of water unavailable to plants. The amount of organic matter and stoniness in soils improves the available water capacity for plant use. Coarser soils tend to have the lowest plant available water capacity, while medium-textured soils tend to have the highest. Decreasing the bulk density of soils reduces water-holding capacity.

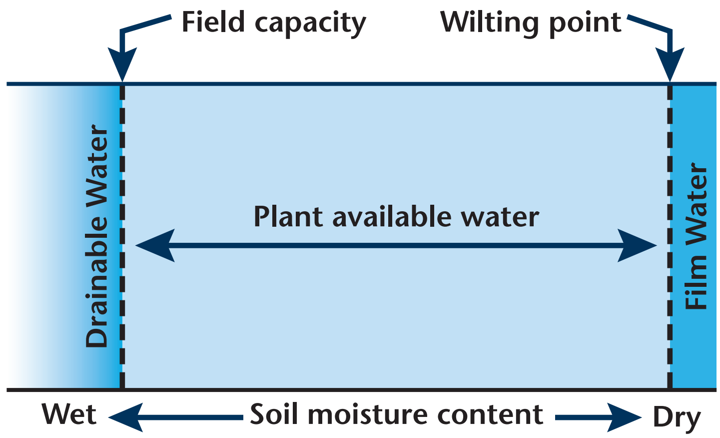


Figure A-6. Plant available water and drainable water in relation to field capacity and wilting point.
(Source: University of Minnesota)

Drainage

Soil drainage is defined as the rate and extent of water removal. That includes water movement across the surface and downward through the soil. Topography is a very important factor in soil drainage. Other factors that affect drainage include the soil layers' texture and soil structure. Poor drainage is indicated by a mottled gray soil color, constantly wet soil, or water *sitting* on the soil surface for a long time after rain or irrigation. If drainage is poor, plant roots are deprived of oxygen. Thus, adequate drainage is essential to good plant growth. Conversely, excessively drained soils, such as very sandy soils or those on steep slopes, tend to hold too little water for normal plant growth.

Cation Exchange Capacity

Soil materials have a net surface charge, usually negative, that allows them to hold and retain ions (i.e., nutrients) against leaching. The net negative charge of a soil is largely attributed to the clay and organic matter in the soil and will naturally attract positively charged nutrients and repel negatively charged nutrients. That explains why cations, the positively charged nutrients (such as ammonium (NH_3^+)), remain in the soil while anions, the negatively charged nutrients (such as nitrate (NO_3^-)), are repelled and easily leached out of the soil.

The cation exchange capacity (CEC) is a measure of the soil's ability to retain cations and, therefore, is indicative of the soil's fertility. In addition to clay and organic matter, pH has an effect on CEC. Increasing soil pH increases its CEC, activating more ion exchange sites.

Soils with low CEC can have one or more of the following characteristics:

- High sand and low clay content.
- Low organic matter content.
- Low water-holding capacity.
- Low pH value.
- Lightly buffered and cannot easily resist changes in pH or other chemical changes.
- Nutrients are leached very easily.
- Productivity can be low.
- Certain types of clay such as kaolinite will have a much lower CEC than a montmorillonite or vermiculite (high shrink and swell clays).

Soils with a higher CEC can have one or more of the following characteristics:

- Low sand and high clay content.
- Moderate to high organic matter content.
- High water-holding capacity.
- Highly buffered and resist changes in pH or other chemical changes.
- Nutrients are retained and leaching losses reduced.

A soil's CEC directly affects the amount of fertilizer that should be used and the frequency with which it should be applied.

Soil Fertility

Soil fertility is the ability of a soil to provide nutrients for plant growth (Table A-3). Many factors affect the availability of elements in soil, including the form of the element found in the soil, pH, soil aeration, soil compaction, soil temperature, and soil moisture. As described, the ability of a soil to retain nutrients is related to its CEC. Many of the important plant nutrients are cations, which are retained by the soil's negative charge. Those include ammonium (NH_4^+), calcium (Ca^{2+}), potassium (K^+), sodium (Na_2^+), aluminum (Al^{3+}), hydrogen (H^+), and magnesium (Mg^{2+}). As the CEC increases, the soil's ability to retain and provide nutrients to plants increases. Therefore, the fertility and productivity of a soil can be greatly influenced by the CEC. Negatively charged ions, or anions, are leached than positively charged ions. For example, NO_3^- is not retained in the soil profile because of its negative charge. An exception occurs with phosphorus (P). Although it exists in the anionic form, the properties of phosphate anions allow them to (1) react with other minerals in the soil and form low-solubility compounds that are unavailable to the plant and (2) to become fixed on and in available sites of clay particles through a process known as phosphorus fixation. Thus, phosphorus leaching is limited unless soil concentrations become very high or in sandy soils because of limited fixation sites.

Table A-3. Essential plant nutrients

Plant-available forms of essential elements	
Primary plant nutrients	
Nitrogen	NH_4^+, NO_3^-
Phosphorus	HPO_4^{2-}, $H_2PO_4^-$
Potassium	K^+
Secondary plant nutrients	
Calcium	Ca^{2+}
Magnesium	Mg^{2+}
Sulfur	SO_4^{2-}
Carbon	CO_2
Hydrogen	H^+, OH^-

Soil pH affects plant nutrient availability because pH greatly influences the solubility of certain elements. Most crops grow best in slightly acidic soils (pH 6.0 to 6.5). Acidification is a natural and continuous process in many soils. Through chemical weathering, cations are released from parent materials and become available on the exchange complex of a clay particle. Soils become acidic when the cations are displaced by acid ions, mostly H^+ and Al^{3+}. Acid ions are prevalent in the soil because of other ongoing chemical processes in the soil that release them. When exposed to water, the non-acidic cations (K^+, Ca^{2+}, and Mg^{2+}) and anions are leached from the soil profile, leaving the exchange complex and soil solution acidic. In areas with high annual rainfall, soils tend to be acidic because of the increased leaching conditions. For that reason, soils in Eastern states are generally more acidic than those in the Midwest and Western United States.

The working of ground limestone into the soil to raise soil pH is referred to as liming. The benefits of liming are both direct and indirect. Some direct benefits include the reduction of Al^{3+} and Mn^{2+} solubility (both ions are toxic to most plants unless at very low concentrations), and the application of Ca^{2+} and/or Mg^{2+}, both of which are plant nutrients. Indirect benefits include increased microbial activity and the increased Ca^{2+} levels in the soil can improve the soil structure. The benefits of liming are generally expected to last for at least 5 and commonly up to 10 years. While liming has many beneficial effects, over liming can easily induce micronutrient deficiencies in many crops adapted to low or moderate pH conditions.

For a plant to take up nutrients, the nutrient must exist in the soil solution (water-filled pore space) and be in a soluble form. A large amount of nutrients are stored in the solid framework (mineral and organic material) of a soil; however, the nutrients are released slowly to the soil solution through chemical and biochemical processes. The soil solution usually holds insufficient quantities of nutrients for plant's nutritional needs. The larger particles (sand, silt, large clay particles, and organic matter), tightly entrap and retain certain nutrient species making them available very slowly over time. Within the colloidal size fraction, nutrients are exposed to a greater surface area and broken down faster, but they are still entrapped and, thus, are only slightly more available. Nutrient ions are also adsorbed to mineral surfaces, in what is considered an exchangeable form, but the nutrients are also only moderately available. It is only when they reach the soil solution that nutrients are free and available for plant uptake and considered *plant available*.

In addition nutrients being plant available, nutrients must be at the root surface for uptake. If nutrients are not in direct contact with the root, they must move by mass flow or diffusion. Root uptake of nutrients is an active metabolic process. Therefore, even if adequate plant-available nutrients are present, factors that deter flow and root metabolism, such as soil compaction, cold temperatures, lack of water or oxygen, can inhibit plant uptake of nutrients.

Forms and Fate of Nitrogen

Nitrogen is an essential part of amino acids, the building blocks for proteins, making it an important plant nutrient. In the soil, it exists in both organic (proteins, amino acids, urea, in living organisms and decaying plant and animal tissues) and inorganic forms [ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and ammonia ($NH_{3(gas)}$)]. The majority of nitrogen in the soils is in an organic form (95 to 99 percent as amine groups in proteins), which is largely unavailable for plant uptake. Figure A-7 illustrates the processes responsible for converting nitrogen into plant available forms.

Microbes break down organic compounds releasing ammonium ions through a process called mineralization. Mineralization occurs as a result of decomposition. The factors that control decomposition control the rate of mineralization and, therefore, the rate at which plant available nitrogen is released to soil. Factors controlling decomposition include soil conditions that encourage microbial growth and the carbon:nitrogen (C:N) ratio of the compound that is being degraded. Adequate soil moisture and aeration, near-neutral soil pH, and warm soil temperatures are conditions that are favorable to a broad range of organisms.

Microbes need carbon, but they also require nitrogen for building cells and extracting energy. The C:N ratio of the compound being decomposed is a critical factor in determining if nitrogen is utilized by the microbes for energy and depleted from the soil or supplied to the plant available nitrogen pool in the soil. When materials with a high C:N ratio, such as corn stalks (C:N ratio is typically 55:1) are added to soil, microorganisms begin to degrade the compound as a food source. Given the limited amount of nitrogen in the source itself, the microbes will scavenge the soil for available nitrogen, which is necessary for decomposition. In such situations, the soil can be depleted of plant available nitrogen. On the other hand, when an organic compound with a low C:N ratio, such as alfalfa hay (C:N ratio is typically 13:1) is added to soil, there is sufficient nitrogen in the compound itself for decomposition. The microbes do not need to use nitrogen from the

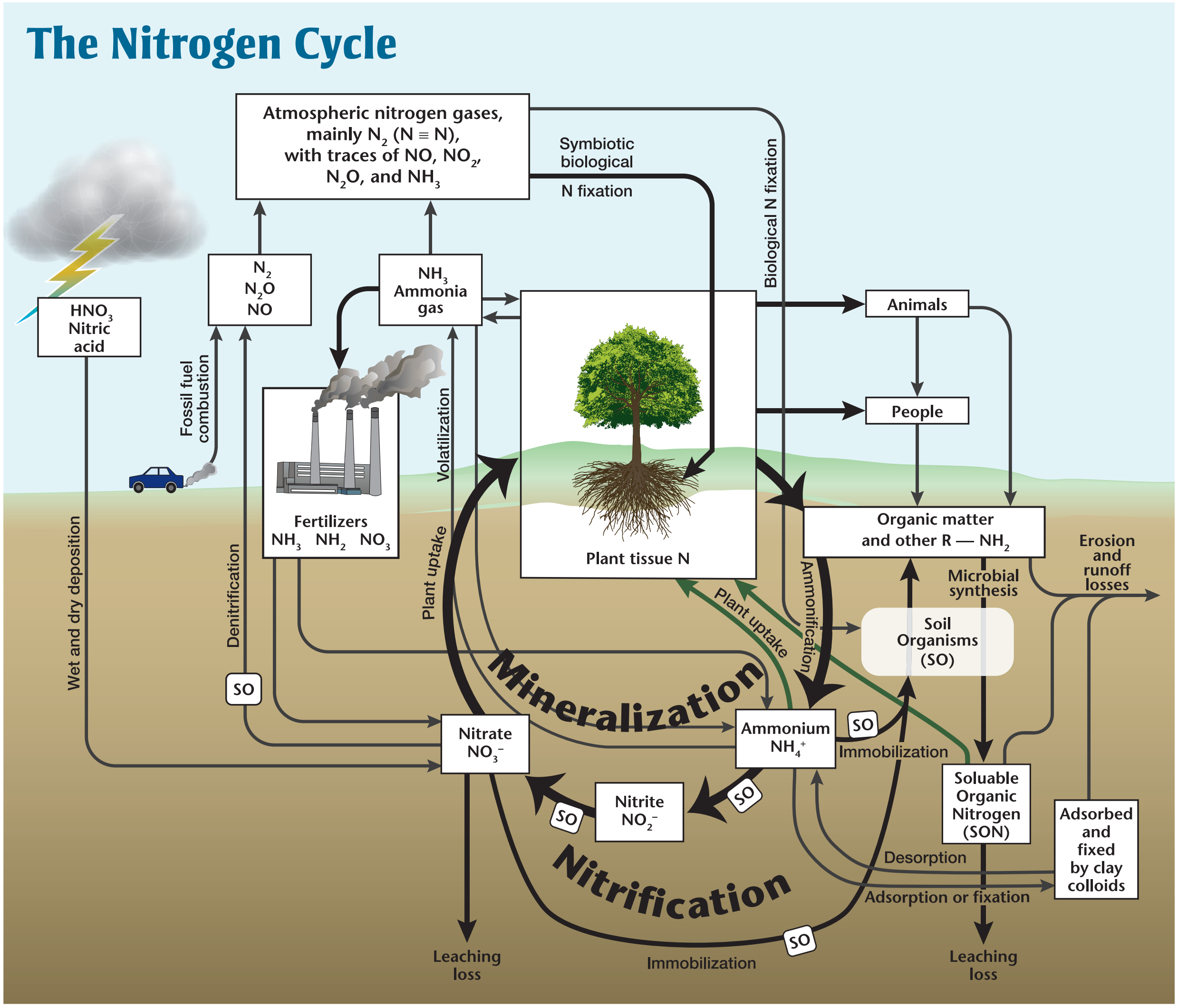


Figure A-7. The Nitrogen Cycle.

soil. Rather, decomposition of the material can release plant available nitrogen from the organic compound to the soil.

As mineralization occurs, if ammonium is released to the soil, it can be directly absorbed by a plant or it can be oxidized to nitrate and then absorbed. Because soil systems often are aerobic, ammonium does not typically persist in the soil in large quantities. Ammonium is a positively charged ion, which means, if it is present in a soil, it can be retained by the negatively charged soil particles on a soil's exchange complex. As previously mentioned, nutrients held on the mineral exchange complex are moderately plant available because, while they are retained on the mineral surface, they can be displaced by competing ions to the soil solution. Ammonium can also become fixed within the crystal structure of certain types of clay particles because of its size and the arrangement of the specific clay particles. Fixed ammonium is only slowly released to the soil solution and would not be a sufficient source of nitrogen for plants.

When manure is land applied as an organic compound, only a small fraction of the nitrogen might be soluble as ammonium and plant available. However, a larger portion of that nitrogen is mineralized by microbes and slowly released over many years. Nitrogen mineralization rates of the organic nitrogen present in the initial land application vary depending on various environmental factors such as soil type, the manure source, and climate. For example, cattle manure mixed with bedding that has been stored under cover will have approximately 60 percent of the organic nitrogen fraction mineralized in the year of application; 6 percent in the second year, and 2 percent in the third year. For many types of manure, 1 to 4 percent of organic nitrogen is still being released 4 years after the initial application. Therefore, calculations to determine annual land applications of nitrogen should account for released forms of nitrogen from previous organic nitrogen applications.

As nitrogen-containing organic compounds such as manure and fertilizers are broken down, ammonia can be released. Ammonia is most commonly found as a gas and is released from a soil system through a process called volatilization. Volatilization occurs at the liquid air interfaces and is controlled by the pH and water content of the soils, which drive nitrogen either into or out of the soil. The loss of ammonia to the atmosphere is driven by high level pH soils. The importance of incorporating manures into soils is to minimize the contact area between the manure and the ambient air to reduce ammonia volatilization. Soils and plants have the ability to sorb ammonia from the atmosphere, but fertilizer recommendations do not consider atmospheric nitrogen sources. As a result, areas that are exposed to high atmospheric ammonia concentrations (such as intensive livestock operations) could be having fertilizers applied at rates in excess of plants' needs.

Nitrate is another plant available form of nitrogen that can enter the soil system through atmospheric deposition, commercial fertilizers, and transformation of ammonium as mentioned above. Ammonium is oxidized to nitrite, which is quickly oxidized to nitrate by nitrifying bacteria as long as favorable soil conditions exist for the bacteria to survive. Nitrite is also plant available, but it can be toxic to plants and rarely persists in the soil in significant concentrations. As opposed to ammonium, nitrate is a negatively charged ion that is not adsorbed to the negatively charged soil mineral surfaces. Therefore, nitrate is readily available to plants, but if excess nitrate persists in the soil solution, the negatively charged nutrient is repelled by the soil surfaces and lost to groundwater through leaching. Factors that contribute to nitrogen leaching or runoff include over-application of nitrogen as fertilizers or manure particularly on sandy or coarse-textured soils; improperly timed applications of nitrogen, poorly designed or nonexistent soil conservation measures; and periods of exceptionally heavy rainfall.

Anaerobic bacteria can also reduce nitrate to nitrogen gas through a process called denitrification. Denitrification is a series of bacteria driven reduction reactions that reduce nitrate ultimately to nitrogen gas. Because denitrification is a reduction reaction, it requires an anaerobic environment, such as saturated soils. Only when soil oxygen levels are low enough, typically in waterlogged or poorly drained soils, will nitrate be fully reduced resulting in the formation of nitrogen gas. When oxygen levels fluctuate, as they commonly do in the field, nitrate will not be fully reduced and nitric oxide (NO) and nitrous oxide (N_2O) can be released to the atmosphere because those are intermediate by-products.

Forms and Fate of Phosphorus

Phosphorus is an important plant nutrient because it is an essential component of deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and the nucleotide adenosine 5'-triphosphate (ATP), which are necessary for intracellular energy transfer. Unlike nitrogen, gaseous forms of phosphorus seldom exist and are often not considered in the phosphorus cycle (Figure A-8).

Organic phosphorus usually occurs in microbial biomass and organic matter compounds. Inorganic phosphorus commonly appears in the form of phosphates (HPO_4^{-2} and $H_2PO_4^{-}$). Relative to other nutrients, phosphorus in soil solution is found in very low concentrations (0.001 to 1 mg/L) that rarely exceed 0.01 percent of total soil phosphorus.

When phosphate ions are added to a soil, they are quickly (within hours) removed from solution to form phosphorus containing compounds with very low solubility. Phosphate most commonly forms compounds with either calcium or iron and aluminum (sometimes manganese). Initially, some ions are retained on the exchange complex, which makes them moderately plant available but with time, they undergo sequential reactions that continually decrease their solubility.

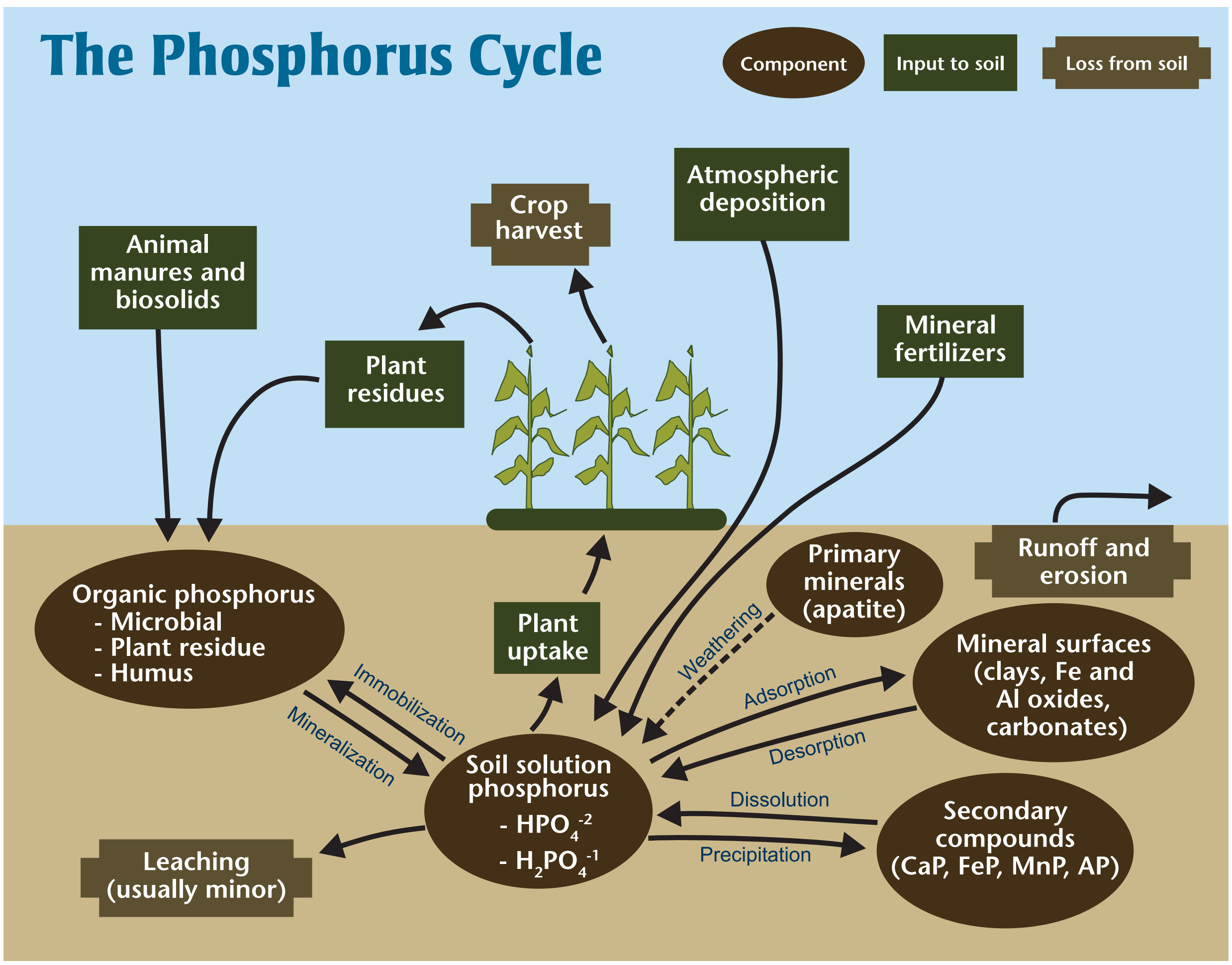


Figure A-8. The Phosphorus Cycle.

Such reactions result in phosphorus permanently bonding to the calcium or aluminum/iron/manganese ions, becoming buried under products from additional precipitation reactions. Those reactions can also entrap phosphorus within the calcium or iron/aluminum/manganese particles. That is regarded as phosphorus fixation and it is not easily reversible.

The capacity for soils to fix phosphorus depends on a number of soil factors including the mineral type, pH, and amount of organic matter. Phosphate ions are negatively charged; therefore, the minerals sorbing and fixing the ions must be positively charged. Certain types of minerals have a greater capacity for sorbing anions than others. The pH of the soil affects the solubility of the calcium and iron and aluminum phosphate compounds with the greatest fixation occurring at low and high pH values. Organic matter and by-products from its decomposition compete with phosphate ions for adsorption sites on mineral surfaces; therefore, soils with low organic matter concentrations tend to fix more phosphorus, making less available to plants. Because fixation depends on available mineral surface area and sorption sites, soils have a finite capacity to fix phosphorus.

Additions of fertilizers and manures typically allow for only 10 to 15 percent of added phosphorus to be taken up by plants because of that fixation capacity. Therefore, during the early and mid-20th century, farmers applied phosphorus in quantities far in excess of the plants' nutritional needs. In addition, manure has historically been applied at rates to meet plant nitrogen requirements, which can supply 2 to 4 times the phosphorus requirement. What was not removed in the harvest could accumulate in the soil in an insoluble, unavailable form. That became common practice and over the years, many fertilized, cultivated soils have reached their phosphorus fixation capacity. Note that that was not the case everywhere. In many developing countries where fertilizer is seldom used, phosphorus is often the limiting nutrient in food-crop production.

If not taken up by plants, phosphorus can be lost with surface runoff as dissolved phosphorus (if not incorporated into a soil) or it can be lost with soil particles through erosion or colloid leaching if sorbed to mineral surfaces. Soil particles containing fixed phosphorus that are lost through erosion might not appear to degrade water quality because of phosphorus fixation. However, in prolonged anaerobic environments (i.e., river beds) iron that is binding phosphorus will be reduced. While oxidized iron is insoluble, reduced iron is soluble allowing for the bound phosphate to be released into solution, contributing to water quality problems like eutrophication.

Water Quality

Water pollution from cropland is controlled in large part by the hydrologic cycle. Precipitation and irrigation add water, which, once at the soil surface, infiltrate, pond, or run off. Two types of losses from soils that affect water quality are (1) percolation or drainage, and (2) runoff. Percolation results in the loss of soluble elements (leaching), thus depleting soils of certain nutrients. Runoff losses generally include water and appreciable amounts of soil (erosion).

Two prime reasons raise concern over the loss of essential elements by leaching and erosion. First is the obvious concern for keeping nutrients in the soil so that they are available to crops. A second and equally significant reason is to keep the nutrients out of streams, rivers, and lakes. Nitrate contamination of ground and surface waters can cause serious environmental damage. Nitrates in drinking water are toxic because they reduce the capacity for blood to carry oxygen. That can be lethal to human infants and can alter normal body functioning in adults. Some underground sources of drinking water have become sufficiently high in nitrate causing health concerns for humans. Likewise, surface runoff waters from heavily fertilized lands can contain levels of nitrate toxic to livestock. While phosphorus is not toxic, it can degrade water quality if lost from a soil system in significant quantities. Excessive growth of algae and other aquatic species takes place in water overly enriched with nitrogen and phosphorus. That process, called eutrophication, depletes the water of its oxygen, thus harming fish, other aquatic species, and ultimately most life in the waterbody.

Infiltration, Percolation, and Leaching

As water enters a soil (infiltration) and moves down through the soil profile (percolation) it carries dissolved nutrients with it (leaching). Leaching losses occur when the amount of rainfall or irrigation water entering a soil exceeds the soil's ability to store it. The amount and rate of nutrient losses are influenced by the amount of rainfall or irrigation, the topography of the landscape, the amount of evaporation, the soil type, and the crop cover.

Soil properties have an effect on nutrient leaching losses. The physical properties of sand, silt, and clay, and the relative proportions of each have direct bearing on nutrient retention. As discussed, coarse soils (soils with a high percentage of sand) generally permit greater nutrient loss than do finer textured soils (soils with higher percentage of silt and clay). Organic matter content and type and amount of clay have significant influence on retention and nutrient storage and exchange.

The loss of nutrients through leaching is also influenced by climatic factors. In regions where water percolation is high, the potential for leaching is also high. Such conditions exist in the United States in the humid east and in the heavily irrigated sections of the west. In non-irrigated, semiarid areas, less nutrient leaching occurs because less water is added to the soil to contribute to the leaching process.

The proportion of rain or irrigation water entering the soil is enhanced by practices that keep the soil surface covered (e.g., with vegetation or mulch) to protect it from the beating action of rain drops that breaks down soil surface structure, decreasing porosity. Rain on bare soil also displaces soil particles that are easily transported by surface runoff.

Numerous best management practices are available to encourage residue management and to minimize negative consequences of soil tillage. Excessive tillage that destroys the surface roughness should be avoided. Tillage across the slope, leaving small ridges, encourages water infiltration. Likewise, terraces can help control the erosive potential of water movement and increase infiltration into the soil.

Runoff and Erosion

A primary principle of soil water management is to encourage water movement into rather than off the soil. The more water runs off the surface, the less infiltrates into the soil. Maintaining good soil structure is critical to reducing runoff; excess water that cannot infiltrate the soil accumulates on the surface and flows downgrade displacing surface soil particles along the way (erosion). Soil erosion damages productive soils and can increase nutrient transport to streams and lakes.

Two steps are recognized in the erosion process—the detachment or loosening influence and transportation by floating, rolling, dragging, and splashing. Freezing and thawing, flowing water, and rain are the major detaching agents. Those actions displace soil particles that are easily transported by surface runoff. Raindrop splash and especially running water facilitate the transport of loosened soil.

Following detachment, three types of water erosion are recognized: sheet, rill, and gully. In sheet erosion, soil is removed more or less uniformly from every part of the slope. However, sheet erosion is often accompanied by tiny channels (rills) irregularly dispersed, especially on bare land newly planted or fallow. That is called rill erosion. The rills can be obliterated by tillage, but the damage is already done—the soil quality in the field is diminished.

Where the volume of runoff water is further concentrated, downward cutting forms larger channels or gullies. That is called gully erosion. The gullies are obstacles to tillage and cannot be removed by ordinary tillage practices. While all types can be serious, the losses from sheet and rill erosion, although less noticeable, are responsible for most of the field soil deterioration.

The quantity of nutrients lost from the soil by erosion can be quite high. Such losses can be counterbalanced only in part by adding fertilizers; even still soils that are severely eroded might not respond well to fertilization. Much of the nitrogen and phosphorus lost is in eroded sediments, which include soil organic matter and finer particles.

Revised Universal Soil Loss Equation Version 2[3]

The Revised Universal Soil Loss Equation, Version 2 (RUSLE2), is designed to predict the long-term average rate of soil loss and guide conservationists on proper cropping, management, and conservation practices for a field or management unit. RUSLE2 cannot be applied to a specific storm or a specific year. Agricultural research coupled with centuries of farmers' experience has identified the major factors affecting erosion.

RUSLE2 is a computer model that uses a detailed mathematical approach for integrating multiple equations that describe how factors such as plant yield, vegetative canopy and rooting patterns, surface roughness, mechanical soil disturbance, amount of biomass on surface, and others affect soil erosion. The basic structure of the RUSLE2 equation is

$$A = RKLSCP$$

where

A = predicted average annual soil loss from rill and inter rill erosion caused by rainfall and its associated overland flow expressed in tons/acre/year.

R = climatic erosivity.

K = soil erodibility measured under a standard condition.

L = slope length.

S = slope steepness.

C = cover and management.

P = support practices (erosion control).

RUSLE2's predicted soil losses can be compared with soil loss tolerances (T) to provide guidelines for effective erosion control.

Soil Loss Tolerance

Soil loss tolerance (T) is the maximum amount of soil loss in tons per acre per year that can be tolerated and still permit a high level of crop productivity to be sustained economically and indefinitely.

A Natural Resources Conservation Service conservation plan is essentially a set of conservation practices that are designed to work in an integrated manner to accomplish an identified level of resource treatment. Developing a conservation plan involves determining the baseline erosion and other associated losses and evaluating the practices that would meet T.

RUSLE2's user interface allows a user to select from its database values to describe site-specific field conditions for climate, soil, topography, and land use. A brief description of each factor and the extent of its influence on soil erosion follows:

Rainfall erosivity, the R factor, is the most important climatic variable used by RUSLE2. Erosivity is related to rainfall amount and intensity, with the latter generally being more influential. A high annual precipitation received in a number of gentle rains can cause little erosion, whereas a lower yearly rainfall descending in a few torrential downpours can result in severe erosion. Temperature is also a key variable as rain and temperature affect the longevity of materials like crop residue and mulch that can prevent erosion. RUSLE2 associates erosivity, precipitation, and temperature values with the location chosen by the user.

The soil erodibility factor, K, indicates the inherent erodibility of a soil. The two most significant and closely related soil characteristics affecting erosion are infiltration capacity and structural stability. The infiltration capacity is influenced greatly by structural stability, especially in the upper soil horizons. In addition, organic matter content, soil texture, the kind and amount of swelling clays, soil depth, tendency to form a surface crust, and the presence of impervious soil layers all influence the infiltration capacity.

The stability of soil aggregates affects the extent of erosion damage in another way. Resistance of surface granules to the beating action of rain saves soil even though runoff does occur. The granule stability of some tropical clay soils accounts for the resistance of those soils to the action of torrential rains. Downpours of a similar magnitude on temperate region clays would be disastrous.

Values used by RUSLE2 for soil erodibility have been determined for most cropland and similar soils across the United States by the U.S. Department of Agriculture–Natural Resources Conservation Service. The user typically selects a soil-map unit name from a list of soils in the RUSLE2 database.

Site-specific values are entered for the topographic factor (*LS*), which reflects the influence of slope length, steepness, and shape characteristics. The greater the steepness of slope, other conditions being equal, the greater the erosion, partly because more water is likely to run off but also because of increased velocity of water flow. The length of the slope or flow path is important because it is directly proportional to the concentration of the flooding water.

Land use is the most important factor affecting rill and interrill erosion because it can be easily changed to reduce erosion. RUSLE2's cover-management (cultural) practices and support practices data are used to describe land use.

Soil detachment and erosive forces can be affected by cover-management practices. The cover and management factor, *C*, indicates the influence of cropping systems and management variables on soil loss. C is the factor over which the farmer has the most control. The type of crop, yield level, and tillage system used are important features to consider when land is used for crops. Forests and grass provide the best natural protection known for soil and are about equal in their effectiveness, but forage crops, both legumes and grasses, are next in protective ability because of their relatively dense cover. Small grains such as wheat and oats are intermediate and offer considerable obstruction to surface wash. Row crops such as corn and soybeans offer relatively little cover during the early growth stages and thereby encourage erosion. Most subject to erosion are fallowed areas where no crop is grown and all the residues have been incorporated into the soil. The marked differences among crops in their ability to maintain soil cover emphasize the value of appropriate crop rotation to reduce soil erosion.

RUSLE2 stores the description of any cover-management practice within its database and allows for selection of the practice that best fits site-specific field conditions. Key variables like yield level or mulch application can be changed so that the practice stored in RUSLE2 more accurately reflects the field conditions.

The support practice factor, *P*, reflects the benefits of contouring, strip cropping, terraces, diversions, small impoundments and other supporting factors. Such support practices reduce erosion primarily by reducing the erosivity of surface runoff. *P* is the ratio of soil loss with a given support practice to the corresponding loss when crop culture is up and down the slope. Like cover-management practices, support practices are selected from the RUSLE2 database and site-specific information such as the location of a practice is entered as required.

References

Brady, N.C., and R.R. Weil. 2002. *The Nature and Properties of Soils*. 13th ed. Pearson Education, Upper Saddle River, NJ.

Smith, R.L., and T.M. Smith. 1990. *Ecology and Field Biology*. Pearson Education, Upper Saddle River, NJ.

USDA-NRCS (U.S. Department of Agriculture, Natural Resources Conservation Service). 2011. *National Soil Survey Handbook*, title 430-VI. <*http://soils.usda.gov/technical/handbook/*>. Accessed November 11, 2011.

Endnotes

[1] Soil aggregrates – Groups of soil particles that bind to each other more strongly than to adjacent particles. The space between the aggregates provide pore space for retention and exchange of air and water. (Definition from USDA: *http://soils.usda.gov/sqi/publications/files/sq_eig_1.pdf*.)

[2] Alluvium – A general term for all detrital material deposited or in transit by streams, including gravel, sand, silt, clay, and all variations and mixtures of these. Unless otherwise noted, alluvium is unconsolidated.
Loess – Material transported and deposited by wined and consisting of predominantly silt-sized particles.
Colluvium – A deposit of rock fragments and soil material accumulated at the base of steep slopes as a result of gravitational action (from Brady and Weil 2002).

[3] Adapted from USDA-NRCS 2011.

Appendix B

Example Letters to Owners/Operators After a Site Visit

Example Letter in Follow-up to an Inspection: Facility *Not Designated* as a CAFO

[NAME & ADDRESS]

Dear Mr./Ms. _____________:

An inspection of your facility, located at [ADDRESS], was conducted on [DATE] by representatives of the [PERMITTING AUTHORITY]. The purpose of the inspection was to determine if conditions or practices on your animal feeding operation (AFO)[1] warrant designating your facility as a concentrated animal feeding operation (CAFO) and, consequently, requiring a National Pollutant Discharge Elimination System (NPDES) permit for operation.

During the inspection, no conditions or practices were observed to warrant designation of your facility as a CAFO at this time. However, the following observations were noted during the inspection.

[NOTE AREAS OF POTENTIAL CONCERN, IF ANY]

We request that you evaluate and address these areas of potential concern to ensure that they do not become problems. Technical information and assistance is available through [LOCAL NRCS OR EXTENSION OFFICE, STATE DEPARTMENT OF AGRICULTURE, OR US EPA's AGRICULTURAL ASSISTANCE CENTER (888/663-2155)].

The [PERMITTING AUTHORITY] may inspect your facility again in the future. Please be advised that any illicit discharges[2] to surface water or to surface water through a direct hydrological connection via ground water are violations of the Clean Water Act and subject to enforcement action with penalties.

Sincerely,

1 An animal feeding operation means a "lot or facility" where animals "have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period; and crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility." 40 CFR 122.23(b)(1). **[or alternate definition established by the Permitting Authority].**

2 In the absence of a NPDES permit, all discharges from the facility are prohibited.

Example Letter in Follow-up to an Inspection: Facility *Designated* as a CAFO

[NAME & ADDRESS]

Dear Mr./Ms. _____________:

An inspection of your facility, located at [ADDRESS], was conducted on [DATE] by representatives of the [PERMITTING AUTHORITY]. The purpose of the inspection was to determine if conditions or practices on your animal feeding operation (AFO)[1] warrant designating your facility as a concentrated animal feeding operation (CAFO) and, consequently, requiring a National Pollutant Discharge Elimination System (NPDES) permit for operation.

During the inspection, the following conditions were observed:

[NOTE THE CONDITIONS THAT SUPPORT THE CAFO DESIGNATION.[2]]

Based on these conditions, the [PERMITTING AUTHORITY] has determined that your facility is or has proposed to be a contributor of pollutants to the waters of the United States. As such, the [PERMITTING AUTHORITY] designates your operation as a CAFO, with the requirement of applying for a NPDES permit and taking immediate steps to cease existing discharges and eliminate the potential for future discharges, except as authorized by a NPDES permit.

1 An animal feeding operation is defined as a "lot or facility" where animals "have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period and crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility" **[or alternate definition established by the Permitting Authority]**.

2 In making a designation, the Director "shall consider the following factors: the size of the AFO and amount of wastes reaching waters of the United States, the location of the AFO relative to waters of the United States, the means of conveyance of animal wastes and process waste waters into waters of the United States, the slope, vegetation, rainfall, and other factors affecting the likelihood or frequency of discharge of animal wastes manure and process waste waters into waters of the United States; and other relevant factors." 40 CFR 122.23(c)(ii)(2).

To apply for a permit for your facility, [PROVIDE SPECIFIC INSTRUCTION AS TO WHETHER THEY ARE REQUIRED TO APPLY FOR AN INDIVIDUAL PERMIT OR SUBMIT AN NOI FOR A GENERAL PERMIT. INCLUDE STEPS AS TO HOW TO GET PERMITTED]

This letter includes web sites, hotlines, and other resources for small businesses that you may use to obtain assistance to comply with these requirements.

The [PERMITTING AUTHORITY] may inspect your facility again in the near future. Please be advised that discharges such as that observed on [DATE] are in violation of the Clean Water Act and as such can subject you to enforcement action with penalties.

Sincerely,

Compliance Assistance Resources

If you operate a small business as defined by the Small Business Administration (defined at 13 CFR 121.201; in most cases, this means a business with 500 or fewer employees), you may find the following information helpful.

The U.S. Environmental Protection Agency (EPA) and the U.S. Small Business Administration (SBA) offer small businesses a wide variety of compliance assistance resources and tools designed to help small businesses comply with federal and state environmental laws. These resources can help businesses understand their obligations, improve compliance and find cost-effective ways to comply through the use of pollution prevention and other innovative technologies.

We encourage you to take advantage of these tools to improve your understanding of and compliance with environmental regulations and avoid the need for future enforcement actions. ***Please note that any decision to seek compliance assistance at this time does not relieve you of your obligation to respond to an EPA request, administrative or civil complaint in a timely manner, does not create any new rights or defenses, and will not affect EPA's decision to pursue this enforcement action***.

Dissemination of this information sheet does not constitute an admission or determination by EPA that your business organization is a small entity as defined by the Small Business Enforcement and Fairness Act (SBREFA) or related provisions nor does it create any new rights or defenses under law.

Web sites

EPA offers a great deal of compliance assistance information and materials for small businesses on the following Web sites:

www.epa.gov	EPA's Home Page
www.smallbiz-enviroweb.org	Small Business Environmental Home Page
www.smallbiz-enviroweb.org/contacts/sbosbeap.aspx	Small Business Environmental Assistance Program State Contacts
www.epa.gov/smallbusiness	Small Business Gateway
www.epa.gov/smallbusiness/help.htm	Small Business Assistance, Help, and Training Web Page
www.epa.gov/compliance/incentives/smallbusiness/	Small Business Compliance and Enforcement
www.epa.gov/compliance/assistance/index.html	Compliance Assistance Home Page
www.epa.gov/oecaagct/tsma.html	EPA Ag Center Small Farm/Small Business Web Page

State Agencies

Many state agencies have established compliance assistance programs that provide on-site as well as other types of assistance. Please contact your local state environmental agency for more information.

Agriculture Compliance Assistance Center

EPA has established national compliance assistance centers, in partnership with industry, academic institutions, and other federal and state agencies, that provide assistance services in sectors heavily populated with small businesses, including agriculture.

- Agriculture Compliance Assistance Center: *www.epa.gov/agriculture*
- National Agriculture Center: 1-888-663-2155 or *www.epa.gov/agriculture/agctr.html*

Hotlines

EPA sponsors more than 50 hotlines and clearinghouses that provide free and convenient avenues to obtain assistance with environmental requirements. EPA's Small Business Ombudsman Hotline can provide you with a list of all the hotlines and assist you with determining which hotline will best meet your needs. Key hotlines that may be of interest to you include:

- EPA's Small Business Ombudsman.............................. (800) 368-5888
- Superfund and EPCRA Call Center.............................. (800) 424-9346
- Safe Drinking Water Hotline ....(800) 426-4791

Small Business Compliance Policy

EPA's Small Business Compliance Policy is intended to promote environmental compliance among small businesses by providing incentives such as penalty waivers and reductions for participation in compliance assistance programs, and encouraging voluntary disclosure and prompt correction of violations. This policy can not be applied to an enforcement action that has already been initiated. Contact EPA's Compliance Assistance and Sector Programs Division (202-564-2310) for information on the Small Business Policy or review the policy online at *http://www.epa.gov/compliance/incentives/smallbusiness/*.

Small Business Administration National Ombudsman

The Small Business and Agriculture Regulatory Enforcement Ombudsman and ten Regional Fairness Boards were established to receive comments from small businesses about federal agency enforcement actions. The Ombudsman will annually rate each agency's responsiveness to small businesses. If you believe that you fall within the Small Business Administration's definition of a small business (based on your SIC designation, number of employees or annual receipts, defined at 13 CFR 121.201) and wish to comment on federal enforcement and compliance activities, contact the SBA's Office of the National Ombudsman at 1-888-734-3247 or *ombudsman@sba.gov*. ***Please note that participation in this program does not relieve you of your obligation to respond to an EPA request, administrative or civil complaint or other enforcement action in a timely manner nor create any new rights or defenses under law. In order to preserve your legal rights, you must comply with all rules governing the administrative enforcement process. The ombudsman and fairness boards do not participate in the resolution of EPA's enforcement action.***

Appendix C

Example NPDES CAFO Permit Annual Report Form

NPDES CAFO PERMIT ANNUAL REPORT

NPDES Permit Number:	Reporting period (mm/dd/yyyy - mm/dd/yyyy): / / - / /
Facility Name:	
Contact Name:	
Facility Address:	

Facility City:	Facility State:	Facility ZIP Code:

Facility Telephone:	Contact Telephone (if different from Facility Telephone):

I. TYPE AND NUMBER OF ANIMALS

Report the maximum number of each type of animal confined at the facility at any one time.

Type	Number in open confinement	Number housed under roof
Mature Dairy Cows		
Dairy Heifers		
Veal Calves		
Other Cattle		
Swine (55 lbs or more)		
Swine (under 55 lbs)		
Horses		
Sheep or Lambs		
Turkeys		
Chickens (broilers)		
Chickens (layers)		
Ducks		
Other (specify) ______________		

II. MANURE, LITTER, AND PROCESS WASTEWATER PRODUCTION

Report the estimated amount of manure, litter, and process wastewater that were generated at the facility in the 12-month period covered by this report.

A. Amount of manure generated in the 12-month period covered by this report. _________ tons

B. Amount of litter generated in the 12-month period covered by this report. _________ tons

C. Amount of process wastewater generated in the 12-month period covered by this report. ________ gallons

III. MANURE, LITTER, AND PROCESS WASTEWATER TRANSFERRED TO OTHER PERSONS

Report the estimated amounts of manure, litter, and process wastewater that were transferred to other persons in the 12-month period covered by this report.

A. Amount of manure transferred in the 12-month period covered by this report. _________ tons

B. Amount of litter transferred in the 12-month period covered by this report. _________ tons

C. Amount of process wastewater transferred in the 12-month period covered by this report. ________ gallons

IV. LAND APPLICATION—ACRES COVERED BY PLAN

Report the total number of acres of land that are covered by the facility's nutrient management plan. Include all land application acres covered by the nutrient management plan, whether or not they were used for land application during the 12-month period covered by this report.

Total number of land application acres covered by the nutrient management plan. _______ acres

V. LAND APPLICATION—ACRES USED

Report the total number of acres of land where manure, litter, or process wastewater generated at the facility was spread. Include only land application areas that are under the control of this CAFO facility.

Total number of acres under the control of the CAFO used for land application of manure, litter, or process wastewater in the 12-month period covered by this report. ________ acres

VI. SUMMARY OF DISCHARGES

Provide a summary of each discharge of manure, litter, and/or process wastewater from the production area(s) that occurred in the 12-month period covered by this report. Attach additional sheets, if needed.

Date[a]	Time[b]	Volume[c]	Location[d,f]	Description[e,f]

a. **Date:** The date of the discharge. If the discharge was detected after it happened, give an estimate of the date when the discharge occurred.
b. **Time:** The time of the discharge. If the discharge was detected after it happened, give an estimate of the time when the discharge occurred.
c. **Volume:** Give an estimate of the number of gallons or tons of manure, litter, or process wastewater discharged.
d. **Location:** The location of the discharge. Provide a specific description of where the manure, litter, or process wastewater was discharged from the production area. Include names of nearby waterbodies, landmarks or other points of reference (e.g., Three Mile Creek, at southeast corner of feedlot where creek bends to the west).
e. **Description:** Provide other relevant information about the discharge, including the source, cause, composition (e.g., emergency overflow of process wastewater from lagoon #2), and impacts observed (e.g., fish kill in waterbody).
f. This information is not required by the NPDES CAFO regulations to be included in the annual report.

VII. NUTRIENT MANAGEMENT PLAN

Indicate whether the facility's nutrient management plan was developed or approved by a certified nutrient management planner. Note: The *[permitting authority]* does not require CAFO owners or operators to use a certified nutrient management planner to prepare or approve nutrient management plans.

Was the current version of this facility's nutrient management plan prepared or approved by a certified nutrient management planner? ❑ Yes ❑ No

VIII. LAND APPLICATION SUMMARY

A. Report the nitrogen (N) and phosphorus (P) content of manure, litter, and process wastewater using the results of the most recent representative manure, litter, and process wastewater tests for N and P. Report the form of N and P used for nutrient management planning purposes in the *Nutrient form* column.

Note: Large CAFOs using the linear approach and all CAFOs using the narrative rate approach must present results taken within 12 months of the date of land application of the manure, litter, and process wastewater.

				Nutrient form
Manure N Content	______________	lbs/ton	as	______________
Manure P Content	______________	lbs/ton	as	______________
Litter N Content	______________	lbs/ton	as	______________
Litter P Content	______________	lbs/ton	as	______________
Process Wastewater N Content	______________	lbs/1,000 gallons	as	______________
Process Wastewater P Content	______________	lbs/1,000 gallons	as	______________

B. For each field, report the actual crop(s) planted, the season (for multiple crops planted in one field), the actual crop yield, and the amount of manure, litter, process wastewater, and supplemental fertilizer applied to each field during the previous 12-month period. Attach additional sheets if necessary.

Field ID	Season	Crop planted	Crop yield (specify units)	Amount to be applied as calculated according to the NMP methodology			Actual amount applied		
				Manure (tons)	Litter (tons)	Process wastewater (gallons)	Manure (tons)	Litter (tons)	Process wastewater (gallons)

C. *Comments (E.g., "Actual amounts of manure applied are greater than the planned amounts due to a drop in the amount of N analyzed in the manure test.")*

D. *For CAFOs with NMPs developed using the narrative rate approach only as described under 40 CFR 122.42(e)(5)(ii)*: For each field used for land application, report the results of the most recent soil nutrient analyses for any soil test taken in the last 12 months.

Field ID	Most recent soil test results					Supplemental fertilizer (pounds/acre)	
	Nitrogen		Phosphorus			N applied	P applied
	ppm	N form	ppm	P form	method		
		as		as			
		as		as			
		as		as			
		as		as			
		as		as			
		as		as			
		as		as			

IX. INSTANCES OF NONCOMPLIANCE NOT PREVIOUSLY REPORTED

During the past 12 months have there been any instances of noncompliance that have not been reported to the permitting authority? ❑ Yes ❑ No If yes, please provide the information requested below.

Note: This information is required to be submitted under 40 CFR 122.41(l)(7) and 40 CFR 122.44(i)(2).

If during the past 12 months instances of noncompliance have occurred that have not been reported to the permitting authority please provide the following information, for each instance, along with this annual report:

- Description of the noncompliance and its cause.
- The period that the operation was in noncompliance with permit conditions, including exact dates and times.
- In cases where the noncompliance has not been corrected, the anticipated time it is expected to continue.
- Description of the steps taken or planned to reduce, eliminate, and prevent reoccurrence of the noncompliance.

X. CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direct supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage this system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Signature: ____ Date: ____________________

Print Name: ____

Submit by [*insert due date/reporting schedule*]

Submit to [*permitting authority and address*]

Appendix D

Example Nutrient Management Plan Recordkeeping Forms

CAFO Weekly Storage, Containment and Treatment Structure Inspections
Log Sheet

Facility Name: ________________________ NPDES Permit No.: ____________

Storage, Containment or
Treatment Structure: ________________________________

Instructions: Use this form to keep track of weekly visual inspections of the structures that you use to store, contain or treat manure, litter, and process wastewater. Use a separate form for each structure.

Keep track of your inspections each week in the table below. Provide the following information:

- the date of the inspection
- the initials of the inspector
- for open liquid waste storage structures, record the level indicated on the depth marker
- for open liquid waste storage structures, indicate whether the wastewater level was below the level required to maintain capacity to store the runoff and precipitation from a 25-year, 24-hour storm.
- use the "Notes" column to describe problems, if you find any, and how they might be fixed
- fill in the "date corrected" column with the date when you correct the problem

	Date	**Initials**	**Depth Marker Reading**	**Wastewater Below Pumping Level?**	**Notes** (Note any problems found and possible solutions.)	**Date Corrected**
Week 1						
Week 2						
Week 3						
Week 4						
Week 5						

	Date	Initials	Depth Marker Reading	Wastewater Below Pumping Level?	Notes (Note any problems found and possible solutions.)	Date Corrected
Week 6						
Week 7						
Week 8						
Week 9						
Week 10						
Week 11						
Week 12						
Week 13						
Week 14						
Week 15						
Week 16						

	Date	Initials	Depth Marker Reading	Wastewater Below Pumping Level?	Notes (Note any problems found and possible solutions.)	Date Corrected
Week 17						
Week 18						
Week 19						
Week 20						
Week 21						
Week 22						
Week 23						
Week 24						
Week 25						
Week 26						
Week 27						

	Date	Initials	Depth Marker Reading	Wastewater Below Pumping Level?	Notes (Note any problems found and possible solutions.)	Date Corrected
Week 28						
Week 29						
Week 30						
Week 31						
Week 32						
Week 33						
Week 34						
Week 35						
Week 36						
Week 37						
Week 38						

	Date	Initials	Depth Marker Reading	Wastewater Below Pumping Level?	Notes (Note any problems found and possible solutions.)	Date Corrected
Week 39						
Week 40						
Week 41						
Week 42						
Week 43						
Week 44						
Week 45						
Week 46						
Week 47						
Week 48						
Week 49						

	Date	Initials	Depth Marker Reading	Wastewater Below Pumping Level?	Notes (Note any problems found and possible solutions.)	Date Corrected
Week 50						
Week 51						
Week 52						

CAFO Weekly Storm Water Diversion and Channel Inspections Log Sheet

Facility Name: ______________________________ NPDES Permit No.: ______________

Instructions: Use this form to keep track of weekly visual inspections of your storm water management structure(s) (including storm water and runoff diversion devices, and devices used to channel contaminated storm water to a wastewater storage or containment structure). List the items that need to be inspected below.

______________________________ ______________________________
______________________________ ______________________________
______________________________ ______________________________
______________________________ ______________________________

Keep track of your inspections in the following table by filling out one row each week when you inspect your storm water management structures. Provide the following information:

- the date of the inspection
- the initials of the inspector
- check the "OK" box if no problems were found
- use the "Notes" column to describe problems, if you find any, and how they might be fixed
- fill in the "date corrected" column with the date when you correct the problem

	Date	**Initials**	**OK** (✓ if no problems found)	**Notes** (Note any problems found and possible solutions.)	**Date Corrected**
Week 1					
Week 2					
Week 3					
Week 4					
Week 5					

	Date	Initials	OK (✓ if no problems found)	Notes (Note any problems found and possible solutions.)	Date Corrected
Week 6					
Week 7					
Week 8					
Week 9					
Week 10					
Week 11					
Week 12					
Week 13					
Week 14					
Week 15					
Week 16					

	Date	Initials	OK (✓ if no problems found)	Notes (Note any problems found and possible solutions.)	Date Corrected
Week 17					
Week 18					
Week 19					
Week 20					
Week 21					
Week 22					
Week 23					
Week 24					
Week 25					
Week 26					
Week 27					

	Date	Initials	OK (✓ if no problems found)	Notes (Note any problems found and possible solutions.)	Date Corrected
Week 28					
Week 29					
Week 30					
Week 31					
Week 32					
Week 33					
Week 34					
Week 35					
Week 36					
Week 37					
Week 38					

	Date	Initials	OK (✓ if no problems found)	Notes (Note any problems found and possible solutions.)	Date Corrected
Week 39					
Week 40					
Week 41					
Week 42					
Week 43					
Week 44					
Week 45					
Week 46					
Week 47					
Week 48					
Week 49					

	Date	Initials	OK (✓ if no problems found)	Notes (Note any problems found and possible solutions.)	Date Corrected
Week 50					
Week 51					
Week 52					

CAFO Nutrient Land Application Log Sheet

Facility Name: ______________________ **NPDES Permit No.:** ______________

Field ID (use the same field identification as used in the NMP): ______________ **Acres:** ______________

Instructions: Use this form to keep records of your land application activities. Maintain a separate sheet for each field. For each land application event, provide the following information in the table below:

- Date: the date that you applied manure, litter, or process wastewater to the field
- Source: the source (e.g., storage structure) of the manure, litter, or process wastewater applied
- Method: the method you used to apply the manure, litter, or process wastewater
- Weather Conditions: the weather conditions 24 hours before, during, and 24 hours after the land application event
- Amount Applied: The total tons of manure or litter or gallons of process wastewater applied
- Total N: the total amount of nitrogen you applied to the field
- Total P: the total amount of phosphorus you applied to the field

The following records also must be maintained on-site along with a current copy of your site-specific NMP:

- Expected crop yield
- Test methods used to sample and analyze manure, litter, soil, and process wastewater
- Results from manure, litter, process wastewater and soil sampling
- Explanation of basis for determining application rates
- Calculations for the total N and P planned to be applied and the total N and P actually applied
- Dates of land application equipment inspections.

Date	Source	Method	Weather Conditions			Amount Applied (specify gallons or tons)	Total N	Total P
			24 hours before	during	24 hours after			

Date	Source	Method	Weather Conditions			Amount Applied (specify gallons or tons)	Total N	Total P
			24 hours before	during	24 hours after			

Daily Water Line Inspection
Log Sheet

Facility Name: ______________________ NPDES Permit No.: ______________

Instructions: Use this form to keep track of your daily water line visual inspections (including drinking and cooling water lines). Initial the form *each day* the after the inspection is done. Mark the "✓ if leak" column if you find a leak.

Year	January		February		March		April		May		June		July		August		September		October		November		December	
20___	Initials	✓ if leak	Initials	✓ if leak	Initials	✓ if leak	Initials	✓ if leak	Initials	✓ if leak	Initials	✓ if leak	Initials	✓ if leak	Initials	✓ if leak	Initials	✓ if leak	Initials	✓ if leak	Initials	✓ if leak	Initials	✓ if leak
1																								
2																								
3																								
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29																								
30																								
31																								

MANURE, LITTER, AND PROCESS WASTEWATER TRANSFER RECORD FORM

Facility Name: ______________________________ NPDES Permit No. ____________

Instructions: Use this form to keep track of all manure, litter, and process wastewater generated at your CAFO facility that you transfer to other persons (i.e. for use or disposal on land not owned by or under the control of your CAFO). Use additional sheets as necessary.

Date of Transfer	Name of Recipient	Address of Recipient	Nutrient Analysis Provided to Recipient	Amount Transferred		
				Manure (tons)	Litter (tons)	Wastewater (gallons)

Appendix E

Minimum Depth of Rain at Which Runoff Begins

Minimum Depth of Rain at Which Runoff Begins

This appendix provides a methodology for estimating the minimum depth of precipitation required to produce runoff for a given field with a given runoff curve number.

Step 1: Estimate the runoff curve for the field or land area of concern. Table 3 in Appendix R provides curve numbers for various combinations of land uses (e.g., row crops), cover treatment or practices (e.g., contoured), and hydrologic conditions (e.g., poor). The runoff curve numbers in this table represent Antecedent Runoff Condition III (e.g., saturated soils). To identify corresponding runoff curve numbers for Antecedent Runoff Condition II (i.e., average conditions) use either Appendix R-3 or Tables 2-2b and 2-2c in Urban Hydrology for Small Watersheds, USDA-NRCS, 1986 (see Appendix E-2).

To predict the possibility of runoff where rainfall is forecast in a season other than winter, it may be reasonable to use runoff curves for Antecedent Runoff Condition II.

Step 2: Using Table 10-1 on page 10-7 of the USDA-NRCS National Engineering Handbook Part 630, Hydrology (see Appendix E-1); select the curve number (CN) for the field being investigated.

Step 3: For the selected curve number in Table 10-1, identify the minimum depth of precipitation in inches required to produce runoff for a given runoff curve number (Column 5, designated with the column header of Curve* starts where P =).

Appendix E-1

National Engineering Handbook Table 10-1
Curve Numbers (CN) and Constants for the Case $I_a = 0.2\ S$

Table 10–1 Curve numbers (CN) and constants for the case $I_a = 0.2S$

1	2	3	4	5	1	2	3	4	5
CN for ARC II	-- CN for ARC -- I	III	S values* (in)	Curve* starts where P = (in)	CN for ARC II	-- CN for ARC -- I	III	S values* (in)	Curve* starts where P = (in)
100	100	100	0	0	60	40	78	6.67	1.33
99	97	100	.101	.02	59	39	77	6.95	1.39
98	94	99	.204	.04	58	38	76	7.24	1.45
97	91	99	.309	.06	57	37	75	7.54	1.51
96	89	99	.417	.08	56	36	75	7.86	1.57
95	87	98	.526	.11	55	35	74	8.18	1.64
94	85	98	.638	.13	54	34	73	8.52	1.70
93	83	98	.753	.15	53	33	72	8.87	1.77
92	81	97	.870	.17	52	32	71	9.23	1.85
91	80	97	.989	.20	51	31	70	9.61	1.92
90	78	96	1.11	.22	50	31	70	10.0	2.00
89	76	96	1.24	.25	49	30	69	10.4	2.08
88	75	95	1.36	.27	48	29	68	10.8	2.16
87	73	95	1.49	.30	47	28	67	11.3	2.26
86	72	94	1.63	.33	46	27	66	11.7	2.34
85	70	94	1.76	.35	45	26	65	12.2	2.44
84	68	93	1.90	.38	44	25	64	12.7	2.54
83	67	93	2.05	.41	43	25	63	13.2	2.64
82	66	92	2.20	.44	42	24	62	13.8	2.76
81	64	92	2.34	.47	41	23	61	14.4	2.88
80	63	91	2.50	.50	40	22	60	15.0	3.00
79	62	91	2.66	.53	39	21	59	15.6	3.12
78	60	90	2.82	.56	38	21	58	16.3	3.26
77	59	89	2.99	.60	37	20	57	17.0	3.40
76	58	89	3.16	.63	36	19	56	17.8	3.56
75	57	88	3.33	.67	35	18	55	18.6	3.72
74	55	88	3.51	.70	34	18	54	19.4	3.88
73	54	87	3.70	.74	33	17	53	20.3	4.06
72	53	86	3.89	.78	32	16	52	21.2	4.24
71	52	86	4.08	.82	31	16	51	22.2	4.44
70	51	85	4.28	.86	30	15	50	23.3	4.66
69	50	84	4.49	.90	25	12	43	30.0	6.00
68	48	84	4.70	.94	20	9	37	40.0	8.00
67	47	83	4.92	.98	15	6	30	56.7	11.34
66	46	82	5.15	1.03	10	4	22	90.0	18.00
65	45	82	5.38	1.08	5	2	13	190.0	38.00
64	44	81	5.62	1.12	0	0	0	infinity	infinity
63	43	80	5.87	1.17					
62	42	79	6.13	1.23					
61	41	78	6.39	1.28					

* For CN in column 1.

Appendix E-2

USDA Urban Hydrology for Small Watersheds (TR-55)

Table 2-2b Runoff curve numbers for cultivated agricultural lands [1]

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

1 Average runoff condition, and I_a=0.2S
2 Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.
3 Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 2-2c Runoff curve numbers for other agricultural lands [1]

Cover description: Cover type	Hydrologic condition	Curve numbers for hydrologic soil group: A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.

2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

4 Actual curve number is less than 30; use CN = 30 for runoff computations.

5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Appendix E-3

Instructions for Determining Precipitation Forecasts for CAFO Permits Using the National Weather Service Website

WARNING: Do not be intimidated. This is much easier then it may seem at first. Once you learn how to do this and save the results in your Favorites you can check both forecasts in less then a minute (or up to a few minutes depending on your internet connection speed). In fact, you may find these forecast models useful in planning other areas of work on your farm.

Start at this website: *www.weather.gov/mdl/synop/products.php*. Once you are there you may wish to save it in your Favorites. If the website has changed or the required forecast models are not longer available, please contact the Michigan Department of Environmental Quality Office listed on your Certificate of coverage or on the cover page of your permit

1. Click on "Forecast Graphics" in the "GFS MOS (MAV)" box (near the center of the page).

2. In the column on the left side, in the drop down box under "Precipitation", click on "24H Prob.>= 0.50 in.". Note: if it has been determined that a smaller precipitation event is capable of producing runoff or erosion then use a smaller precipitation probability such as "24H Prob. >=0.25 in.".

3. This will bring up a map of the U.S. showing precipitation probabilities as colored bands or areas for the upcoming 24 hour period. Precision is not ideal because it covers all of the U.S. but estimate the color for the proposed land application area. If the precipitation probability is 70% or greater (blue shades) then you should not land apply. You can save the map in your favorites.

4. Underneath the map are day & time boxes such as "Tuesday" and "00" and "12". That would be Tuesday midnight and noon, GMT (Greenwich Mean Time) which is 5 hours ahead of EST (Eastern Standard Time) and 4 hours ahead of EDT (Eastern Daylight Time). So "Tuesday 00" would be 7 p.m. EST or 8 p.m. EDT Monday. The map forecast is for the 24 hour period ending at the highlighted time. The first box, which will be highlighted when you bring up the map, will give the map for the upcoming 24 hour period. You can click on subsequent time periods to see future forecasts. You should always check the immediate upcoming 24 hour forecast just prior to a planned land application event.

After you have finished checking the maps use your back button or go to your Favorites to return to the above website.

1. Click on "Text Message By Station List" in the "GFS MOS (MEX)" box (toward the right side on the page).

2. In the list of states on the left side click on "Michigan".

3. In the list that comes up on the right side click in the box for the station closest to the land application location. You may need to select 2 or 3 stations if none are close to the land application area. If selecting more then one station, note the 4-letter station designation after each station name so you know which chart is for which station.

4. Once you have selected the station(s) scroll to the bottom of the Michigan station list and click on "Go to the bottom to submit now". Then click on the "Submit Query" box.

5. You will now have a very confusing chart for each selected station (you can save this page in your Favorites). Look down the left hand column for "Q24" and read across the first number. It will be one digit from 0 to 6. This is the only number you need to be concerned with. This number is the quantity precipitation forecast for the upcoming 24 to 48 hour period. 0 = no precipitation, 1 = 0.01" to 0.09", 2 = 0.1" to 0.24", 3 = 0.25" to 0.49", 4 = 0.5" to 0.99", 5 = 1.0" to 1.99" and 6 = > 2.0". If it is 4 or greater you may not land apply. Note: if it has been determined that a smaller precipitation event is capable of producing runoff or erosion then use a smaller precipitation quantity forecast number. For example, if 0.35" of precipitation in 24 hours on a particular field will produce runoff or erosion then you may not land apply if the number is 3 or greater.

6. You may need to check the charts 2 or 3 times in advance of a planned land application event to determine the precipitation amount forecasted for the land application time frame.

In the event that you are immensely curious as to what all the rest of the data on these charts mean, then go back to the website at the top on these instructions and in the left hand column click on "GFS Description" to get to an explanation page.

Once you have saved the map and charts in your Favorites, you can click on those links and get to the current map or chart(s) with just one click!

Appendix F

Voluntary Alternative Performance Standards for CAFOs

Introduction

The examples in this appendix are for informative purposes only. The examples assume, but do not guarantee, that the confined animal feeding operation (CAFO) meets all applicable federal, state, and local requirements.

The U.S. Environmental Protection Agency's (EPA's) long-term vision for CAFOs includes continuing research and progress toward environmental improvement. CAFOs, U.S. Department of Agriculture (USDA), land grant universities, state agencies, equipment vendors, and other agricultural organizations are now working to develop new technologies to reduce nutrient, pathogen, and other pollutant losses to surface water; ammonia and other air emissions; and groundwater contamination from animal manure. In the future, as those technologies are developed and improved, EPA believes that they could offer CAFOs the potential to match or surpass the pollutant reduction achieved by complying with the current requirements. EPA believes that some CAFOs will voluntarily develop and install new technologies and management practices equal to or better than the current requirements described in the CAFO rule of this manual in exchange for being allowed to discharge the treated effluent. (For the purposes of this appendix, the current technology controls required under the CAFO effluent limitation guidelines (ELG) described in the CAFO rule will be referred to hereafter as the *baseline* technology requirements.) That is why EPA has created the voluntary performance standards program for CAFOs.

This appendix presents an overview of the baseline requirements and the *voluntary performance* standards program, which includes a description of who can participate in the program, how participation in the program will affect existing CAFO National Pollutant Discharge Elimination System (NPDES) permits, and a step-by-step description of the requirements associated with program participation.

A. Overview of the Baseline Requirements

As described in the CAFO rule, the baseline production area requirements for all existing beef, dairy, heifer, veal, swine, and poultry CAFOs are the same. However, baseline requirements vary for new operations. A summary of the requirements is presented in Table F-1.

Table F-1. Summary description of baseline requirements

Existing and new large beef, dairy, heifer and existing large swine, poultry and veal CAFOs
1. Baseline requirements prohibit the discharge of manure and process wastewaters. 2. A CAFO may discharge when rainfall events cause an overflow from a storage structure designed, constructed, operated, and maintained to contain the following: • All manure, litter, and all process wastewaters including manure, wastewater, and other wastes accumulated during the storage period as reflected by the design storage volume • Direct precipitation from a 25-year, 24-hour rainfall event • Associated runoff from a 25-year, 24-hour rainfall event

B. Overview of the Voluntary Performance Standards Program

Under the voluntary performance standards program, existing and new Large beef, heifer, and dairy CAFOs and existing Large swine, poultry, and veal CAFOs are allowed to discharge process wastewater that have been treated by technologies that the CAFO demonstrates results in equivalent or better pollutant removals from the production area than would otherwise be achieved by the baseline requirements.

Program Benefits

CAFOs are expected to derive substantial benefits from participating in this program through greater flexibility in operation, increased goodwill of neighbors, reduced odor emissions, potentially lower costs, and overall improved environmental stewardship. EPA is considering other possible incentives to encourage participation in this program.

B.1. Program Participation

All CAFOs electing to participate in the program should have a good compliance history (e.g., no ongoing violations of existing permit standards or history of significant noncompliance). In most cases, participation will result in an individual NPDES permit addressing the site-specific nature of the alternative technology and establishing site-specific discharge limitations.

B.2. Pollutants of Concern

In general, all CAFOs applying for the voluntary performance standards program must design the treatment technology to achieve equal or less quantities of 5-day biochemical oxygen demand (BOD_5), total nitrogen (N) (ammonia, nitrite/nitrate, and organic N), total phosphorus (P), and total suspended solids (TSS) than the baseline system. EPA selected those parameters because of their high concentrations in manure-type wastestreams and their impact on surface water quality if not treated. In addition, many conventional wastewater treatment technologies, in the process of treating those four selected pollutants, will result in treatment and removal of other pollutants. To qualify for voluntary alternative performance standards, the CAFO may also be required to remove other specific pollutants, such as pathogens and metals, if such pollutants are present in the wastestream at concentrations that could affect surface water quality, as determined appropriate by the permitting authority.

B.3. Required Technical Analysis

CAFOs requesting site-specific effluent limitations to be included in NPDES permits must submit a supporting technical analysis and any other relevant information and data that would support such site-specific effluent limitations. For more information, see Section C of this appendix.

B.4. Validation of Equivalent Pollutant Reductions

The CAFO must attain the limitations and requirements of a permit on the basis of alternative technologies as of the date of permit coverage (Title 40 of the *Code of Federal Regulations* [CFR] section 412.31(a)(3). If those alternative limits will not be met as of the date of permit coverage, such as because of startup of certain wastewater treatment technologies, the permitting authority would need to incorporate a compliance schedule into an enforceable order that would establish milestones for implementing the alternative technologies and fully meeting the permit limitations. The permitting authority should consider whether it is appropriate to select a permit term that is less than 5 years to allow the permitting authority to evaluate whether the alternative technologies have resulted in the permit limitations being met.

If the permitting authority grants a request for voluntary alternative performance standards, the CAFO should, at a minimum, be required to take monthly effluent samples from the treatment system to verify continued permit compliance. The permitting authority may determine that the CAFO must take more frequent samples (such as during startup) or collect samples on a basis other than monthly (such as during all discharge events in the case of intermittent discharging technologies). CAFOs should be required to analyze for the following pollutants: BOD_5, total N, total P, and TSS. The permitting authority may also require a CAFO to monitor other pollutants regularly. If monthly pollutant discharges from the alternative treatment system are greater than specified in the NPDES permit, a CAFO could be subject to both state and EPA enforcement actions.

General versus Individual NPDES Permits

A general NPDES permit is written to cover a category of point sources with similar characteristics for a defined geographic area. The majority of CAFOs may appropriately be covered under NPDES general permits because CAFOs generally involve similar types of operations, require the same kinds of effluent limitations and permit conditions, and discharge the same types of pollutants.

Individual NPDES permits might be most appropriate for CAFOs that are exceptionally large operations, are undergoing significant expansion, have historical compliance problems, or have significant environmental concerns. Individual permits will generally include all the permit conditions contained in the general NPDES permit and some additional requirements specific to the permitted facility. Additional requirements could include liners and covers for manure and wastewater storage units and more frequent water quality monitoring.

B.5. Relationship to Existing NPDES Permits

EPA expects that most CAFOs will be subject to a general, rather than an individual, permit that requires compliance with the baseline effluent guidelines requirements. If a CAFO decides to pursue voluntary performance standards based on a treatment technology that allows a discharge, EPA expects the permit authority to require the CAFO prepare and submit an application for an individual NPDES permit. The application will include general information about the CAFO (e.g., ownership, responsible persons, location, receiving stream), waste characteristics, information about the treatment system including design and operational parameters, and expected effluent quality from the proposed treatment system. A CAFO may not discharge from the alternative treatment system until the permitting authority has issued an NPDES permit that allows the discharge.

C. Step-By-Step Requirements for Participation in the Voluntary Performance Standards Program

The voluntary performance standards program has two main requirements: the CAFO must estimate the pollutant discharge associated with the baseline system and must demonstrate that the alternative treatment technology achieves an equivalent or better reduction in the quantity of pollutants discharged from the production area. This section provides detailed recommendations for how such showings should be made, along with a description of the information that must be submitted to the permitting authority to obtain alternative performance standards.

C.1. Determining Baseline Pollutant

If a CAFO decides to participate in the voluntary performance standards program, the CAFO must conduct a technical analysis to estimate the pollutant discharge associated with the baseline[1] waste management system (e.g., anaerobic treatment lagoon). At a minimum, the technical analysis must include the information in the text box at right [see 40 CFR part 412.31(a)(2)].

Technical Analysis of Discharge

40 CFR part 412.31(a)(2) …The technical analysis of the discharge of pollutants must include

(A) All daily *inputs* to the storage system, including manure, litter, all process waste waters, direct precipitation, and runoff.

(B) All daily *outputs* from the storage system, including losses due to evaporation, sludge removal, and the removal of wastewater for use on cropland at the CAFO or transport off site.

(C) A calculation determining the predicted median annual overflow volume based on a 25-year period of actual rainfall data applicable to the site.

(D) Site-specific pollutant data, including N, P, BOD_5, TSS, for the CAFO from representative sampling and analysis of all sources of input to the storage system, or other appropriate pollutant data. (E) Predicted annual average discharge of pollutants, expressed where appropriate as a mass discharge on a daily basis (lbs/day), and calculated considering paragraphs (a)(2)(i)(A) through (a)(2)(i)(D) of this section.

In a limited number of circumstances, the calculated median annual overflow volume based on a 25-year period of actual rainfall data may be zero. In those instances, the permit authority may allow the CAFO to calculate an average overflow volume for the 25-year period.

One approach for estimating pollutant discharges is to use a computer simulation model, spreadsheet, or similar program. One can either develop a new model or revise an existing model that estimates pollutant discharges from waste management systems. The models can be used to evaluate site-specific climate and wastewater characterization data to project the pollutant discharge from a baseline system. The model should evaluate the daily inputs to the waste management system, including all manure, litter, all process wastewaters, direct precipitation, and runoff. The model should also evaluate the daily outputs from the waste management system, including losses due to evaporation, sludge removal, and the removal of wastewater for use on cropland at the CAFO or transported off-site. CAFOs can use the model to predict the median annual overflow from the storage system that would occur over a 25-year period. Next, the CAFO should use the overflow predictions, combined with representative pollutant concentrations in the overflow, to predict the annual average discharge of pollutants (including nitrogen, phosphorus, BOD_5, and TSS) over the 25 years evaluated by the model. For the complete list, see 40 CFR part 412.31(a)(2)(i)(E).

Site-specific information that a CAFO should gather and input to the model to calculate the predicted annual discharge of pollutants from the baseline system includes the following [also see 40 CFR part 412.31(a)(2)]:

- Data on actual local precipitation from the past 25 years. Precipitation data are available from the National Weather Service and possibly a local airport. One can also obtain local precipitation data from EPA's Better Assessment Science Integrating point and Nonpoint Sources (BASINS) model at *http://www.epa.gov/OST/BASINS/b3webwn.htm*. State weather data are at *http://www.epa.gov/ost/ftp/basins/wdm_data/*. Historical weather can also be obtained from National Climatic Data Center.
- Soil type and permeability in drylot areas. Site-specific soil permeability data can be obtained from the local Soil Conservation District office.
- The rate of evaporation from the storage system (e.g., lagoon, pond, holding tank). Evaporation rate data are available from the National Weather Service or EPA's BASINS model website.
- The concentration of BOD_5, total N, total P, TSS, and other pollutants as required by the Director, measured in a representative sample collected from the waste management system.
- Starting volume in the waste management system based on process wastes and runoff collected since the last land application or waste management system pump-out or sludge cleanout or both.
- Projected total design storage volume to store manure, wastewater, and other wastes accumulated during the storage period as reflected by the design storage volume (see Chapter 5.3 of this document).
- Change in the waste management system's volume due to the estimated daily flow of process wastes.
- Change in the storage system volume due to direct precipitation and evaporation.
- Change in the storage system volume due to runoff from open lot areas.
- Change in volume due to waste management system pump-out or sludge cleanout and land application.

The model should calculate the net change in the volume of the liquid storage area daily and add it to the previous day's total. If the total volume is greater than the maximum design volume, the excess volume overflows. Also, CAFOs can calculate the mass pollutant discharge from the overflow by multiplying the overflow by the pollutant concentration (BOD_5, total N, total P, TSS) measured in the representative sample.

Examples 1 and 2 at the end of this appendix present the results of a technical analysis conducted for example dairy and swine CAFOs, respectively.

C.2. Demonstrating That an Alternative Control Technology Achieves Equivalent or Better Pollutant Reductions

EPA recommends that CAFOs follow the steps shown below to demonstrate that an alternative control technology will achieve equivalent or better pollutant reductions:

- Measuring volume or quantity of manure, wastewater, and runoff generation from production areas.
- Collecting samples of manure, wastewater, and runoff to determine raw or untreated pollutant concentrations for treatment system design using the same pollutant parameters as measured for a baseline.
- Preparing a conceptual design of the treatment system showing equipment sizing, operational requirements, and expected pollutant reductions by each treatment step.
- Estimating the volume and frequency of discharge from the treatment system.
- Estimating or measuring the concentration of the effluent from the treatment system.
- Results of pilot testing to verify the treatment system will achieve equivalent or better pollutant reductions than baseline for all required constituents (including BOD_5, total N, total P, and TSS) and to gather information for design of the full-scale treatment system. Any pilot testing needs to be related to representative/typical production and climate conditions expected at the CAFO. Therefore, multiple testing episodes or sites might be necessary to adequately capture the actual conditions at the CAFO. Consider on-site pilot testing to demonstrate that the proposed system will work at the CAFO.

Examples 1 and 2 summarize the methods that could be used by the example CAFOs to determine if an alternative treatment system performed equivalent to or better than the baseline system. In the examples, the permit authority would require the CAFO to continue to collect testing data until the alternative technology has been proven at the site. Thereafter, the CAFO might need to collect samples only frequently enough to demonstrate compliance with their NPDES permit limitations.

Can a CAFO Demonstrate Equivalency Using Practices Already in Existence at the Site?

Yes. If the practices already in place at the operation provide equivalent or better pollutant reductions than the predicted average annual pollutant discharge for the baseline requirements, the CAFO can apply for an alternative performance standard. Example 3 shows how data from an existing pollution prevention/treatment system were compared to the baseline system to develop site-specific permit limits for an egg production facility.

C.3. Obtaining an Alternative Performance Standard

The next step in participating in the voluntary performance standards program is to submit an application to the permitting authority along with the technical analyses, conceptual design, results of any pilot-scale testing and any other relevant data before constructing the full-scale treatment system. The permitting authority should review the application, technical analyses, and conceptual design, and then compare the pilot-scale testing results with the predicted annual average discharge of pollutants to verify that the proposed treatment system is reasonable, appropriate, and will likely achieve the predicted results. In addition, the permit authority should confirm that the quantity of pollutants discharged from the production area is equal to or less than the quantity of pollutants discharged under baseline. The Director has the discretion to request additional information to supplement the CAFO's application, including conducting an on-site inspection of the CAFO. 40 CFR § 412.31(a)(2)(E)(ii). Once an application is approved, a CAFO can proceed with detailed design and construction of the alternative control technology. After the treatment system's construction but before start-up [see 40 CFR part 412.31(a)(3)], the CAFO must obtain an NPDES permit specifying the discharge limitations. Also see Section B.4 of this appendix.

Footnotes

[1] Recall a baseline system at the CAFO is a system that meets the requirements as described in the CAFO Rule [see 40 CFR part 412.31(a)(1)].

Example 1. Whole Milk Dairy, Lancaster, Pennsylvania

Background

Whole Milk Dairy (WMD) is a Large CAFO in Lancaster County, Pennsylvania. WMD milks 1,200 dairy cows per day, plus manages 400 heifers and 400 calves. Milk cows are confined in a 550,000-square-foot-area containing three free stall barns, the milking parlor, and yard. Free stall barn alleys are cleaned three times a day (every 8 hours) using a flush system. Sawdust is used for bedding in the free stall barn. Silage is kept covered. All flush water, cow wash-water, and parlor cleanup and sanitation water is directed to the existing 3,351,252-cubic-foot manure holding lagoon.

All liquids in the holding lagoon are applied to crop land four times each year consistent with the site's NMP. Thus, the lagoon has 90 days of storage capacity. To help show the storage structure has adequate capacity, WMD assumes that the storage volume is never less than the accumulated sludge volume plus the minimum treatment volume. Although solids are periodically removed and thus more volume is available to store process wastewater, runoff, and precipitation, this conservative assumption reserves the sludge volume for the maximum amount of accumulated solids over the storage period.

Approximately 40 percent of the milk cow confinement area is paved or roofed. Precipitation from roofed areas drains onto the paved portion of the milk cow confinement area before being discharged to the manure holding lagoon. All paved areas have curbing to contain manure and precipitation. Unpaved areas have reception pits to collect manure and precipitation before discharge to the manure holding lagoon. Heifers and calves are managed on a non-paved 300,000-square-foot-dry lot that discharges to the manure holding lagoon. Any overflows from the lagoon might eventually reach a receiving surface waterbody (in this case, the Susquehanna River).

Summary of baseline overflow volume and pollutant loading calculations

Process Wastewater Generation:	25,857 ft^3/day (193,400 gal/day)
Sludge Volume (constant):	870,807 ft^3
Minimum Treatment Volume (constant):	1,530,000 ft^3
Total Existing Storage Lagoon Volume:	3,351,252 ft^3 (25 million gallons)
Volume in Lagoon at Start:	2,400,807 ft^3 (Sludge Volume + Minimum Treatment Volume)
Precipitation Volume (median):	40 in/yr
Evaporation Rate (median):	57 in/yr
Runoff (median):	17,033 ft^3/yr
Liquid/Solids Removal for Crop Application:	Completely dewater all lagoon liquids four times per year

Calculated baseline overflow volume method

Daily Accumulation of Lagoon Liquids (ft^3/day) = Process Waste (ft^3/day) + Runoff (ft^3/day) + ((Precipitation-Evaporation (ft/day)) x Lagoon Surface Area (ft^2)

Volume of Lagoon Liquids (ft^3) = Previous Days' Volume (ft^3) + Daily Accumulation of Lagoon Liquids Volume (ft^3/day)

Example 1. Whole Milk Dairy, Lancaster, Pennsylvania *(continued)*

If the Volume of Lagoon Liquids (ft^3) is greater than the following:

Existing Storage Lagoon Volume (ft^3) - Sludge Volume (ft^3) - Minimum Treatment Volume (ft^3)], then

Overflow Volume = Volume of Lagoon Liquids (ft^3) - [Existing Storage Lagoon Volume (ft^3) - Sludge Volume (ft^3) - Minimum Treatment Volume (ft^3)]; and

Volume of Lagoon Liquids (ft^3) is adjusted to the following:

[Existing Storage Lagoon Volume (ft^3) - Sludge Volume (ft^3) - Minimum Treatment Volume (ft^3)] (the maximum volume of liquids the lagoon can store)

If it is a land application day:

The Volume of Lagoon Liquids (ft^3) = 0

Calculated Overflow Volume for WMD: 57,386 ft^3/yr (429,247 gal/yr)

WMD collected a representative sample of liquid from the storage lagoon to calculate the annual pollutant discharge of BOD_5, total N, total P, and TSS as a result of the overflow volume. The sample was collected from the top 12 inches of the lagoon surface because the majority of overflow will likely be attributed to that zone. The sampling results are shown below:

BOD_5:	600 mg/L	(5.0 lbs per 1,000 gallons)
Total N:	268 mg/L	(2.2 lbs per 1,000 gallons)
Total P:	208 mg/L	(1.7 lbs per 1,000 gallons)
TSS:	1,500 mg/L	(12.5 lbs per 1,000 gallons)

On the basis of the overflow and the measured concentration, the annual pollutant discharges from the lagoon were calculated by multiplying the flow by the concentration as shown in the example for BOD_5 below:

BOD_5: 600 mg/L x 3.785 L/gal x 429,247 gal/yr x 2.2 lbs/kg x 1 kg/10^6 mg = 2,145 lbs/yr

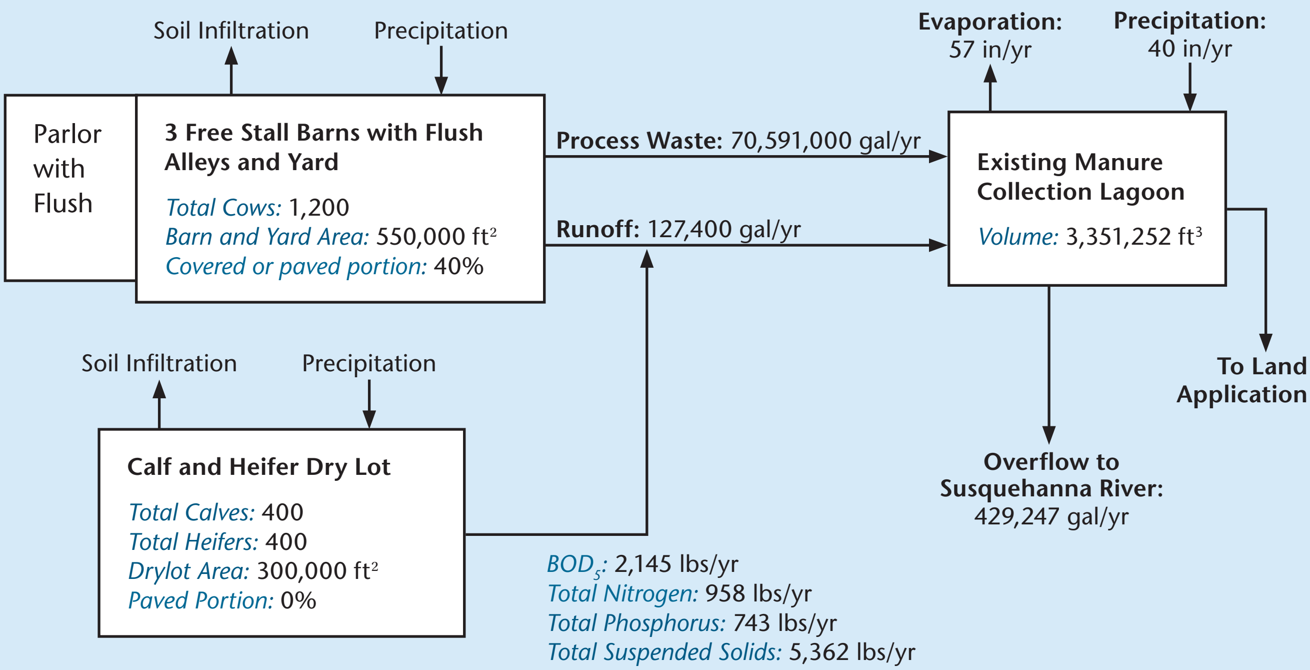
A summary of the pollutant loadings based on the overflow rate and concentration is shown below.

BOD_5:	2,145 lbs/yr
Total N:	958 lbs/yr
Total P:	743 lbs/yr
TSS:	5,362 lbs/yr

Example 1. Whole Milk Dairy, Lancaster, Pennsylvania *(continued)*

Diagram of baseline waste management system

The following figure is a block diagram of WMD summarizing the inputs and outputs from the manure storage lagoon and the overflows and pollutant loadings. Any overflows from the lagoon eventually reach a surface waterbody (in this case, the Susquehanna River).



Waste characterization and alternative treatment system evaluation

WMD in cooperation with its consultant, Tick Engineering, has decided to voluntarily pursue an alternative to its existing lagoon to have a constant discharge of treated water to the Susquehanna River. The treatment train it selected consists of primary clarification, aerobic biological treatment, and final polishing using an engineered wetland. Tick Engineering conducted pilot-scale testing of the system June 15 to November 15 at WMD using actual process wastewater. The conceptual design calculations and pilot-scale treatment test are summarized below.

Waste flow and characterization

Tick Engineering conducted a daily composite sample of manure, flush water, wash water, parlor cleanup and sanitation water and rainwater during a 7-day operational period in April 2003 to characterize the wasteload discharged to the storage lagoon. The combined volume of manure, flush water, wash water, parlor cleanup water and rainwater was also measured during the 7-day sampling period in April, 2003. The average daily flow to the lagoon, which included one day of rainfall was 176,410 gallons. Waste characterization data and calculated average daily loading to the treatment system are summarized below:

Example 1. Whole Milk Dairy, Lancaster, Pennsylvania *(continued)*

Pollutant	Concentration (mg/L)	Influent (lbs/day)
BOD_5:	1,701	2,496
Total N:	478	702
Total P:	74	109
TSS:	12,269	18,018

Daily pollutant loadings were calculated by multiplying the concentration for each constituent by the average daily flow as shown in the example below for BOD_5:

BOD_5 Loading: 1,701 mg/L x 3.785 L/gal x 1 kg/1,000,000 mg x 2.2 lbs/kg x 176,410 gal/day = 2,496 lbs/day

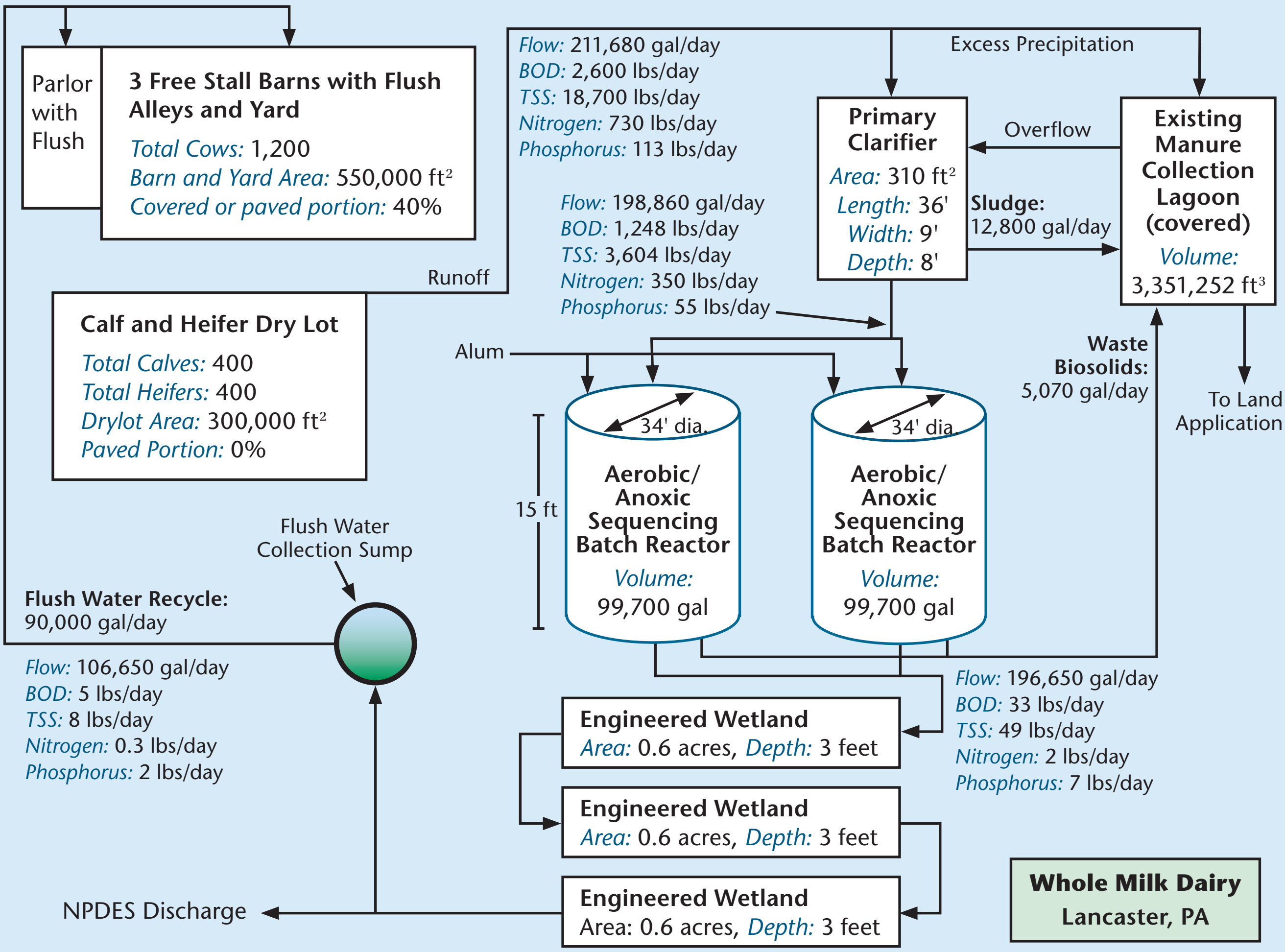
The treatment system design is based on a flow excess of 20% or 211,690 gallons per day. Flows greater than 211,690 gal/day will overflow back to the existing 3,351,252-cubic-foot lagoon. During dry-weather periods, excess water and direct precipitation from the lagoon will be pumped back to the beginning of the treatment system for processing. The following figure is a flow diagram showing the treatment equipment and sizes, flows in and out of each treatment unit, and the pollutant reductions by each treatment step. Note that WMD will have the capability of recycling nearly 90,000 gallons per day of treated effluent for manure flushing.

Alternative treatment system effectiveness

The average concentration of target pollutants measured in the effluent from the pilot-scale treatment system during the 6-month study is shown below. The calculated monthly loadings for the full-scale treatment system is based on an average daily flow of 176,410 gallons entering the treatment system minus a recycle flow of 90,000 gallons per day for manure flushing.

Example 1. Whole Milk Dairy, Lancaster, Pennsylvania *(continued)*

Diagram of alternative treatment system



Comparison of the baseline overflow to the discharge from the alternative treatment system

Pollutant	Baseline overflow (lbs/yr)	Treatment system discharge (lbs/day)
BOD_5:	2,145	1,830
Total N:	958	110
Total P:	743	730
TSS:	5,362	2,920

Conclusion: The loadings comparison clearly shows the proposed treatment system consisting of primary clarification, aerobic biological treatment and final polishing using an engineered wetland would achieve a quantity of pollutants discharged from the production area that is equal to or less than the quantity of pollutants that would be discharged using baseline treatment. Note: This analysis pertains to the technology-based requirements of the CAFO rules and does not include an assessment of whether a discharge would meet the state's water quality standards.

Example 2. KF Pork Producers, Davenport, Iowa

Background

KF Pork Producers (KFP) is a Large CAFO in Scott County, Iowa. KFP has 7,000 grower swine with an average weight of approximately 140 pounds. Swine are housed in a 57,400-square-foot-barn with 10 confinement pens. Manure is washed from pens daily using a flush system. All manure and flush water drains into storage tanks beneath the partially slotted concrete floor. Storage tanks are emptied daily by pumping the manure and flush water to an existing 3,931,800-cubic-foot manure holding lagoon.

KFP, in consultation with local residents, avoids de-watering the storage structure on weekends and holidays. Liquids in the holding lagoon are applied to crop land (to the maximum daily hydraulic loading) on the 7th, 14th, 21st, and 28th days of each month during the freeze-free period between April 21 and September 14, assuming that there has been no significant precipitation during the 3 days before the day of application. (The nutrient applications are tracked by KFP's NMP and are not further considered here.) KFP assumes that the storage volume is never less than the accumulated sludge volume plus the minimum treatment volume. Although there are times that solids are removed and more space is available for process wastewater, runoff, and precipitation, that conservative assumption reserves storage space for the maximum amount of accumulated solids over the storage period.

Summary of baseline overflow volume and pollutant loading calculations

Process waste generation:	8,356 ft^3/day (62,500 gal/day)
Sludge Volume (constant):	486,091 ft^3 (3.6 million gal)
Minimum Treatment Volume (constant):	661,500 ft^3 (4.9 million gal)
Total Existing Storage Lagoon Volume:	3,931,800 ft^3 (29.4 million gal)
Volume of Liquids and Solids in Lagoon at Start:	1,206,083 ft^3 (Sludge Volume + Minimum Treatment Volume + Accumulated Process Wastes Since Last Liquid Application)
Precipitation Volume (average):	26 in/yr
Evaporation Rate (average):	98 in/yr
Liquid/Solids Removal for Crop Application:	Land apply lagoon liquids to the maximum hydraulic loading of the crop land on days 7, 14, 21, and 28 of each month unless there has been precipitation in the past 3 days before the application day (That occurs between the freeze-free days between April 21 and September 14)

Calculated baseline overflow volume method

Daily Accumulation of Lagoon Liquids (ft^3/day) = Process Waste (ft^3/day) + [Precipitation – Evaporation] (ft/day) x Lagoon Surface Area (ft^2)

Volume of Lagoon Liquids (ft^3) = Volume of Lagoon Liquids from Previous Day (ft^3) + Daily Accumulation of Lagoon Liquids (ft^3)

Example 2. KF Pork Producers, Davenport, Iowa *(continued)*

If the Volume of Lagoon Liquids (ft^3) is greater than the following:

Existing Storage Lagoon Volume (ft^3) - Sludge Volume (ft^3) - Minimum Treatment Volume (ft^3)], then

Overflow Volume = Volume of Lagoon Liquids (ft^3) - [Existing Storage Lagoon Volume (ft^3) - Sludge Volume (ft^3) - Minimum Treatment Volume (ft^3)]; and

Volume of Lagoon Liquids (ft^3) is adjusted to the following:

[Existing Storage Lagoon Volume (ft^3) - Sludge Volume (ft^3) - Minimum Treatment Volume (ft^3)]
(the maximum volume of liquids the lagoon can store)

If it is an application day (day 7, 14, 21, or 28 of the period between April 21 and September 14), the Volume of Lagoon Liquids (ft^3) = Volume of Lagoon Liquids (ft^3) - Max Hydraulic Loading (ft3)

Calculated Overflow Volume for KFP: 158,419 ft^3/yr (1,184,970 gal/yr)

KFP collected a representative sample of liquid from the storage lagoon to calculate the annual pollutant discharge of BOD_5, total N, total P, and TSS as a result of the overflow volume. The sample was collected from the top 12 inches of the lagoon surface because the majority of overflow will likely be attributed to that zone. The sampling results are shown below:

BOD_5:	1,650 mg/L
Total N:	270 mg/L
Total P:	102 mg/L
TSS:	3,000 mg/L

On the basis of the overflow and the measured concentration, the annual pollutant discharges from the lagoon were calculated by multiplying the flow by the concentration as shown in the example for BOD_5 below:

BOD_5: 1,650 mg/L x 3.785 L/gal x 1,184,970 gal/yr x 2.2 lbs/kg x 1 kg/10^6 mg = 16,280 lbs/yr

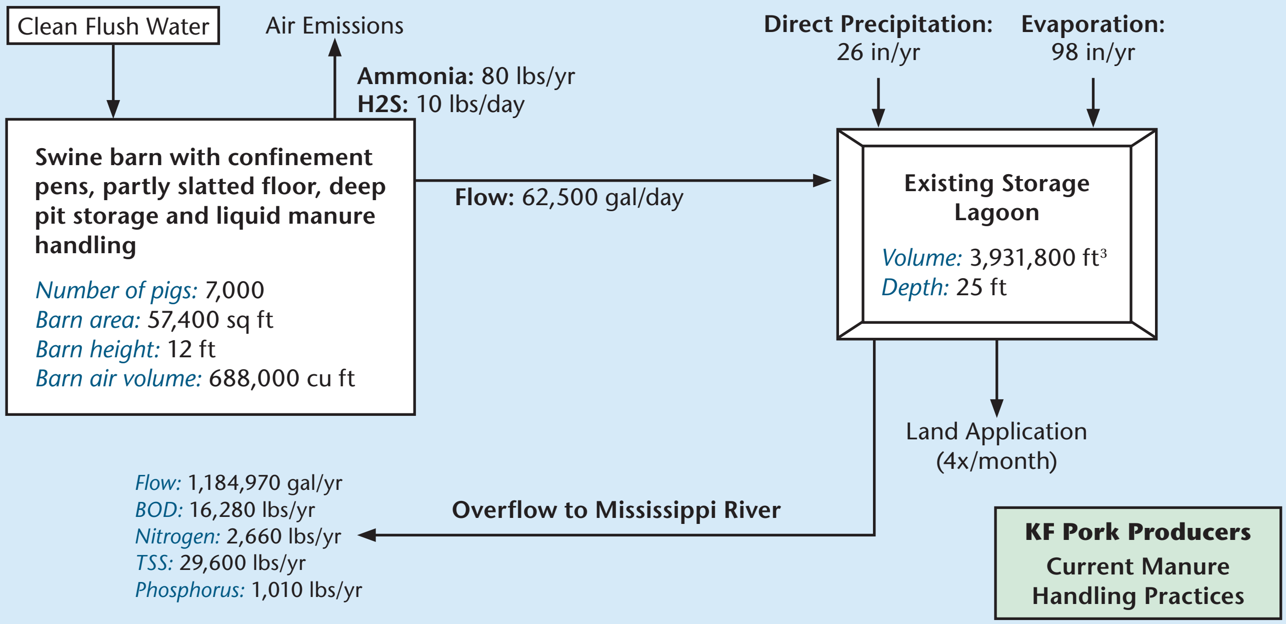
A summary of the pollutant loadings based on the overflow rate and concentration is shown below.

BOD_5:	16,280 lbs/yr
Total N:	2,660 lbs/yr
Total P:	1,010 lbs/yr
TSS:	29,600 lbs/yr

Example 2. KF Pork Producers, Davenport, Iowa *(continued)*

Diagram of baseline waste management system

The following figure is a block diagram of KFP summarizing the inputs and outputs from the manure storage lagoon and the overflows and pollutant loadings. Any overflows from the lagoon discharge to a surface waterbody (in this case, the Mississippi River).



Waste characterization and treatment system evaluation

KFP realized it was not cost-effective to haul excess nutrients in the liquid manure. KFP, in cooperation with its consultant, WB Engineering, conducted a whole-farm audit to determine if pollutant releases could be reduced at the facility by applying new technologies. WB Engineering examined discharges of pollutants from lagoon overflows, estimated air emissions of ammonia and hydrogen sulfide, and worked with KFP to determine if changes in swine feed rations could lower the amount of ammonia and P entering the manure. Finally, WB examined manure application rates to determine if more frequent removals of manure/sludge from the lagoon could provide additional storage capacity and less frequent overflows.

As a result of the whole-farm audit, KFP decided to further evaluate a new wastewater treatment system plus an off-gas treatment system for air removed from both the swine barn and manure pits. Changes in feed rations were not implemented on recommendations from both an animal nutritionist and the local agricultural extension agent, and additional application rates of manure to KFP's crop land would have exceeded nutrient requirements according to the facility's NMP.

The treatment train selected for KFP consists of primary clarification, a vibrating membrane filtration system, and final polishing using a biological trickling filter. For off-gas from the swine barn and manure pits, a biofilter using inorganic media was selected to remove ammonia and hydrogen sulfide. Pilot-scale testing of both the wastewater and air treatment system was conducted March 20 to September 20, 2003, by WB Engineering. Pilot 20 2003 by WB Engineering. A summary of the conceptual design calculations and pilot-scale treatment test results are below.

Example 2. KF Pork Producers, Davenport, Iowa *(continued)*

Waste flow and characterization

WB Engineering collected a daily composite sample of manure and flush water during a 7-day operational period in March 2003 to characterize the wasteload discharged to the storage lagoon. The volume of manure and flush water was also measured during the 7-day sampling period in April, 2003. The average daily flow to the lagoon was 62,500 gallons. Waste characterization data and calculated average daily loading to the treatment system for the target pollutants are summarized below:

Pollutant	Concentration (mg/L)	Influent (lbs/day)
BOD_5:	3,766	1,960
Total N:	753	392
Total P:	301	157
TSS:	11,863	6,174

Daily pollutant loadings were calculated by multiplying the concentration for each constituent by the average daily flow as shown in the example below for BOD_5:

BOD_5 Loading: 3,766 mg/L x 3.785 L/gal x 1 kg/1,000,000 mg x 2.2 lbs/kg x 62,500 gal/day = 1,960 lbs/day

The wastewater treatment system design is based on a flow excess of 20% or gallons per day. Flows greater than 75,000 gallons per day will overflow to the existing 1,500,000-cubic-foot lagoon. During dry-weather periods, excess water from the lagoon will be pumped back to the beginning of the treatment system for processing. Note that KFP will have the capability of recycling nearly 22,600 gallons per day of treated effluent for manure flushing.

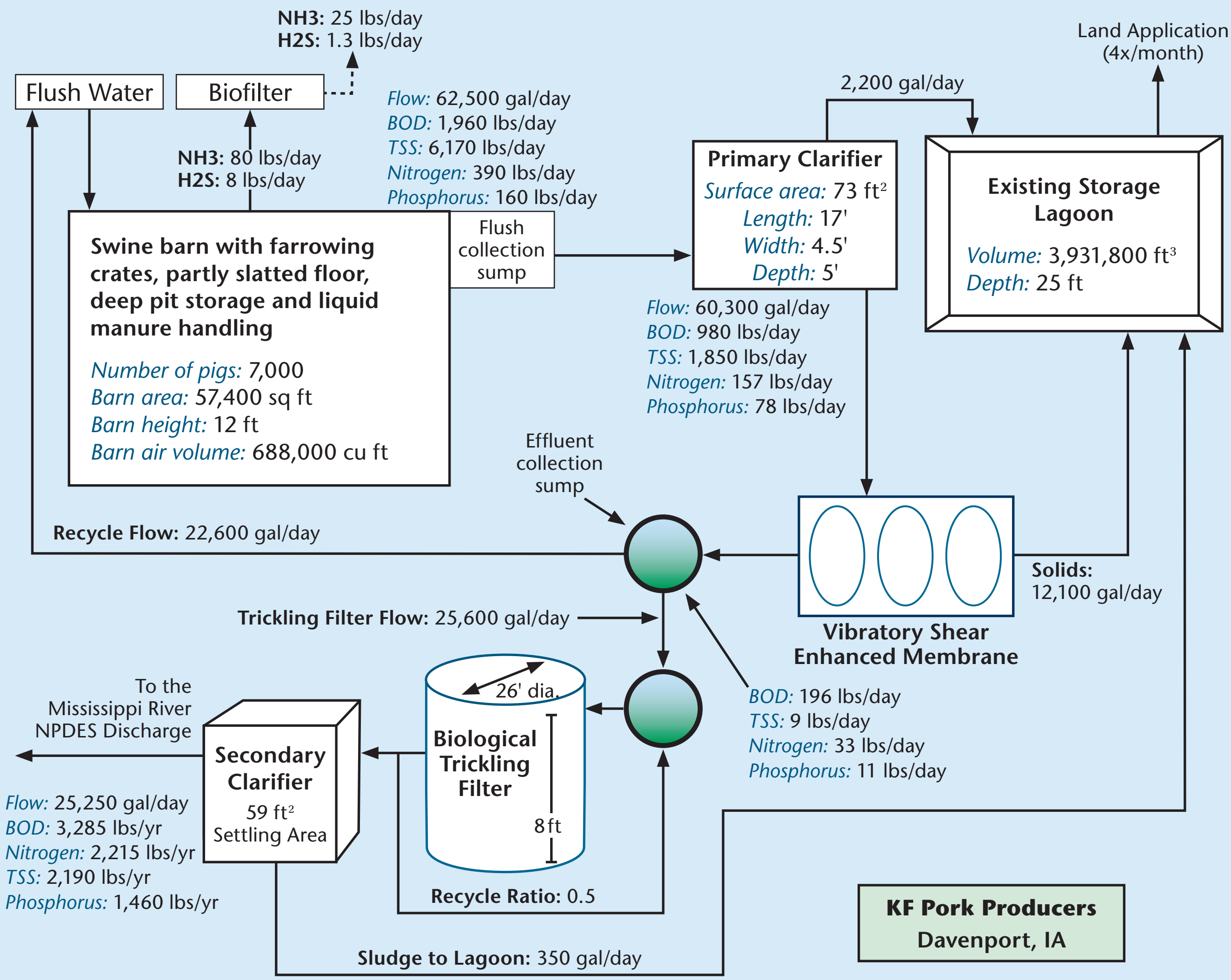
Off-gas from the swine barn and deep pit areas was characterized by collecting air samples from areas near the exit fans. The average concentration of ammonia and hydrogen sulfide measured in the off-gas was 54 ppm and 4 ppm, respectively. On the basis of a measured exhaust rate from all the exit fans for the barn and pit areas, WB Engineering estimates approximately 80 lbs/day of ammonia and approximately 10 lbs/day of hydrogen sulfide is emitted to the atmosphere. Design of the biofilter for treatment of off-gas was provided by BIOREM and consists of new fans and duct work to move air through a single discharge point and an in-ground biofilter to destroy ammonia and hydrogen sulfide.

Treatment system effectiveness

The average concentration of target pollutants measured in the effluent from the pilot-scale wastewater treatment system during the 6-month study is shown in the table below. The calculated monthly loading for the full-scale treatment system is based on an average daily flow of 25,250 gallons. The remaining 37,750 gallons of water that enter the treatment system is used for either recycle or contains concentrated treatment residuals that are discharged to the existing storage lagoon. KFP now has the additional flexibility to collect solids and concentrated nutrients from the existing sludge lagoon and haul them off-site for other uses.

Example 2. KF Pork Producers, Davenport, Iowa *(continued)*

Diagram of alternative treatment system



Comparison of the baseline overflow to the discharge from the alternative treatment system

Pollutant	Baseline overflow (lbs/yr)	Treatment system discharge (lbs/day)
BOD_5:	16,280	3,285
Total N:	2,664	2,215
Total P:	1,006	1,460
TSS:	29,602	2,190

Example 2. KF Pork Producers, Davenport, Iowa *(continued)*

The average concentration of ammonia and hydrogen sulfide measured in the off-gas from the biofilter during the 6-month pilot-scale treatment test is shown below. The biofilter removed approximately 70 percent of the ammonia and 87 percent of the hydrogen sulfide in the gas stream. The biofilter also eliminated all odors from the swine CAFO's off-gas.

Biofilter treatment results during the 6-month pilot test

Pollutant	Influent loading (lbs/day)	Gas flow (cfm)	Effluent loading (lbs/day)	Odor
Ammonia	80	23,000	25	None
Hydrogen Sulfide	10	23,000	1.3	None

Conclusion: Comparison of the pilot-scale testing results with the calculated overflow discharges indicates the proposed treatment system cannot achieve a quantity of pollutants discharged for all the targeted pollutants that is equal to or less than the quantity of pollutants that would be discharged under the baseline performance standards. Because the proposed treatment system cannot achieve the reduction for all target pollutants, the permitting authority denies the facility's request for an individual NPDES permit for operation and discharge of water from the proposed treatment system. If modifications to the treatment system can be made that lower the annual discharge of phosphorus, an individual permit might be considered.

KFP has still decided to install a new biofilter system to remove odors, ammonia, and hydrogen sulfide from its air stream to address complaints from neighbors regarding smells from the facility.

Example 3. Birvan Egg Farms, Okeechobee County, Florida

Background

Birvan Egg Farms (Birvan) is a Large CAFO in Okeechobee County, Florida. Birvan has 40,000 laying hens with an average weight of approximately 3 pounds. Birds are housed in a high-rise cage system. Manure drops from the cages to the floor below and is picked up by the wet flush system and transferred to the anaerobic digester. The anaerobic digester removes the majority of nutrients, BOD_5, and volatile solids while generating methane that is used in the facility's boiler system. Effluent from the anaerobic digester is pumped through a vibrating membrane filtration system for polishing residual solids, BOD_5, and nutrients before land application of the polished water to a small grass field. All solids are hauled and sold off-site. Birvan elected to install an anaerobic treatment system rather than a holding pond because of space constraints and the lack of crop land to apply liquids and solids. The manure treatment system has been in operation since 1996.

Birvan calculated the overflow volume and loading from a baseline system (a liquid storage structure) that could have been installed at the facility and compared the results with the loadings being obtained from the existing treatment system.

Summary of baseline overflow volume and pollutant loading calculations

Estimated Storage Lagoon Volume if Constructed:	58,200 ft^3 (435 thousand gallons)
Process Wastewater Generation:	374 ft^3/day (2,800 gal/day)
Volume of Liquids and Solids in Lagoon at Start:	635 ft^3 (Sludge Volume + Minimum Treatment Volume + Accumulated Process Wastes Since Last Liquid Application)
Precipitation Volume (average):	61 in/yr
Evaporation Rate (average):	90 in/yr
Sludge Volume (constant):	5,900 ft^3
Minimum Treatment Volume (constant):	9,200 ft^3
Assumed removal rate:	2x per month from January 21 to December 9
Daily Accumulation of Lagoon Liquids (ft^3/day) =	Process Waste (ft^3/day) + [Precipitation - Evaporation (ft/day)] x Lagoon Surface Area (ft^2)
Volume of Lagoon Liquids (ft^3) =	Previous Days' Volume (ft^3) + Accumulation Volume (ft^3/day)

Calculated baseline overflow volume method

Daily Accumulation of Lagoon Liquids (ft^3/day) = Process Waste (ft^3/day) + [Precipitation - Evaporation (ft/day)] x Lagoon Surface Area (ft^2)

Volume of Lagoon Liquids (ft^3) = Previous Days' Volume (ft^3) + Accumulation Volume (ft^3/day)

Example 3. Birvan Egg Farms, Okeechobee County, Florida *(continued)*

If the Volume of Lagoon Liquids (ft^3) is greater than the following:

Existing Storage Lagoon Volume (ft^3) - Sludge Volume (ft^3) - Minimum Treatment Volume (ft^3)], then

Overflow Volume = Volume of Lagoon Liquids (ft^3) - [Existing Storage Lagoon Volume (ft^3) - Sludge Volume (ft^3) - Minimum Treatment Volume (ft^3)]; and

Volume of Lagoon Liquids (ft^3) is adjusted to the following:

[Existing Storage Lagoon Volume (ft^3) - Sludge Volume (ft^3) - Minimum Treatment Volume (ft^3)] (the maximum volume of liquids the lagoon can store)

Calculated Overflow Volume for Birvan 3,162 ft^3/yr (23,651 gal/yr)

Birvan collected a representative sample of liquid from the digester to calculate the annual loading of BOD_5, total N, total P, and TSS that would be discharged as a result of the overflow volume. The sample was collected from the top 12 inches of the digester surface because the majority of overflows will likely be attributed to this zone. The sampling results are shown below:

BOD_5:	1,500 mg/L
Total N:	750 mg/L
Total P:	100 mg/L
TSS:	3,200 mg/L

On the basis of the overflow and the measured concentration, the annual pollutant discharges from the storage system was calculated by multiplying the flow by the concentration as shown in the example for BOD_5 below:

BOD_5: 1,500 mg/L x 3.785 L/gal x 23,651 gal/yr x 2.2 lbs/kg x 1 kg/10^6 mg = 295 lbs/yr

A summary of the pollutant loadings based on the overflow rate and concentration is shown below.

BOD_5:	295 lbs/yr
Total N:	148 lbs/yr
Total P:	20 lbs/yr
TSS:	433 lbs/yr

Treatment system evaluation

Birvan has been collecting monthly samples for BOD_5, total N, total P, and TSS from the existing treatment system since early 1997. The measured monthly concentrations in the treatment system effluent and the total flow through the treatment system over the past 12 months are shown below.

Example 3. Birvan Egg Farms, Okeechobee County, Florida *(continued)*

Measured treatment system effluent concentration and total influent flow during the past 12 months

Month	BOD_5 (mg/L)	N (mg/L)	P (mg/L)	TSS	Total flow (gal)
June	20	3.3	0.6	14	83,800
July	21	5.2	0.8	15	83,200
August	13	1.6	0.7	10	84,600
September	8	0.8	0.6	9	83,900
October	9	0.6	0.4	7	84,200
November	18	3.5	0.6	13	84,700
December	13	2	0.7	11	84,300
January	6	0.7	0.4	9	82,900
February	8	0.7	0.4	8	83,900
March	19	1.8	0.8	13	84,700
April	20	4.2	1.2	15	85,100
May	7	2.7	0.8	14	84,300
Median	**13**	**1.9**	**0.6**	**12**	**84,250**

As shown in the figure below, the vibrating membrane filter generates a concentrated wastestream equaling 20% of the influent flow (16,850 gal/month). That concentrated wastestream is sent to a 10,000-gallon holding tank before off-site shipment. Effluent from the vibrating membrane filter enters a lift station where submersible pumps transfer approximately 45,000 gallons per month back to the layer house for manure flushing. According to a measured average flow rate of approximately 22,400 gallons per month at Outfall 001 and the concentration of pollutants in the vibrating membrane treatment system effluent, the following annual loadings to St. Lucie Canal were calculated and compared to the baseline overflow loadings.

Comparison of the Calculated Baseline Overflow Discharge to the Treatment System Discharge

Pollutant	Baseline overflow (lbs/yr)	Treatment system discharge (lbs/day)
BOD_5:	295	29
Total N:	148	4.2
Total P:	20	1.3
TSS:	433	27

Conclusion: The comparison shows that the existing treatment systems consisting of an anaerobic digester and vibrating membrane filtration system achieve better performance than the baseline system for all targeted pollutants. If water quality constraints for fecal coliform in the St. Lucie Canal make additional treatment necessary, Birvan is also considering increasing the temperature of the digester to make it thermophilic, a practice known to reduce fecal coliform in the effluent.

Example 3. Birvan Egg Farms, Okeechobee County, Florida *(continued)*

Diagram of existing treatment system