CHAPTER 8

TREATMENT TECHNOLOGIES AND BEST MANAGEMENT PRACTICES

8.0 INTRODUCTION

This chapter provides an overview of treatment technologies and best management practices (BMPs) for pollution prevention at animal feeding operations (AFOs), as well as for the handling, storage, treatment, and land application of wastes. The discussion focuses on technologies and BMPs currently implemented at domestic AFOs, but it also describes technologies and BMPs that are under research and development, are undergoing laboratory or field testing, or are used in other countries.

Many waste management technologies and BMPs are used by more than one animal sector, and information on them is presented in a general discussion form. However, the manner in which a particular technology or BMP is used or its degree of acceptance can vary among sectors. These differences are presented by animal sector where necessary.

8.1 Pollution Prevention Practices

Pollution prevention practices can be divided into feeding strategies that reduce the concentration of pollutants in waste and practices that reduce the amount of water used in the handling of wastes. Reduced water use or handling of wastes in a dry or drier form lowers the risk of pollutants entering surface waters. Reduced water use has the added benefit of making the waste less expensive to move from the facility site.

8.1.1 Feeding Strategies

Feeding strategies designed to reduce nitrogen (N) and phosphorus (P) losses include more precise diet formulation, enhancing the digestibility of feed ingredients, genetic enhancement of cereal grains and other ingredients resulting in increased feed digestibility, and improved quality control. These strategies increase the efficiency with which the animals use the nutrients in their feed and decrease the amount of nutrients excreted in the waste. With a lower nutrient content, more manure can be applied to the land and less cost is incurred to transport excess manure from the farm. Strategies that focus on reducing P concentrations, thus reducing overapplication of P and associated runoff into surface waters, can turn manure into a more balanced fertilizer in terms of plant requirements.

Feeding strategies that reduce nutrient concentrations in waste have been developed for specific animal sectors, and those for the swine, poultry and dairy industries are presented separately in the following discussion. The application of these types of feeding strategies to the beef industry has lagged behind other livestock sectors and is not discussed here.

8.1.1.1 Swine Feeding Strategies

Practice: Precision Nutrition for Swine

Description: Current swine feed rations can result in overfeeding proteins and other nutrients to animals because they are designed to ensure that nutritional requirements are met and growth rate maintained. Precision nutrition entails formulating feed to meet more precisely the animals' nutritional requirements, causing more of the nutrients to be metabolized, thereby reducing the amount of nutrients excreted. For more precise feeding, it is imperative that both the nutritional requirements of the animal and the nutrient yield of the feed are fully understood.

When swine are fed typical diets, the P use efficiency is on the order of 10 to 25 percent, while the N use efficiency is on the order of 30 percent. These figures suggest that swine use these nutrients very inefficiently. An excess of N in the diet, principally from protein in feed, leads to inefficient utilization of nutrients. Phytate-phosphorus[1] (phytate-P), the most common form of P in feedstuffs (56 to 81 percent), is not well utilized by pigs because they lack intestinal phytase, the enzyme needed to remove the phosphate groups from the phytate molecule. Therefore, supplemental P is added to the diet to meet the pig's growth requirements, while phytate-P from the feed is excreted in the urine, thus increasing P concentrations in the manure. Because some feedstuffs are high in phytase, and because there is some endogenous phytase in certain small grains (wheat, rye, triticate, barley), there is wide variation in the digestibility of P in feed ingredients. For example, only 12 percent of the total P in corn is digestible whereas 50 percent of the total P in wheat is digestible. The P in dehulled soybean meal is more available than the P in cottonseed meal (23 versus 1 percent), but neither source of P is as highly digestible as the P in meat and bone meal (66 percent), fish meal (93 percent), or dicalcium phosphate (100 percent).

Application and Performance: Lenis and Schutte (1990) showed that the protein content of a typical Dutch swine ration could be reduced by 30 grams per kilogram without negative effects on animal performance. They calculated that a 1 percent reduction in feed N could result in a 10 percent reduction in excreted N. Monge et al. (1998) confirmed these findings by concluding that a 1 percent reduction in feed N yielded an 11 percent reduction in excreted N. According to Van Kempen and Simmins (1997), reducing the variation of nutrients in feed by using more appropriate quality control measures would reduce N waste by 13 to 27 percent. Experts believe that N losses through excretion can be reduced by 15 to 30 percent in part by minimizing excesses in diet with better quality control at the feed mill (NCSU, 1998).

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[1]Most plant P occurs in the form of phytate, which is P bonded to phytic acid.

Plant geneticists have produced strains of corn that contain less phytate-P (i.e., low-phytate corn) and are more easily digested than typical strains, resulting in less P excreted in manure. Allee and Spencer (1998) found that hogs fed low-phytate corn excreted an average of 37 percent less P in manure, with no adverse effects on animal growth. In a study by Bridges et al. (1995), two weight classes of grower-finisher pigs (66.1 and 101.7 kg) were given maize-soybean meal diets lower in protein and P to determine the reduction in N and P in pig waste when compared with pigs fed a conventional diet. Total N waste was reduced by 32 percent and 25 percent for the two weight classes, while total P excretion was reduced by 39 percent and 38 percent, respectively. The study also modeled the impact of reductions in dietary protein and P over the complete grower-finisher period using the NCPIG model developed by the North Central Regional Swine Modeling Committee. Model results showed a reduction of approximately 44 percent in total N and P excretion compared with the conventional diet, with little impact on the time of production. In addition, the Fédération Européenne des Fabricants d'Adjuvants pour la Nutrition Animale in Belgium (FEFANA,1992) calculated that the selection of highly digestible feedstuffs should result in a 5 percent reduction in total waste.

Advantages and Limitations: Precision feeding results in a higher feed efficiency (less feed used per pound of pig produced); however, any cost savings are at least partially offset by the cost of analyzing the nutrient content of feedstuffs. Consumer reaction to use of genetically modified crops to feed swine has not been determined yet.

Operational Factors: Precision feeding requires that feed manufacturers have the necessary equipment and procedures to create precision feeds within specified quality control limits. In general, feed manufacturers have traditionally limited quality control to measuring N, which correlates poorly with amino acid content in feedstuffs (van Kempen and Simmins, 1997). Precision feeding will also increase the costs and complexity of feed storage at the feeding operation.

Demonstration Status: Data on the frequency of use of precision nutrition are not available. Much of the information available on precision nutrition is derived from small-scale research experiments at the USDA and universities.

Practice: Multiphase and Split-Sex Feeding for Swine

Description: Multiphase feeding involves changing diet composition weekly instead of feeding only two different diets during the period from the 45-kg size to slaughter. Multiphase feeding is designed to better match the diet with the changing nutritional requirements of the growing animals.

Application and Performance: Feeding three or four diets during the grow-finish period instead of only two diets will reduce N excretion. According to models such as the Dutch Technical Pig Feeding Model by van der Peet-Schwering et al. (1993), multiphase feeding reduces N and P excretion by 15 percent. The modeling results have been confirmed by animal trials that showed a 12.7 percent reduction in N excretion in urine and a 17 percent reduction in P excretion.

Advantages and Limitations: Dividing the growth period into more phases with less spread in weight allows producers to meet more closely the pig's protein requirements. Also, because gilts (females) require more protein than barrows (males), separating barrows from gilts allows lower protein levels to be fed to the barrows without compromising leanness and performance efficiency in the gilts.

Operational Factors: Multiphase and split-sex feeding require separate feeding areas and pens for the different types of animals. It is also more costly to produce a different feed every week.

Demonstration Status: The *Swine '95* report (USDA APHIS, 1995) showed that 96.2 percent of grower/finisher operations fed two or more different diets. Of these operations, 63.4 percent progressed to a different diet based on animal weight, 5.3 percent changed diets based on either age or the length of time on the feed, and 30.0 percent based diet changes on equal consideration of weight and time. Of the 96.2 percent of grower-finisher operations that feed more than one diet, 18.3 percent practiced split-sex feeding. Split-sex feeding is used much more frequently in medium (2,000-9,999 head) and large operations (10,000+ head) than in small operations (less than 2,000 head).

Practice: Improved Feed Preparation for Swine

Description: Milling, pelleting, and expanding are examples of technological treatments that improve the digestibility of feeds. By reducing the particle size, the surface area of the grain particles is increased, allowing greater interaction with digestive enzymes. NCSU (1998) reported that the industry average particle size was approximately 1,100 microns and that the recommended size is between 650 and 750 microns. Expanders and extruders are used mainly to provide flexibility in ingredient selection and to improve pellet quality rather than to improve nutrient digestion.

Application and Performance: As particle size is reduced from 1,000 microns to 700 microns, excretion of N is reduced by 24 percent. Vanschoubroek et al. (1971) reviewed many articles regarding the effect of pelleting on performance and found that not only did animals prefer pelleted feed over mash feed, but feed efficiency improved by 8.5 percent and protein digestibility improved by 3.7 percent with pelleted feed.

Advantages and Limitations: Although reducing particle size less than 650 to 750 microns can increase feed digestibility, it also increases greatly the costs of grinding and reduces the throughput of the feed mill. Smaller-sized particles can also result in an increased incidence of stomach ulcers in animals. In some cases, chemical changes resulting from the high temperatures created in grinding machines may decrease feed digestibility.

Operational Factors: A reduction in the particle size of the feed might result in manure with finer solids particles. This may affect the performance of manure management practices, including possible effects on the efficiency of manure solid-liquid separators.

Demonstration Status: Data on the frequency of use of feed preparation techniques are not available.

Practice: Feed Additives for Swine

Description: Enzymes are commonly used in feed to improve the digestibility of nutrients. For example, plant P is often present in the form of phytate, which is digested poorly in swine, resulting in most of the P in feedstuffs being excreted in the manure. To prevent P deficiency, digestible P is added to swine rations, resulting in even more P in the manure. The enzyme additive phytase has been shown to improve P digestibility dramatically, and can be used to reduce the need for digestible P additives.

Other enzyme additives facilitate the retention of amino acids and digestive fluids, decreasing the amount of N excreted. Enzymes such as xylanases, beta-glucanases, and proteases upgrade the nutritional value of feedstuffs. Xylanases and beta-glucanases are enzymes used to degrade nonstarch polysaccharides (NSP) present in cereals such as wheat and barley. Swine do not secrete these enzymes and therefore do not have the capability to digest and use NSP. Because the NSP fraction traps nutrients that are released only upon partial degradation of the NSP fraction, addition of xylanase or beta-glucanase or both to cereal-containing diets can result in improvements in both digestibility and feed efficiency. In addition, supplementing the diet with synthetic lysine to meet a portion of the dietary lysine requirement is an effective means of reducing N excretion by pigs. This process reduces N excretion because lower-protein diets can be fed when lysine is supplemented. The use of other amino acid feed supplements is being tested.

Application and Performance: Mroz et al. (1994) showed that phytase increases P digestibility in a typical swine diet from 29.4 percent to 53.5 percent. They also demonstrated that phytase addition improved the digestibility of other nutrients in the feed such as calcium, zinc, and amino acids that are bound by phytase. For example, the addition of phytase to a commercial diet increased the digestibility of lysine by 2 percent while the digestibility of protein improved from 83.3 to 85.6 percent. Van der Peet-Schwering (1993) demonstrated that the use of phytase reduced P excretion by 32 percent in nursery pigs (a finding similar to the FEFANA [1992] predictions). Lei et al. (1993) found that feeding pigs 750 phytase units per gram of basal diet yielded a decrease in fecal P excretion of 42 percent without adverse health effects. This addition resulted in a linear improvement in phytate-P utilization. Graham and Inborr (1993) reported that enzyme additions improved the digestibility of protein in a wheat/rye diet by 9 percent.

Beal et al. (1998) used proteases on raw soybeans and observed a significant improvement in daily gain (+14.8 percent); feed efficiency, however, was improved by only 4.3 percent. Dierick and Decuypere (1994) saw a substantial improvement in feed efficiency when using proteases in combination with amylases and beta-glucanases, an improvement larger than that achieved with each enzyme individually. Studies have shown that protein levels can be reduced by 2 percent when the diet is supplemented with 0.15 percent lysine (3 pounds lysine-HC1 per ton of feed) without harming the performance of grower-finisher pigs.

Advantages and Limitations: Feed additives, especially synthetic amino acids and enzymes, increase the cost of feeding. Phytase, for example, was once too expensive to use as a feed additive. This enzyme can now be produced at lower cost with recombinant DNA techniques. As technology improves, it is likely that the costs associated with other feed additives will decrease similarly.

Operational Factors: The level of phytase required in swine feed varies with the age of the animal. These different levels are likely determined by the development of digestive enzymes and intestines of the pig, with the younger pig being less developed. Lysine supplements can be used to achieve even greater reductions in the level of protein in diets, but only if threonine, tryptophan, and methionine are also supplemented.

Demonstration Status: The use of proteases in animal feeds is not widespread because of conflicting results from trials. With the advancement of enzyme-producing technology, as well as a better understanding of the role of enzymes in animal nutrition, proteases and other enzymes (e.g., pentosanases, cellulase, and hemicellulases, as tested by Dierick, 1989) are likely to play a greater role in animal nutrition. As their costs come down, the Amino Acid Council foresees an increased use of synthetic amino acids as a method of reducing N excretion as well as improving animal performance and decreasing feeding costs.

8.1.1.2 Poultry Feeding Strategies

Poultry operators have traditionally employed feeding strategies that focus on promoting animal growth rates or maximizing egg production. Feed additives have also been used to prevent disease and enhance bone and tissue development. As noted in Chapter 4, productivity has increased dramatically over the past several decades. The decrease in the average whole-herd feed conversion ratio (pounds of feed per pound of live weight produced) has translated into reduced feed input per bird produced. Smaller feed requirements can mean decreased manure output, but, until recently, development of better feeding strategies and advances in genetics have not focused on manure quality or quantity generated. Environmental issues associated with animal waste runoff have compelled the poultry industry to look for improved methods of waste prevention and management, including feeding regimes that can reduce the nutrient content of manure.

Dietary strategies to reduce the amount of N and P in manure include developing more precise diets and improving the digestibility of feed ingredients through the use of enzyme additives and genetic enhancement of cereal grains.

Practice: Precision Nutrition for Poultry

Description: Precision nutrition entails formulating feed to meet more precisely the animals' nutritional requirements, causing more of the nutrients to be metabolized, thereby reducing the amount of nutrients excreted. For more precise feeding, it is imperative that both the nutritional requirements of the animal and the nutrient yield of the feed are fully understood. Greater understanding of poultry physiology has led to the development of computer growth models that take into account a variety of factors, including strain, sex, and age of bird, for use in implementing a nutritional program. By optimizing feeding regimes using simulation results, poultry operations can increase growth rates while reducing nutrient losses in manure.

Application and Performance: The use of improved feeds tailored to each phase of poultry growth has improved productivity significantly. Feed conversion ratios for broilers and turkeys have decreased steadily over the past several decades. Egg production productivity has also been boosted as operators have introduced improved nutrient-fortified feed.

Advantages and Limitations: Improved precision in feeding strategies offers numerous advantages, including reduction of nutrients in animal manure and better feed conversion rates. Improved formulations are also cost-effective and reduce the probability of wasteful overfeeding of poultry.

Operational Factors: Precision nutrition requires detailed knowledge of poultry nutritional requirements and maintenance of detailed records to ensure that dietary adjustments are performed in a timely manner to maximize growth potential.

Demonstration Status: The use of precise nutrient formulations has already generated large increases in productivity in the poultry sector. Many of the poultry operations are under contract and receive feedstuffs with precise formulations from the integrator. Ongoing research will likely continue to result in productivity improvements.

Practice: Use of Phytase as a Feed Supplement for Poultry

Description: Phosphorus, an essential element for poultry growth and health, is typically added to poultry feed mixes. However, because poultry are deficient in the enzyme phytase and cannot break down the protein phytate, much of the P contained in feed cannot be digested (Sohail and Roland, 1999). Because poultry cannot produce phytase, up to 75 percent of the P contained in feed grains is excreted in manure (NCSU, 1999).

One feeding strategy used by poultry operators to reduce P levels in manure is to add microbial phytase to the feed mix.[2] This enzyme is produced by a genetically modified fungus, *Aspergillus*

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[2] As noted in Chapter 4, some experts believe phytase should not be provided to poults because of the enzyme's adverse effect on bone development in turkeys, while other experts believe it will enhance growth.

niger. The final enzyme product is usually available in two forms, a powder or a liquid (Miller, 1998). The phytase enzyme reduces P excretion by releasing the phytate-P contained in the cell walls of feed grains. The released P can then be absorbed by the bird's intestine and used for its nutrient value. A secondary beneficial effect of using phytase is that manure P content is further reduced because less inorganic P needs to be added to poultry diets (Edens and Simons, 1998).

Application and Performance: Phytase can be used to feed all poultry. Phosphorus reductions of 30 to 50 percent have been achieved by adding phytase to the feed mix while simultaneously decreasing the amount of inorganic P normally added (NCSU, 1999).

Advantages and Limitations: Addition of phytase to feed significantly reduces P levels in poultry manure. The high cost of phytase application equipment has discouraged more widespread use.

Operational Factors: Because phytase is heat-sensitive, it must be added to broiler and turkey feeds after the pelleting process (NCSU, 1999). The phytase is added by spraying it on the feed. This can result in uneven distribution and variable doses. Studies have shown that phytase efficacy is related to calcium, protein, and vitamin B levels in a complex manner. Further, phytase efficacy can be degraded by excess moisture, which can be a problem if mash (wet) feed is used for broilers (Miller, 1998). The shelf life of phytase is usually not a problem, because feed is typically consumed within 2 weeks or less at most operations.

Demonstration Status: Phytase is in use at many poultry operations. Application equipment for adding phytase to large volumes of feed is undergoing field testing.

Practice: Genetically Modified Feed for Poultry

Description: Using genetically modified animal feed offers poultry operators another way to reduce P levels in bird manure. In 1992, a research scientist at the USDA Agricultural Research Service developed a nonlethal corn mutant that stored most of its seed P as P rather than as phytate. The total P content in the mutant corn was the same as that found in conventional corn, except that there was a 60 percent reduction in phytic acid. The P released by the reduction in phytic acid P becomes available to the consuming animal as inorganic P (Iragavarapu, 1999).

Application and Performance: Genetically modified feed can be used for all poultry types. The potential for reducing P levels is quite large. One variety of corn with a high available P content has 35 percent of the P bound in the phytate form compared with 75 percent for normal corn (NCSU, 1999). Recent tests of a new hybrid corn, developed by USDA and the University of Delaware, demonstrated a 41 percent decrease in P levels in manure. Soluble P levels in waste decreased by 82 percent, compared with the amount produced by poultry fed a standard commercial diet (UD, 1999).

Advantages and Limitations: New hybrid varieties of grain can increase poultry utilization of plant P. Adding phytase to the modified feed further reduces manure P levels and can eliminate the need for nutrient supplements. The increased cost of feed and phytase additives might limit their use.

Operational Factors: The use of genetically modified feed would not differ from the use of conventional feed, although the increase in available nutrients in the feed would diminish the need for supplements.

Demonstration Status: Since its discovery in 1992, the mutant corn has been made available to commercial companies for further research, development, and commercialization of hybrid grains. Some hybrid varieties are currently used; others are in the research or demonstration stage. As more of these products are developed and prices are lowered, the use of hybrid grains combined with enzyme additives will likely increase.

Practice: Other Feeding Strategies to Reduce Nutrient Excretion for Poultry

Poultry operators use additives other than phytase to reduce manure nutrient content. These additives include synthetic amino acids and protease, and they are designed to facilitate more efficient digestion of N compounds and allow the use of smaller proportions of nutrients in feed while not adversely affecting animal growth rates and health. Researchers have also demonstrated that feed enzymes other than phytase can boost poultry performance and reduce manure production (Wyatt, 1995). Enzymes currently added to barley and wheat-based poultry feed in Britain and Europe include xylanases and proteases. Currently, the use of additives such as synthetic amino acids and enzymes could significantly increase feed costs. These costs, however could be expected to decrease over time as the technology matures and is more widely used by animal feed operators.

8.1.1.3 Dairy Feeding Strategies

Feeding strategies to reduce nutrient losses from dairy operations, primarily N and P, are focused on improving the efficiency with which dairy cows use feed nutrients. A more efficient use of nutrients for milk production and growth means that a smaller portion of feed nutrients ends up in manure. Elimination of dietary excesses reduces the amount of nutrients in manure and is perhaps the easiest way to reduce on-farm nutrient surpluses (Van Horn et al., 1996). Reducing dietary P is the primary practice being used; however, a number of related management strategies also reduce nutrient levels in the manure by increasing the efficiency with which dairy cows use feed nutrients. These strategies include measuring the urea content of milk, optimizing feed crop selection, and exposing cows to light for a longer period of the day.

Practice: Reducing Dietary Phosphorus (P) for Dairy Cattle

Description: Reducing the level of P in the diets of dairy cows is the primary and most important feeding strategy for reducing excess nutrients given (1) P's central role as a limiting nutrient in many soils, (2) evidence indicating that dairy operators, as a whole, are oversupplying P in dairy diets, and (3) the N-P imbalance in cow manure, which favors reductions of P to produce a more balanced fertilizer. Reducing the amount of P in dairy diets has also been shown to reduce production costs and increase overall profitability.

The latest edition of the National Research Council's (NRC) nutrient requirements for dairy cows recommends dietary P levels of 0.36 to 0.40 percent of dry matter for high-producing dairy cows in lactation (NRC, 1989). Dietary P in excess of these requirements has been shown to have no beneficial effect on animal health or production. Most excess P passes through the cows' systems and is excreted as manure, which is later applied to land. Rations, however, typically average 0.50 percent P or more (Knowlton and Kohn, 1999). Supplemental feeding of dicalcium phosphate–often the second most expensive component in dairy cow diets–is the usual practice by which a dairy cow's rations achieve this level. A number of studies have addressed the adequacy of current dietary P recommendations. These studies include Steevens et al., 1971; Tamminga, 1992; McClure, 1994; and Chase, 1998.

Application and Performance: This practice should be applicable to all dairy operations. The amount of manure P resulting from a given level of dietary P is estimated using the following equation (Van Horn, 1991):

$$\text{Manure P} = 9.6 + 0.472*(\text{Intake P}) + 0.00126*(\text{Intake P})^2 - 0.323*\text{Milk}$$

Manure and intake P are measured in grams, and milk production is measured in kilograms. Based on this formulation, assuming that each lactating cow produces 65 pounds of milk a day, Table 8-1 quantifies reductions in manure P resulting from reduced P intake (Keplinger, 1998). Four scenarios are considered: a 0.53 percent P diet, which is considered the baseline, and three reduced P diet scenarios. Comparing the 0.40 percent scenario against the baseline, P intake during lactation is reduced by 25 percent, while manure P is reduced by 29 percent. During the entire lactation period, manure P is reduced by 14.63 pounds per cow from the baseline level of 50.45 pounds per cow. For the entire year (lactation and nonlactation periods), manure P per cow is reduced by 27 percent.

Table 8-1. Per Cow Reductions in Manure P Resulting from Reduced P Intake During Lactation

Percentage of P in Diet	Daily		Manure P (lb)		Reduction from Baseline (0.53%)		
	P Intake (lb)	Manure P (lb)	During Lactation	Entire Year	Amount (lb)	During Lactation	Entire Year
0.53	0.265	0.165	50.5	55.1	0.0	0	0
0.49	0.245	0.150	45.8	50.4	4.7	9	8
0.46	0.230	0.139	42.4	47.0	8.1	16	15
0.43	0.215	0.128	39.1	43.7	11.4	23	21
0.40	0.200	0.117	35.8	40.4	14.6	29	27

Advantages and Limitations: Supplemental feeding of dicalcium phosphate to dairy cows represents a substantial expense to dairy farmers–the second most expensive nutrient in a herd's mixed ration (Stokes, 1999). The economic advantages of reducing supplemental P, based on a study on the Bosque River watershed of Texas (Keplinger, 1998), suggest that a dairy operator who adopts a 0.40 percent P diet compared with the baseline 0.53 percent diet would save $20.81 per cow annually. A survey of scientific literature on the subject reveals no adverse impact on either milk production or breeding from reducing dietary P to NRC-recommended levels.

Another advantage to producers is the impact of reduced manure P on land application practices. Many states incorporate a P trigger in manure application requirements. For example, in Texas, state regulation requires waste application at a P rate (versus an N rate) when extractable P in the soil of an application field reaches 200 parts per million (ppm). Applying manure with a lower P concentration would slow and possibly eliminate the buildup of P in application fields, thereby delaying or eliminating the need to acquire or transform more land into waste application fields. When manure is applied at a P rate, greater quantities can be applied if it contains a lower P concentration. Thus, application fields would require less chemical N, because manure with lower P concentrations is a more balanced fertilizer. In addition, reduced land requirements for waste application fields would represent substantial savings to dairy producers in cases in which a P application rate is followed.

Operational Factors: It is possible that factors such as climate, temperature, and humidity, as well as operation-specific factors, influence the effectiveness of steps taken to reduce dietary P; however, there are no published studies that address this issue. Dairy cows, for instance, are more prone to disease in moist climates and suffer heat stress in hot climates. Average milk production per cow varies greatly across geographic regions of the United States–averaging 21,476 pounds in Washington state versus only 11,921 pounds in Louisiana (USDA, 1999). Because dairy cow productivity and health are influenced by climate, it is likely that climate may also influence the effectiveness of nutrient reducing feeding strategies, particularly those which depend on productivity gains. The magnitude and even the direction of the influence of factors such as temperature, humidity, and the like on nutrient-reducing feeding strategies, however, have not been established.

Demonstration Status: Dairy rations typically average 0.50 percent P or more (Knowlton and Kohn, 1999), much higher than the NRC recommendation of 0.40 percent. A survey of milk producers in north Texas by a milk producers' organization indicated dietary P averaged 0.53 percent. A 1997 survey of professional animal nutritionists in the mid-south region (Sansinena et al., 1999), indicates nutritionists' recommendations of dietary P averaged 0.52 percent, or 30 percent higher than the high end of NRC's current recommendation. Survey respondents cited several reasons for recommending final ration P in excess of NRC standards: "Almost half of the respondents (15 of 31) expressed a belief that lactating cows require more P than suggested by the NRC" (Sansinena et al., 1999). The next most prevalent reason given was that a safety margin was required. Justifications for the safety margin included a lack of confidence in published ingredient P values and concern for variable P bioavailability in feed ingredients. Professional opinion also suggests that dietary P in dairy cow diets averages around 0.52 percent throughout the nation, although this percentage may be declining. Because of the heightened awareness of both the environmental benefits and the cost savings attainable by reducing P in dairy cow diets, some operators have adopted the NRC recommendation. Recent articles in dairy trade magazines have recommended adoption of the NRC standard for both environmental and economic benefits.

Practice: Milk Urea N Testing for Dairy Cattle

Description: There have been significant developments recently in the use of milk urea N (MUN) as a method for testing and fine-tuning dairy cow diets for protein feeding. Measured MUN concentrations are used as a proxy for the nutritional well-being of the cow.

Research has shown that mean MUN concentration levels from a group of cows should fall into specific ranges. By comparing the results of MUN tests with these ranges, the tests can be used as a monitoring tool to evaluate a herd's protein nutritional status. For cows fed at optimal dry matter intake, expected mean values of MUN concentrations range from 10 to 14 milligrams per deciliter (mg/dL) (Ferguson, 1999; Jonker et al., 1998). Field studies of MUN levels of dairy herds in Pennsylvania (using a very large sample–312,005 samples) have reported average MUN concentrations of 14 mg/dL (Ferguson, 1999). Implicit in this level is that even allowing for the inherent large variability of MUN testing, the diets of some herds contain excess MUN levels that have no economic value; this also suggests that N in manure can be reduced by reducing excess N in dairy diets. The importance of reducing dietary protein levels is highlighted in a study (Van Horn, 1999) that estimates that for every 1 percent reduction in dietary protein, excretion of N may be reduced by 8 percent.

Application and Performance: This practice should be applicable to all dairy operations. The elimination of excess dietary protein with the use of the MUN test to evaluate protein levels in dairy cow feeds could reduce N levels in manure by 6 percent (Kohn, 1999). In addition, further methods to improve N utilization in dairy cows and raise the efficiency of feed delivery may be revealed by MUN testing.

Advantages and Limitations: Through MUN testing and the evaluation of other variables, farmers can identify which cows are eating too much protein, and fine-tune diets, thereby reducing N output in manure. Advantages of MUN testing are the possibilities of reducing ration costs by eliminating excess protein and improving the efficiency of feed delivery (Kohn, 1999). A disadvantage of animal group feeding strategies is that they become more difficult to set up and manage as group size decreases. The cost-effectiveness of custom feeding individual cows is as yet unproven.

Operational Factors: The large variability within and between herds and breeds of cows limits the usefulness of MUN testing, but it does not reduce the test's important role as a monitor of ration formulation.

Demonstration Status: This practice is primarily at the research stage and has not become widespread.

Practice: Diet Formulation Strategies for Dairy Cows

Description: Diet formulation strategies have received new examination. Alternative diet formulations to the NRC recommendations–notably the Cornell Net Carbohydrate and Protein model (CNCPS) (Sniffen et al., 1992)–that are more complicated than the NRC recommendations have been developed and they suggest feeding about 15 percent less protein to a herd at the same level of production for certain conditions (Kohn, 1996). Evaluations of the CNSPS model's performance have been mixed, and further research is needed. Thus, the CNCPS is not currently recommended for routine diet formulation.

Theoretically, protected amino acid supplements have the potential to be part of an important strategy in increasing the efficiency of protein use by dairy cows, thereby reducing N losses. If amino acid supplements can be made effectively for dairy cows (avoiding rumen-associated problems), they could replace large portions of a dairy cow's protein intake. In theory, protected amino acid supplements could significantly reduce N intake and hence N levels in manure. In practice, the benefits of using protected amino acid supplements may not be as dramatic because the need to balance diet formulations may create limitations.

Application and Performance: This practice should be applicable to all dairy operations. Some evaluation of the alternative diet formulation suggested by the CNCPS implies a significant increase in milk production (from 24,100 pounds/cow per year to more than 26,000 pounds/cow per year) and a large reduction in N excretion (of about one-third) (Fox et al., 1995). More recent evaluations using two different large data sets (Kalscheur et al., 1997; Kohn et al., 1998) present mixed results, with the CNCPS performing better in some aspects and the NRC recommendations in others. Thus, results of the CNCPS evaluation should be considered preliminary. In theory, the use of protected amino acid supplements has great potential to improve nutrient efficiency. A typical lactating cow is assumed to require 1.1 pounds per day of N intake; by successfully substituting protected methionine and lysine for feed protein, this N intake and resulting manure N could be dramatically reduced (Dinn et al., 1996), but this research is preliminary.

Advantages and Limitations: Alternative diet formulations could improve nutrient efficiency. Information on limitations is unknown at this time, and EPA is continuing research in this area.

Operational Factors: The cost of preparing and storing multiple feed stuffs limits the use of this practice to the number of diets that the operator feels justifies the additional expense. Additional research on this practice is needed.

Demonstration Status: This practice is primarily at the research stage and has not become widespread.

Practice: Animal Feed Grouping for Dairy Cows

Description: Grouping strategies offer another method of realizing gains in nutrient efficiency. When grouping does not occur and the whole herd receives the same diet, cows may receive suboptimal diets and nutrient export to manure may be greater. Using grouping strategies to their greatest effect to improve nutrient efficiency would entail individualized diets. Feeding strategies already reviewed, such as the MUN concentration test, can be used in conjunction with grouping strategies or individual diets.

Application and Performance: This practice should be applicable to all dairy operations. Grouping strategies have been shown to reduce nutrient intakes and manure nutrients. When all the lactating cows are fed together according to current recommendations, they consume 7 percent more N and P, and 10 percent more nutrients are excreted in manure, compared with the individualized feeding strategy. Half of the gains of individualized diets could be achieved with two groups (Dunlap et al., 1997).

Advantages and Limitations: This practice could improve nutrient efficiency. Information on limitations is unknown at this time, and EPA is continuing research in this area.

Operational Factors: As noted under diet formulation strategies, the cost of preparing and storing multiple feedstuffs limits the use of this practice to the number of diets that the operator feels justifies the additional expense. Additional management input is also required in separating the animals into groups.

Demonstration Status: Dairy operations currently employ a range of grouping strategies (from no grouping to individual diets) to improve the efficiency of feed nutrients.

Practice: Optimizing Crop Selection

Description: Optimizing crop selection is another potential strategy for reducing nutrient losses in combination with dairy diets to meet annualized herd feed requirements with minimal nutrient losses. In whole-farm simulation of various crop strategies (corn silage, alfalfa hay, and a 50:50 mixture) the 50:50 mixture was judged to have performed best (when evaluated by N losses per unit of N in milk or meat) (Kohn et al., 1998). Converting dairy operations from confined to pasture operations is also considered a strategy for reducing nutrient loss on a per cow or operation basis. Kohn’s model, however, found that a strategy of grazing versus confinement for lactating cows produced higher N loss per unit of milk produced because the decline in milk production was greater than the decline in manure nutrients (Kohn et al., 1998).

Application and Performance: This practice should be possible at operations that have sufficient land. In simulation of crop selection strategies involving whole-farm effects, mixed alfalfa hay and corn silage (50:50) was judged the best strategy for minimizing nutrient flows from the farm. N losses were minimized to 2.9 units for every unit of N in meat or milk, compared with a loss of

3.5 units in the corn-based strategy, a 21 percent reduction (Kohn, 1999). Phosphorus accumulations did not tend to vary among the different strategies.

Advantages and Limitations: Optimal crop selection based on whole-farm effects suggests that the strategy that was most nutrient efficient in terms of N loss per unit of N in meat and milk is also the strategy that gains the most productivity from N; this strategy might, therefore, be the most cost-effective (Kohn et al., 1998). A grazing (versus confinement) strategy may or may not be cost-effective depending on the structure of individual dairy operations.

Operational Factors: Unknown at this time.

Demonstration Status: This practice is primarily at the research stage and has not come into widespread use.

Practice: Increasing Productivity

Description: The literature suggests that there are several feeding strategies that focus on increasing productivity as a route to nutrient efficiency. While the focus is on increased milk production, an important associated benefit of these strategies is that they result in greater milk production per unit of nutrient excreted. One approach involves exposing dairy cows to light for longer daily periods of the day through the use of artificial lighting. A longer daily photoperiod (18 hours light/6 hours dark) increases milk yields relative to those of cows exposed to the natural photoperiod (Dahl et al., 1996).

Application and Performance: This practice should be applicable at all operations that confine their animals. The artificial lighting technology to extend the daily photoperiod of dairy cows to 18 hours a day has been shown to be effective in increasing the nutrient efficiency of the farm. For an increase in milk production of 8 percent the herd's feed nutrients would be required to increase by only 4.1 percent, and N and P excretions would rise by only 2.8 percent when compared versus a typical herd without artificial lighting (Dahl et al., 1996, 1998).

Advantages and Limitations: The artificial lighting technology is expected to be cost-effective. It is estimated that the initial investment in lighting can be recouped within 6 months. One observed advantage of milking three times a day rather than twice a day is that it reduces stress on the herd (Erdman and Varner, 1995). Because of the increased labor involved, the economic advantage of milking three times a day is variable and dependent on the individual farm (Culotta and Schmidt, 1988).

Operational Factors: To use this practice many dairy operations would need to install and operate additional lights.

Demonstration Status: This practice is primarily at the research stage and has not come into widespread use.

8.1.2 Reduced Water Use and Water Content of Waste

This section presents practices that reduce the water content in the waste stream. The production of a drier waste can be accomplished by three methods: (1) handling the waste in a dry form, (2) reducing the use of water at the AFO, or (3) separating the solid fraction of the waste from the liquid fraction. Most poultry operations currently handle their waste in a dry form, and this section does not apply to them.

Practice: Dry Scrape Systems and the Retrofit of Wet Flush Systems

Description: Scraper systems are a means of mechanically removing manure, and they can be used to push manure through collection gutters and alleys similar to those used in flush systems. For best results, scrapers should have a minimum depth of 4 inches in open gutters and 12 to 24 inches in underslat gutters (MWPS, 1993).

Retrofitting a wet flush system with a dry scrape system involves reconstructing the existing manure handling equipment within a livestock housing structure. A scraper blade replaces flowing water as the mechanism for removing manure from the floor of the structure.

In flush systems, large volumes of water flow down a sloped surface, scour manure from the concrete, and carry it to a manure storage facility. There are three basic types of flush systems: underslat gutters, narrow-open gutters, and wide-open gutters or alleys. Underslat gutters are used primarily in beef confinement buildings and swine facilities in which animals are housed on slats to prevent disease transmission as a result of animals coming into contact with feces. Narrow-open gutters are typically less than 4 feet wide and are used predominately in hog finishing buildings. Wide-open gutters or alleys are most often seen in dairy freestall barns, holding pens, and milking parlors. The water used in a flush system can be either fresh or recycled from a lagoon or holding basin (Fulhage et al., 1993; MWPS, 1993).

Application and Performance: Removing manure with a scraper is appropriate for semisolid and slurry manure, as well as drier solid manure. The flush system is an appropriate means of removal for both semisolid and slurry manure. Retrofitting a flush system to a scraper system appears to be most feasible in underslat gutters and wide alleys. A major concern to be addressed is the discharge area of the scraper. Existing collection gutters, pumps, and pipes used in a flush system will likely be inadequate for handling the undiluted manure product.

Replacing a flush system with a dry scrape system dramatically reduces the amount of water used in manure handling and also reduces the tonnage of manure by decreasing dilution with water. There are several options for storing manure from a scrape system, including prefabricated or formed storage tanks, from which contaminants are less likely to seep.

Retrofitting a flush system with a scrape system will not treat or reduce pathogens, nutrients, metals, solids, growth hormones, or antibiotics. The concentrations of these components will actually increase with the decrease in water dilution.

Advantages and Limitations: In a building with a scrape system, the manure removed from the livestock housing area is in slurry or semisolid form (depending on species) and no water need be added. Compared with a wet flush system, the resulting manure product has a greater nutrient density and increased potential for further treatment and transportation to an area where the manure product is needed as a fertilizer. A large lagoon is usually necessary for storing and treating flush waste and water; handling manure in a drier form, on the other hand, significantly decreases the volume and tonnage of the final organic product. Although this is an important advantage when it is necessary to transport manure to areas where there is an increase in available land base, it can be a disadvantage in that an irrigation system would not be able to transport the thicker slurry that results from the use of a scrape system.

The greater volume of contaminated water and waste created in a flush system generally dictates that storage in a large lagoon is required. There are more options for storing manure removed with a scrape system. These storage alternatives may be more suited to practices that reduce odors (e.g., storage tank covers), more appropriate for areas with karst terrain or high water tables, and more aesthetically desirable.

The drawbacks of using a scrape system rather than a flush system include an increased labor requirement because more mechanical components need maintenance, a higher capital outlay for installation, an increased requirement for ventilation, and less cleanliness. Using a flush system to remove manure results in a cleaner and drier surface with less residual manure and less in-house odor, thus creating a better environment for livestock. Furthermore, alleys can be flushed without restricting animal access. As mentioned above, the discharge area of the scraper is a concern. Existing pumps and pipes may be unable to handle the undiluted manure. Moreover, a completely new manure storage structure might be needed (Vanderholm and Melvin, 1990).

Operational Factors: Both the scrape and flush systems have disadvantages when used in open barns during winter months, but a scrape system is more likely to function properly at lower temperatures.

If alleys are straight with continuous curbs, alley scrapers can usually be installed, but alley lengths of up to 400 feet in dairy freestall barns may make installation of scraping systems impractical. Scrapers work best when they can be installed in pairs of alleys so the chain or cable can serve each and form a loop. It might be necessary to cut a grove into the concrete alley for the chain or cable to travel in. The decision of whether to cut a channel or let the chain rest on the pavement is best left to the manufacturer. It should be noted that maintenance requirements associated with the chain and cable will likely be high because of corrosion caused by continuous contact with manure. Hydraulic scrape units that operate on a bar and ratcheting blade are also available (Graves, 2000).

Demonstration Status: The use of scrape systems and the practice of retrofitting a flush system are not common in the livestock industry. Inquiries regarding the use of this practice have been made to manure management specialists, agricultural engineers, and manufacturers of scraper systems. Very few professionals indicated that they had any experience in the area or were aware of the practice being used. Those professionals willing to comment on the implications of retrofitting seemed to believe that it would be most feasible and advantageous on dairies (Graves, 2000; Jones, 2000; Lorimor, 2000; Shih, 2000).

Practice: Gravity Separation of Solids

Description: Gravity settling, separation, or sedimentation is a simple means of removing solids from liquid or slurry manure by taking advantage of gravitational forces. The engineering definition of a settling or sedimentation tank is any structure that is designed to retain process wastewater at a horizontal flow rate less than the vertical velocity (settling rate) of the target particles.

In agricultural applications, gravity settling is a primary clarification step to recover solids at a desired location where they can be managed easily, thereby preventing those solids from accumulating in a downstream structure where they would be difficult to manage. A wide range of gravity separation practices are used in agriculture, including sand and rock traps, picket dams, and gravity settling basins designed to retain 1 to 12 months' accumulation of solids.

Settling tanks can be cylindrical, rectangular, or square. Agricultural settling tanks have been made with wood, metal, concrete, and combinations of materials. Some are earthen structures. In agriculture, gravity separation is sometimes accomplished without a recognizable structure, including techniques such as a change in slope that allows particles to settle when the liquid velocity drops.

The critical design factor in sedimentation tanks is surface overflow rate, which is directly related to the settling velocity of particles in the wastewater (Loehr, 1977). Faster settling velocities allow for increased surface overflow rates, while slower settling velocities require decreased overflow rates to remove settleable particles. In "ideal" settling, the settling velocity (Vs) of a particle is equal to that particle's horizontal velocity (VH), where

$$VH = Q/DW$$

Q is the flow through the tank
D is the tank depth
W is the tank width

The American Society of Agricultural Engineers (ASAE, 1998) has defined several types of gravity separation techniques:

- Settling Channels: A continuous separation structure in which settling occurs over a defined distance in a relatively slow-moving manure flow. Baffles and porous dams may be used to aid separation by further slowing manure flow rates. Solids are removed mechanically once liquids are fully drained away.

- Settling Tank: A relatively short-term separation structure, smaller in size than a settling basin. The liquid is allowed to fully drain away for solids removal by mechanical means.
- Settling Basin: A relatively long-term separation structure, larger in size than a settling tank. Solids are collected by mechanical means once the liquids evaporate or have been drained away.

Application and Performance: Gravity separation is relatively common in the United States. Separation is used to reduce clogging of downstream treatment or handling facilities. Reduced clogging means improved lagoon function and better wastewater treatment. Most beef feedlots in the Midwest and Great Plains use gravity separation ponds to collect solids from rainfall runoff, thus improving the function of runoff collection ponds. Gravity separation basins are used across the country on hog farms to reduce solids accumulation in tanks or lagoons they discharge to. It is likely that more dairies with flush systems use gravity settling for solids recovery rather than mechanical separators to preserve lagoon capacity.

Table 8-2 shows the substantial range of treatment efficiencies for gravity settling of manure. The performance of a gravity separation basin depends on the design goal and ability of the operator to maintain the system in design condition. Performance will vary with animal type, animal feed, dilution water, flow rate, percent of capacity already filled with solids, temperature, and biological activity. The data ranges in Table 8-2 may be explained in part by the time span separating the studies. More recent studies show reduced solids recovery from swine manure. This may be partly due to the fact that animal diets have changed over the years, with feed more digestible and more finely ground these days. Further, feed is ground to different particle sizes that have different settling characteristics, thus potentially affecting separation basin performance. In addition, ruminants are fed materials that have different settling characteristics than those fed to nonruminants. Process variables such as overflow velocities are seldom reported in the literature, but they are important determinants of separation basin performance. Extra water from processing or precipitation and already settled material will increase the flow rate across a settling basin, reducing settling time and solids capture. In many agricultural settling basins, biological activity resuspends some settled materials which then pass through the separator. At best, one can conclude from these data that gravity settling can recover in swine wastes a larger percentage of total solids (TS), volatile solids (VS), and total nitrogen (TN) than another separation technique reviewed for the practice, mechanical solid-liquid separation, that follows in this chapter.

Table 8-2. Performance of Gravity Separation Techniques

Recovered in Separated Solids, Percent						
	TS	**VS**	**TN**	**P_2O_5**	**K**	**COD**
Swine (Moser et al., 1999)	39-65	45-65	23-50	17-50	16-28	25-55
Beef (Edwards et al.,1985; Lorimore et al., 1995) and Dairy (Barker and Young, 1985)	50-64	NA	32-84	20-80	18-34	NA

TS=Total solids; VS=volatile solids; TN=total nitrogen; P_2O_5=pyrophosphate; K=potassium, COD=chemical oxygen demand.

Because of short return times, pathogen reduction through settling is minimal; however, settling might reduce worm egg counts. No information is available on growth hormones in manure or on how settling might affect growth hormones that may be found in manure. Degradation of antibiotics usually hinders their detection in manure, and no information is available on the effect of settling on antibiotics in manure.

Taiganides (1972) measured 80 to 90 percent recovery of copper, iron, zinc, and phosphorus with settled swine solids. The study also reported that 60 to 75 percent of the sodium, potassium, and magnesium settled and was recovered.

Advantages and Limitations: The main advantage of gravity settling is the relatively low cost to remove solids from the waste stream. Recovering solids prevents the buildup of those solids in ditches, pipelines, tanks, ponds, and lagoons. Dairy solids consist mostly of fiber and can be composted and recycled as cow bedding material, or they can be composted and sold as a soil amendment. Swine solids are finely textured, hard to compost aerobically, and rapidly degraded to odoriferous material if handled improperly. Beef solids collected from lot runoff can become odoriferous if left in a separation basin, but they can be composted for sale to crop farms, nurseries, or soil products companies.

Collected solids are a more concentrated source of nutrients than the separated liquid, resulting in decreased hauling costs per ton of nutrient. The separated liquid has a reduced nutrient content and can be applied to a smaller acreage than the original material.

Disadvantages of solids separation include the need to clean out the separator, the potential odor emitted from the basin, the odor produced by solids removed from the basin, and attraction of insects and rodents to the separated solids. Additional costs are incurred when the solids and liquids from pig manure are managed separately.

Operational Factors: Solids separators do not function if they are frozen or experience horizontal flow rates higher than the solids settling rate. Solids tend to separate better at warmer temperatures.

Demonstration Status: Gravity separation is the most common solids separation technique in use in the United States.

Practice: Mechanical Solid-Liquid Separation

Description: Solids-liquid separation is used to recover solids prior to their entry into downstream liquid manure facilities. Solids recovery reduces organic loading and potential accumulation of solids and improves the pumping characteristics of animal manure. Mechanical separation equipment is used to reduce the space required for separation, to produce a consistent separated solid product amenable to daily handling, to produce a liquid product that is easily pumped for spreading, or to recover specific particle sizes for other uses such as bedding.

Mechanical separation equipment is readily available for animal wastes. Mechanical separators include static and vibrating screens, screw press separators, rotary strainers, vacuum filters, centrifugal separators, belt filter presses, and brushed screen/roller presses. Static screens are the most popular mechanical separators because they are inexpensive to buy, install, and operate. All other mechanical separation techniques are less common.

Static screens are usually mounted above grade on a stand to allow solids accumulation beneath. Barn effluent is typically pumped up to the screen, where the liquids pass through while the solids collect on the screen surface. Screens are typically inclined, causing accumulating solids to slide down from the screen toward collection. There are multiple configurations with different screen designs, screen materials, screen opening spacing, influent distribution, post-use washdown, and additional pressing of separated solids.

Vibrating screens are flat or funnel-shaped screens supported on springs and oscillated by an eccentric drive. The vibrations cause the solids to move from the screen for collection.

With screw presses, manure is pumped to the base of a turning open-flight auger that goes through a screen tube made of welded wire, wedge wire, perforated metal, or woven screen material. Solids collect on the screen, forming a matrix as the auger advances them. A tensioned opening restricts the flow of materials up the auger and out from the tube. The retained material is squeezed by the auger against the screen tube and tensioned opening until it overcomes the tension and exits. The matrix acts as a filter allowing the collection of finer particles than are collected by other types of screens. The auger wrings liquid from the separated solids by forcing material against the plug of material held by the tensioned opening and screen tube.

A rotary strainer is a slowly rotating, perforated cylinder mounted horizontally. Waste flows by gravity onto the cylinder at one end, where solids are scraped from the cylinder surface and moved to the exit end. Liquids pass through the screen for collection and removal (ASAE, 1998). Vacuum filters are horizontally mounted, rotating perforated cylinders with a cloth fiber cover. A vacuum is used to draw liquids from the wastewater. Wastewater flows onto the cylinder surface, liquids pass through the screen, and solids are scraped from the cloth at a separation point (ASAE, 1998).

A centrifugal separator, or centrifuge, is a rapidly rotating device that uses centrifugal force to separate manure liquids from solids. One type, a relatively low-speed design, uses a cylindrical or conical screen that can be installed vertically or horizontally. Manure is fed into one end, and solids are then contained by the screen, scraped from it, and then discharged from the opposite end. The liquid passes through the screen. A second type, a higher-speed decanter, uses a conical bowl in which centrifugal force causes the denser solids to migrate to the bowl exterior where they are collected. Less dense liquids are forced to the center for collection ASAE, 1998).

A belt press is a roller and belt device in which two concentrically running belts are used to squeeze the manure as it is deposited between the belts. The belts pass over a series of spring-loaded rollers where liquids are squeezed out or through the belt, and remaining solids are scraped off at a belt separation point (ASAE, 1998).

Brush screen presses are rectangular containers with four vertical sides and a bottom consisting of two half-cylindrical screens lying side by side to provide two stages of separation. Within each screen rotates a multiple-brush and roller assembly that sweeps the manure across the screen. Manure is pumped into one side of the separator. The liquids are forced through the screen by the brush/roller while the solids are retained by the screen and pushed from the separator on the opposite side (ASAE, 1998).

Application and Performance: Mechanical separation is used to reduce clogging of downstream treatment or handling facilities. The use of this practice to preserve lagoon capacity by separating solids is relatively common among dairies using flush manure collection. Reduced clogging means improved lagoon function and better wastewater treatment. Mechanical separation of solids from manure, however, is relatively rare because of the added costs.

Table 8-3 shows the range of treatment efficiencies for the mechanical separation of manure. These systems do not perform as well as gravity separation, but they produce a more consistent product delivered as a solid for easy collection. Most manufacturers and owners are less concerned about the percentage of recovery or the properties of the recovered material than they are about the total solids concentration of the separated solids. Performance will vary with animal type, animal feed, dilution water, flow rate, percent of capacity already full of solids, temperature, and biological activity. In general, pig manure has finer solids than cow manure, and recovery of pig manure constituents is in the low end of the ranges in Table 8-3, whereas cow manure constituent recovery is in the upper portion of the range.

Table 8-3. Summary of Expected Performance of Mechanical Separation Equipment

Separation Technique	Recovered in Separated Solids, Percent				
	TS	**VS**	**TN**	**P_2O_5**	**COD**
Stationary screen	10-25	10-25	5-15	10-20	5-20
Vibrating screen	10-20	10-20	10-20	8-15	10-20
Screw press	20-30	20-30	10-20	20-30	20-40
Centrifuge	40-60	40-60	20-30	25-70	30-70
Roller drum	20-30	20-30	10-20	10-15	10-25
Belt press/screen	40-60	40-60	30-35	15-20	30-40

Source: Moser et al., 1999.

Pathogen reduction through mechanical separation is negligible. No information is available on growth hormones in manure or on the effect of mechanical separation on growth hormones that may be found in manure. Degradation of antibiotics usually hinders their detection in manure, and no information is available on the effect of mechanical separation on antibiotics in manure.

No significant information was found on the effect of mechanical separation on heavy metal content of either the solids or the liquids. Work in gravity separation suggests that metals are associated with fine particle sizes that would pass with the liquids through mechanical separation.

Static (stationary) screens are most commonly used for separating solids from dilute solutions with solids concentrations of 5 percent or less. The more dilute the solution, the more likely that discrete particles will be collected on the screen because there is less particle-versus-particle interference. The dilute solution also washes finer particles from larger, retained particles and through the screen.

Vibrating screens are used for separating solids from dilute solutions with solids concentrations of 3 percent or less. Vibrating screens will generally process more flow per unit of surface area than static screens because the vibrating motion moves the solids from the screen. Vibrating screens are more sensitive than static screens to variations in solids content and wastewater flow (Loehr, 1977).

Static screens and vibrating screens usually collect 10 to 15 percent of the total solids from manure. An owner generally selects a screen that will not easily clog, or blind (i.e. one with larger screen spacing), instead of choosing an optimized screen and feed pump to avoid both screen blinding, when the slurry thickness changes, and the creation of a soggy solids pile.

Screw presses can handle thicker materials than most separators, and are used to separate manures that have between 0.5 and 12 percent total solids. Chastain et al. (1998) noted, however, that a screw press did not separate well unless the total solids content of the waste was above 5 percent. Because screw presses first allow the solids to form a matrix and catch fine solids, the percent solids recovery is generally greater than for other solids separators. The screw press is designed to produce drier solids (up to 35 percent). Solids recovery is dependent on the screen tube openings and the setting of the retaining tension. The higher the tension is set, the harder the screw squeezes the separated material, and the more solids are forced out through the screen. Tighter settings for drier solids may significantly affect the useful life of both auger and screen.

Belt presses are expensive, require a trained operator, operate best with chemical addition, and cannot process rocks and barn parts found in manure. With or without chemical addition, however, they can do a good job of separating 40 percent or more of the total solids. Nevertheless, the cost of belt presses, plus the extremely high cost of maintenance and the need for continuous operator presence, makes their use problematic.

The primary advantage of centrifugation over other separators appears to be in the reduction of total P, but centrifugation is also clearly more efficient than screening for removal of all constituents. Managed by trained operators, centrifuges will recover over 60 percent of the total solids. Nevertheless, the large capital cost, the need for trained operators, and the high maintenance costs have made this equipment impractical for farm use.

Advantages and Limitations: The main advantages of mechanical separation are the consistent level of solids removal from the waste stream and the delivery of separated solids at a recovery location. Recovering solids prevents the buildup of those solids in ditches, pipelines, tanks, ponds, and lagoons. Dairy solids, which consist mostly of fiber, can be composted and recycled as cow bedding material. Dairy solids have also been composted and sold as a soil amendment. Swine solids are finely textured, hard to compost aerobically, and rapidly degraded to odoriferous material if handled improperly.

Collected solids are a more concentrated source of nutrients than the separated liquid, resulting in decreased hauling costs per ton of nutrient. The separated liquid has a reduced nutrient content and can be applied to a smaller acreage than the original material.

Disadvantages of solids separation include operation and maintenance requirements, potential odor production from collection basins and separated solids, and attraction of insects and rodents to the separated solids. Additional costs are incurred when the solids and liquids in swine manure are managed separately.

Operational Factors: Mechanical solids separators do not function if the manure or the face of the machine is frozen, but they can operate under a wide variety of other conditions.

Demonstration Status: Mechanical solids separation is being used at thousands of dairies and perhaps several hundred hog farms. Regarding specific technologies, static screens are most commonly used, whereas vibrating screens and rotary strainers are seldom used on farms today. Vacuum filters are infrequently used on farms because inorganic materials such as rocks and metal bits tend to rip the filter fabric. High capital and operating costs have limited farm use of centrifugal separators. Brush screen presses may occasionally be found on farms, but the low throughput rate has limited its use. Screw presses are in use at a few hundred dairy farms, but at a very limited number of swine farms in the United States.

Practice: Two-Story Hog Buildings

Description: The two-story, High-Rise™ hog building design (Menke et al., 1996) integrates manure collection, storage, and treatment in a single, enclosed facility. The building is designed to pen approximately 1,000 head of hogs on the second floor of a two-story building, with a dry manure collection and storage system on the first (ground) level. The second floor features solid side walls and totally slatted floors. The manure falls through the slats to the first floor area, which is covered with 12 to 18 inches of a dry bulking agent such as sawdust, oat or wheat straw, corn fodder, or shredded newspaper. The design includes sliding doors on the ground level to allow for tractor and loader access.

The building's unique, two-fold ventilation system maintains superior air quality in the swine holding area and dries the manure in the storage area (Figure 8-1). Clean air is pulled from the ceiling through continuous baffle inlets and is directed down over the swine vertically (with no horizontal, pig-to-pig air movement). Air exits the swine holding area through the floor slats and is pulled horizontally to the outside of the first-floor pit area by 14 computer-controlled

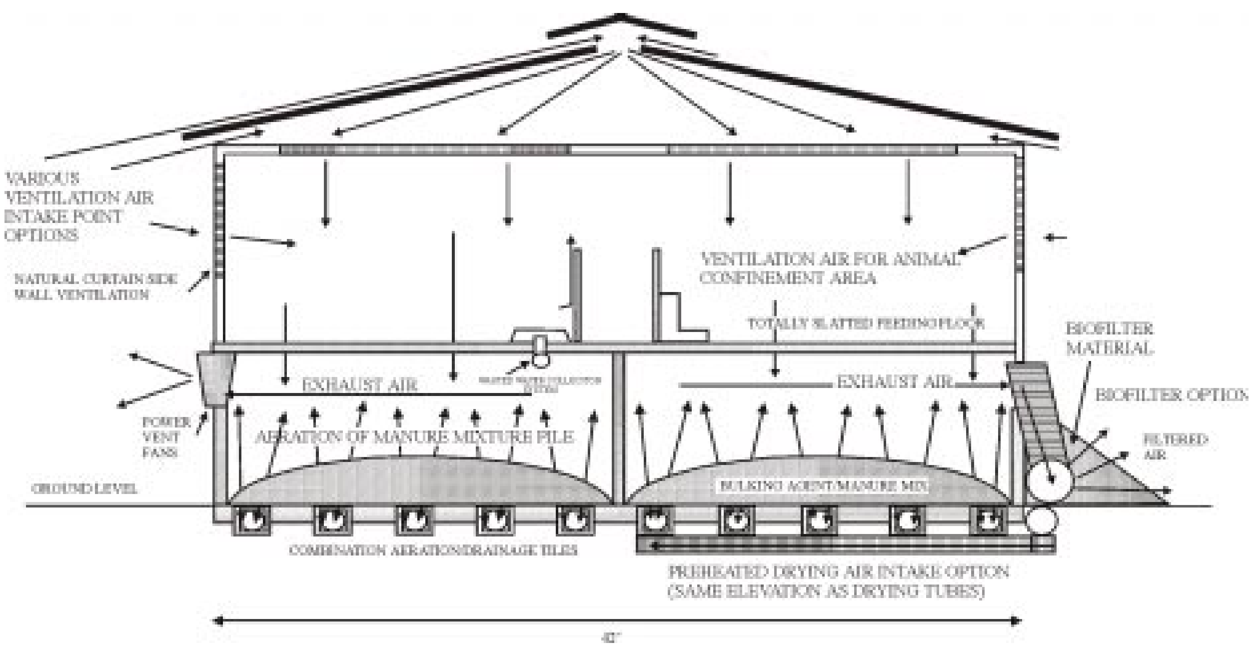

Figure 8-1. High-Rise Hog Building

ventilation fans mounted on the pit walls. This system prevents air from the manure pit from rising to the animal area. The second part of the ventilation system involves pumping air through the manure by floor aeration. PVC pipes with approximately 3,200 3/8-inch holes are installed before the concrete floor is poured. Two large fans on either end of the building force air through perforations in the concrete and into the composting mixture on the ground floor.

Application and Performance: Management practices, swine care, and feeding are much the same as with conventional confinement. The High Rise facility is distinctive because it incorporates dry manure handling and storage into a traditional confinement production scenario. The system dries the manure mixture and maintains an aerobic environment to facilitate the composting process. Drying and homogeneity of the mixture are also facilitated by mixing with a tractor and loader or skid-steer loader. Frequency of mixing varies from once per production cycle to biweekly, depending on the saturation of bedding. The semicomposted bedding mixture is removed once per year and can be further composted, land applied, or sold. A typical 1,000-head unit produces 500 tons of semicomposted product per year.

The High Rise facility is best suited for areas where there is limited local land base for manure application; sandy, porous soils; limited water supply; or an existing market for compost or partially composted material.

The aerobic decomposition that occurs within the pit results in a significant volume reduction in the manure. In fact, initial trials have shown that loading the pit with 12 to 18 inches (approximately 11 tons) of bedding results in only 2.5 to 3 feet of manure to be removed at the end of 1 year. This is estimated as a 22 percent reduction in manure volume and a 66 percent reduction in manure tonnage (Envirologic, 1999; Mescher, 1999). These figures are based on a final product with 63 percent moisture. When compared with liquid/slurry hog manure that is approximately 90 percent moisture, this presents a great advantage in areas where there is a lack of local land base and manure must be transported more than 3 to 4 miles to alternative areas for application. Manure with 63 percent moisture is considered to be in dry form and can be hauled in a semi truck with an open trailer rather than in a liquid tanker pulled by a tractor.

The aerobic decomposition and drying that reduce the volume and tonnage of the final organic product do not result in a reduction of the overall nutrient content. In fact, with the exception of N and sulfur (some of which volatilizes) nutrients will be more concentrated in the resulting semicomposted product. The semicomposted manure is four times more concentrated than liquid manure from treatment lagoons.

The High-Rise facility incorporates both manure treatment and storage in a completely aboveground handling system. In addition, the ground-level manure storage area is enclosed in poured concrete. This is especially advantageous in sites with porous soils or fragmented bedrock. Such locations are unfit or, at the least, potentially dangerous areas for earthen basin and lagoon construction due to concerns regarding ground water contamination. Furthermore, belowground concrete pits have an increased potential for ground water pollution if leaking occurs in a region with porous soils or fragmented bedrock. The aboveground concrete manure storage of the High-Rise building allows visual monitoring for leakage.

Information is not currently available on the reduction of pathogens, heavy metals, growth hormones, or antibiotics in the manure product as it is removed from the High-Rise facility. However, research on some of these topics is currently underway. Based on the composition of the product, temperature readings within the manure pack, and knowledge of the composting process, several speculations can be made. Destruction of pathogens in the composting process is a result of time and temperature. The higher the temperature within the manure pack, the less time it takes to eliminate pathogens. In general, the temperature within the manure pack needs to exceed the body temperature of the animal and pathogen destruction is most effective at 120 °F or higher. Temperature readings taken in the manure pack in the High-Rise facility ranged from only 45 to 78 °F (Keener, 1999). The predominant reason for the manure packs not reaching a high enough temperature is the continuous aeration provided. It is unlikely that there is a significant reduction of pathogens at this temperature. There may be some decrease in pathogen numbers due to the length of time (up to one year) the manure pack remains in the building. Further composting of the manure pack once it is removed from the High-Rise structure would allow the product to reach temperatures high enough for complete pathogen destruction.

The composting process has no effect on the quantity of heavy metals in the manure. Further, because of the decrease in volume and tonnage of the manure, heavy metals will be more concentrated. Composting does, however, influence the bioavailability of the metals, causing them to be less mobile. The extent to which the mobility of heavy metals is decreased in the semicomposted product removed from the High-Rise facility is unknown.

The degree to which growth hormones and antibiotics degrade during the composting process is unknown and is not widely studied.

Designers of the High-Rise facility claim a savings of 1.8 million gallons of water per 1,000 head of hogs annually when compared with a conventional pull-plug flush unit. This conservation results from using wet-dry feeders and eliminating the addition of water for manure removal and handling. A reduction in the amount of water used in the system results in less waste product to be handled.

Advantages and Limitations: As explained above, the dry manure handling system used in the High-Rise facility significantly decreases the volume and tonnage of the final organic product. This is an important advantage when transportation to areas where there is an increased land base for manure application is necessary. However, because the semicomposted product has greater concentrations of macronutrients, with the possible exception of N (which might volatilize), the number of acres needed to correctly apply the manure does not decrease. Nitrogen volatilization during the composting process creates the possibility of upsetting the nutrient balance in manure. For example, if manure was applied to land with the application rate based on the amount of N in the manure, P and potassium could be applied at rates 10 times the recommended rate. This problem is eliminated if application rates are based on the P content of manure. Additional commercial N application might be necessary depending on the crop being produced.

Data from an initial trial show that the manure product removed from the High-Rise facility has a fertilizer value of about $19 per ton at 60.7 percent moisture, with an organic matter content of 29.8 percent. Secondary studies show that the manure mixture is of adequate content for further composting, which is necessary to sell manure commercially. These factors create an increased opportunity to broker manure and possibly provide supplemental income to the swine production enterprise (Envirologic, 2000).

Observations and data resulting from the first year of study in the High-Rise structure indicate that there is a significant decrease in odor using the dry manure handling system. Ammonia measurements on the swine housing level averaged from 0 to 8 parts per million (ppm), with an overall mean of 4.3 ppm and spikes of up to 12 ppm in times of decreased ventilation (winter months). In a conventional confinement building with a deep, liquid pit, ammonia levels of 20 to 30 ppm are commonplace. Ammonia levels on the ground level of the High-Rise building vary inversely with building ventilation and have exceeded a short-term exposure rate of 50 ppm in the winter. It must be realized, however, that the basement level is not occupied during normal conditions. Large sliding doors are opened when the facility is cleaned to let in fresh air and facilitate the entry of a tractor/loader. Ammonia levels external to the outside exhaust fans averaged 23.3 ppm, but quickly dissipated (Keener et al., 1999).

No hydrogen sulfide gas was detected in the swine holding area. Levels on the first floor were minimal (National Hog Farmer, 2000). Decreased levels of these potentially toxic gases improve air quality and prevent excessive corrosion in the building.

Producers who plan to build a High-Rise facility can expect a 15 percent increase in capital outlay compared to a 1,000-head, tunnel ventilation finisher with an 8-foot-deep pit. Cost projections prepared for the company that manufactures the High-Rise building indicate that reduced cost for manure handling and transportation offsets the additional building cost (Envirologic, 2000). Solid manure handling is less automated than many liquid manure handling systems. Although solid systems have lower capital costs, labor costs are higher than those associated with liquid systems. Labor costs are expected to be less than traditional scrape and haul systems because the slatted floors eliminate the need to scrape animal areas frequently.

In addition to the increased capital requirement, the cost of utilities is also elevated. Additional energy is needed to power the many ventilation fans. Electricity usage averages roughly twice that of a naturally ventilated confinement barn. Accounting for all of these factors, the cost of production in a High-Rise facility is approximately $180 per pig. This is 28 to 30 percent greater than the cost of production in a confinement structure with a shallow pit, and 15 to 18 percent greater than in a more conventional deep pit (Mescher et al., 1999).

The ventilation system that pumps air over the swine holding area keeps the swine and slats dry, resulting in cleaner swine and fewer injuries. Also, there is no flow of air from pig to pig, which helps prevent airborne transmission of disease. The combination of decreased moisture and exceptional air quality leads to improved animal health and decreased medication costs.

Data from a single High-Rise facility show that animal performance was the same or better than that of conventional facilities with respect to average daily gain, days to market, feed conversion, mortality, and the number of culls. In fact, the decreased number of days to market translates into 0.2 to 0.3 more production cycles per year, creating potential to increase profits significantly. It is speculated that improvement in performance measures is due to better air quality (Envirologic, 2000).

Leachate from the manure mixture appears to be minimal if mixing is done on a regular basis. Rodents in the basement pit might become a problem if control measures are not taken.

Operational Factors: Artificial climate control and ventilation in the building make the High-Rise building appropriate in most climates . It is estimated that air in the building is exchanged every 10 to 15 seconds, providing an environment of uniform temperature and humidity throughout the building year-round. Over a 1-year span, the mean air temperature taken from several test areas within the building varied only ± 2 °F from the desired temperature. There were, however, differences of up to 10 °F between testing areas on the swine floor (Stowell et al., 1999). The building is equipped with a standard sprinkling system for use in hot summer months.

Demonstration Status: The High-Rise facility technology has been tested with finisher pigs since 1998 at a single research facility in Darke County, Ohio. The vendor has built four commercial grow-finish buildings since that time and they are currently in production in west central Ohio. The vendor is also developing prototypes for other phases of swine production using the same manure handling system.

Practice: Hoop Structures

Description: Hoop structures are low-cost, Quonset-shaped swine shelters with no form of artificial climate control. Wooden or concrete sidewalls 4 to 6 feet tall are covered with an ultraviolet and moisture-resistant, polyethylene fabric tarp supported by 12- to 16-gauge tubular steel hoops or steel truss arches placed 4 to 6 feet apart. Hoop structures with a diameter greater than 35 feet generally have trusses rather than the tubing used on narrower hoops. Some companies market hoops as wide as 75 feet. Tarps are affixed to the hoops using ropes or winches and nylon straps.

Generally, the majority of the floor area is earthen, with approximately one-third of the south end of the building concreted and used as a feeding area. The feeding area is designed with a slight slope (1 to 2 percent) to the outside of the building in case of a waterline break and is raised 12 to 19 inches above the earthen floor to keep the feeding area clear of bedding material. Approximately 150 to 200 finisher hogs or up to 60 head of sows are grouped together in one large, deep-bedded pen. The building should be designed so that the group housing area provides approximately 12 square feet of space per finisher pig, or 27 square feet per sow.

Hoop structures are considered a new and viable alternative for housing gestational sows and grow-finish pigs. Gestational housing systems being used in the United States are modeled after conventional Swedish style, deep-bedded gestation and breeding housing. In Sweden today, deep-bedded housing systems with individual feeding stalls are the conventional method of dry sow housing. There are feeding stalls for each sow, with connecting rear gates and individually opening front gates, a deep-bedded area for the group-housed sows, and bedded boar pens. The stalls are raised approximately 16 inches above the ground to accommodate the deep-bedding pack in the center.

In each production scenario, plentiful amounts of high quality bedding are applied to the earthen portion of the structure, creating a bed approximately 12 to 18 inches deep. The heavy bedding absorbs animal manure to produce a solid waste product. Additional bedding is added continuously throughout the production cycle. Fresh bedding keeps the bed surface clean and free of pathogens and sustains aerobic decomposition. Aerobic decomposition within the bedding pack generates heat and elevates the effective temperature in the unheated hoop structure, improving animal comfort in winter conditions.

Application and Performance: The hoop structure originated in the prairie provinces of Canada. Recently, interest in this type of structure has increased in Iowa and other states in the Midwest. Swine production in this type of facility is most prevalent for finishing operations, but is also used to house dry gestational sows. Other possible uses in swine production include gilt development, isolation facilities, housing for light pigs, breeding barns, farrowing, and segregated, early weaning swine development. A hoop structure is an appropriate alternative for moderately sized operations. An “all in, all out” production strategy must be used with finishing pigs.

The manure from hoop structures is removed as a solid with the bedding pack. The high volume of bedding used creates an increased volume of waste to be removed. Typically, a front-wheel assist tractor with a grapple fork attachment on the front-end loader is required to clean out the bedding pack. In a finishing production system, the bedding pack is removed at market time, usually two to three times per year. In gestational sow housing, slightly less bedding is required, and the bedding pack is typically removed one to four times a year depending on the stocking density and quality of bedding.

A limited amount of information is available on the manure characteristics, both inside the hoop and during consequent manure management activities. The manure content within the pack is highly variable. Dunging areas are quickly established when swine are introduced into the deep-bedded structure. These areas contain a majority of the nutrients within the pack. Results of an Iowa State University study are shown in Table 8-4. Samples were taken on a grid system at nine areas throughout the bedding pack (three samples along the west side of the building, three along the center, three along the east).

Table 8-4. Examples of Bedding Nutrients Concentrations

Bedding Nutrients by Location[a]				
Site	**Total Moisture (percent)**	**Total Nitrogen (lb/ton)**	**Phosphorus (lb/ton)**	**Potassium (lb/ton)**
West1	73.7	20	21	12
West2	75.2	22	22	12
West3	68.5	22	31	16
Center1	67.4	14	20	26
Center2	22.9	11	21	37
Center3	27.6	22	17	26
East1	68.5	29	24	29
East2	30.6	36	40	51
East3	73.5	16	13	15
Mean	56.4	21.3	23.2	24.8
Standard Deviation	22.3	7.6	7.6	13.0

[a] Adapted from Richard et al., 1997.

Temperatures throughout the bedding pack also varied greatly. Bedding temperature was highest in the sleeping/resting area where the moisture content is approximately 50 percent. Bedding temperatures were lowest in the wet dunging areas that contain 60 to 70 percent moisture. The lower temperatures were likely caused by anaerobic conditions that prevent oxidation of carbon and, therefore, reduce the amount of heat generated (Richard et al., 1997; and Richard and Smits, 1998).

Richard et al. and Richard and Smits (1997, 1998) also examined the loss of N in the hoop structure bedding pack. One-third of the N was lost while swine were housed in the structure. This loss was hypothesized to be caused largely by ammonia volatilization and possibly from nitrate leaching. An additional 10 percent reduction in N occurred as the bedding pack was removed from the hoop. This loss was also hypothesized as being a result of ammonia volatilization. Additional N was lost during the composting process, with the amount lost corresponding to the specific composting process demonstrated. In general, the composting process that resulted in the greatest reduction of volume also had the greatest N loss (Richard and Smits, 1998).

Nitrogen leaching potential was examined in yet another study at Iowa State University. The hoop facility used in this trial was located on hard-packed soil with a high clay-content. Following one production cycle, the surface NO_3-N was 5.5 times greater than the initial level. There was no significant change in NO_3-N at other depths ranging to 5 feet. Following a second production cycle, the NO_3-N levels at all depths to 5 feet increased three times compared with those taken following the initial production cycle (Richard et al., 1997). Nitrate was the only form of N tested.

The Medina Research Centre in Australia studied N and P accumulation in the soil beneath hoop structures. The hoop structures were constructed on Swan Coastal Plain sandy soils. Two trials were conducted in the same location approximately 6 weeks apart. In each trial there was no increase in the concentration of extractable P in the soil profile when compared with baseline data (Jeffery, 1996).

Advantages and Limitations: The quality of the work environment in a deep-bedded hoop structure is generally good. There is no liquid manure and therefore less odor than with conventional systems. The building structure and recommended orientation provide for a large volume of naturally ventilated air. Also, because the manure is solid, storage requirements are minimized.

The high degree of variability within the bedding pack makes it difficult to predict nutrient content. Some areas can have a high fertilizer value, whereas others have high carbon and low N content. The latter can lead to N immobilization and result in crop stress if applied during or immediately prior to the growing season. For these reasons, it is desirable to mix the bedding pack to achieve a higher degree of uniformity. Some mixing will occur during the removal and storage of the manure. Treatments that allow for additional mixing, such as composting in windrows, appear to offer considerable benefits. Initial studies at Iowa State University found that composting improved uniformity, and provided for a 14 to 23 percent reduction in moisture and a 24 to 45 percent reduction in volume (Richard and Smits, 1998). It should be noted that bedding from gestational sow facilities is typically drier than that from finishing facilities. The lack of moisture is likely to limit the extent of composting unless additional manure or moisture is added.

Trials comparing a conventional confinement system to hoop structures have been performed at Iowa State University. The swine raised in the hoop structure experienced similar performance. Specifically, there was a low level of swine mortality (2.6 to 2.7 percent), comparable and acceptable average daily gain, and a slightly poorer feed efficiency (8 to 10 percent) for swine raised in the winter months (Honeyman et al., 1999). Poor feed efficiency in winter months is due to an increased nutrient/energy requirement to maintain body heat. These findings supported an earlier study by the University of Manitoba that found swine finished in hoop structures to have excellent health, similar rates of gain, poorer feed efficiency in colder months (10 to 20 percent), low swine mortality, and similar days to market (Conner, 1993). Moreover, similar results were found in a South Dakota State University study. Several researchers have identified proper nutrition for swine raised in hoops as an area needing further research.

With respect to housing dry gestational sows, providing a lockable feeding area for each sow affords similar advantages to those of traditional gestation crates. Producers have the ability to keep feed intake even, eliminate competition for feed, administer treatments and medication effectively, lock sows in for cleaning and bedding, and sort and transfer sows for breeding or farrowing through the front gates. Furthermore, group housing stimulates estrus (the period of time within a female's reproductive cycle in which she will stand to be bred), reduces stress to the sow, and alleviates many foot and leg problems common in sows. Fighting is minimized by the use of feeding stalls and introducing new sows at optimal times, such as farrowing. Concreting the deep-bedded section to prevent sows from rooting is an option, but it increases capital outlay (Honeyman et al.,1997).

Iowa State University has conducted demonstration trials on gestating sows in deep-bedded hoop structures. Conception rate, farrowing rate, number of swine born alive, and birth weight on groups gestated in the hoop structure were all excellent. The sow performance results indicate that hoop structures are an exceptional environment for gestating sows. It must be noted, however, that sow groups were not mixed and new sows were not introduced during the trial. With respect to breeding, hot weather is of greater concern than cold weather. Excessive high temperatures can be detrimental to breeding performance. Boars exposed to elevated effective temperatures will experience poor semen quality for a 6- to 8-week period that begins 2 to 3 weeks following exposure. Sows are more tolerant to high temperatures, except during the first 2 to 3 weeks of gestation and the final 2 weeks prior to farrowing. Litter size and birth weight can be severely altered during these periods (Honeyman et al., 1997).

Iowa State University has also conducted preliminary trials with farrow-to-finish production, early weaned pigs, and wean-to-finish production. These studies concluded that, although each may be a viable alternative, many details must still be worked out before they all become successful consistently.

The hoop system offers several benefits with respect to animal welfare and behavior. Honeyman et al. (1997) stated that one of the most extreme stresses in livestock production results when an animal is prevented from controlling various aspects of its environment. This lack of control is apparent in many of today's conventional production systems and is responsible for an unduly high level of stress that affects general health, reproduction, and welfare. Production in a deep-bedded hoop structure allows each animal to control its own microenvironment by burrowing down into the bedding, huddling, or lying on top. Deep-bedded hoops also allow swine to root through and ingest some bedding at will. This is especially advantageous in dry-sow gestational housing. The behavior serves two purposes. First, swine have an inherent drive to root. Being able to do so prevents frustration, boredom, and, hence, aggression. Second, consumption of bedding material quiets any hunger the pig may feel. Increased genetic evolution has led swine to have an increased drive to eat. Gestating sows are typically fed a limited amount of feed, satisfying what is estimated to be only 30 to 50 percent of their appetite. Stereotypic behavior is indicative of a suboptimal environment and will ultimately have implications on an animal's general health and production. No evidence of stereotypic behavior is cited in any of the deep-bedded system studies (Honeyman et al., 1997).

The initial capital outlay for hoop structures is about 30 percent less than the capital requirement associated with a typical double-curtain swine finishing building (Harmon and Honeyman, 1997). Additionally, hoop structures are highly versatile and have many alternative uses (e.g., equipment storage) if production capacity is not needed. Production in hoop structures requires a greater amount of feed and large volumes of high quality bedding, however. Bedding is the key to successful production in hoop structures. These differences make the cost of production comparable to that of a traditional confinement setting.

Hoop structures are easy to construct with on-farm labor. In Iowa State University trials, hoop structures show no visible signs of deterioration after 4 years (Honeyman, 1995). The average useful life of a hoop structure is estimated to be 10 years (Brumm, 1997).

The amount of bedding used in the studies averages 200 pounds per finisher pig in each production cycle, with a greater amount of bedding being used in the winter months. It is estimated that approximately 1,800 pounds of high quality bedding per gestational sow are needed each year (Halverson, 1998). The amount of labor is directly proportional to the amount of bedding and ranges from 0.3 to 0.6 hours per pig (Richard et al., 1997). A survey distributed to producers of finishing pigs in hoop structures and compiled by Iowa State University found actual labor requirements to average 0.25 hours per pig (Duffy and Honeyman, 1999). Labor requirements rely on many factors, including farm size, level of automation, and experience with the production system. Based on the trials conducted at each university, the labor requirement was considered to be reasonable and competitive with other finishing systems (Conner, 1993; Richard et al., 1997).

The large amount of bedding required in hoop structure production can limit its feasibility for some producers. Many types of bedding can be used. Corn stalks, oat straw, wheat straw, bean stalks, wood shavings, and shredded paper have all been used with some success, although shredded corn stalks are the most common. Selection of the appropriate bedding type is based on many factors. First, the availability of bedding must be considered. This is specific to geographical area but may also be limited by climate. An early snow or a wet fall could prevent stalk baling. Second, in several areas of the Midwest, federally mandated conservation plans on highly erodible land require residue to be left on the land. In such cases, harvesting corn and bean stalks may not be appropriate. Finally, bedding storage is an important consideration. Generally, bedding baled in the fall and used by the spring can be stored outdoors. Bedding needed for spring and summer use, however must be stored undercover in a well-drained area to avoid loss in quality and quantity.

Internal parasite control must be aggressive because swine are continually in contact with their feces. Several of the Iowa State University studies note that flies are a potential problem for hoop houses in warm months. Furthermore, rodent and bird problems may be difficult to control. Also, in the summer, incidental composting within the bedding pack can create unwelcome heat and may lessen the animals' comfort. It has not been determined whether there is severe potential for disease and parasite buildup in the soil beneath the hoop structure.

Operational Factors: Production in a hoop structure relies on bedding, intensive management, and keen husbandry for success. Climate control is a major factor in determining the feasibility of deep-bedded hoop structures. The recommended orientation of the buildings is north to south (depending on geographical area), to take advantage of the prevailing summer winds. Air enters the facility through spaces between the sidewall and the tarp and at the ends. Warm, moist air moves toward the top of the arch and is carried out the north end by natural currents. Various end structures are available that supply adjustable levels of ventilation. In the winter months, the north end is generally closed and the south is at least partially opened. If the ends are closed too tightly, high levels of humidity can become a problem. On average, the inside air temperature in the winter is only 5° to 8° F warmer than outside temperatures. This is different from the effective temperature which the swine can alter by burrowing into the deep bedding. In summer months, both ends are left open. Ultraviolet resistant tarp and sprinklers inside the structure help to control the temperature within the structure. Air temperature in the summer averages 2° to 4° F lower than outside temperature (Harmon and Xin, 1997). The length of the hoop structure also has an effect on air temperature because of the rate of air exchange. Wider and longer hoop structures often have ridge vents to improve ventilation.

Demonstration Status: Hoop structures have been used successfully in the United States for housing finishing pigs and dry gestational sows. Grow-finish production is the most common use for hoop structures in swine production. Recently, there has been an increased interest in this type of production system in the Midwest, including the states of Iowa, Illinois, Minnesota, Nebraska, and South Dakota. It is estimated that more than 1,500 hoop structures have been built for swine production in Iowa since 1996 (Honeyman, 1999). Furthermore, initial demonstrations have been conducted with early weaned pigs and in farrow-to-finish production. Hoop structures are being used to house swine in at least seven Canadian provinces. Currently, more than 400 hoop structures are used for swine finishing in Manitoba (Conner, 1994).

Practice: Rotational Grazing

Description: Intensive rotational grazing is known by many terms, including intensive grazing management, short duration grazing, savory grazing, controlled grazing management, and voisin grazing management (Murphy, 1998). This practice involves rotating grazing cattle (both beef and dairy) among several pasture subunits or paddocks to obtain maximum efficiency of the pasture land. Dairy cows managed under this system spend all of their time not associated with milking out on the paddocks during the grazing season and beef cattle spend all of their time out on the paddocks during the grazing season. Intensive rotational grazing is rarely if ever used at swine and poultry operations. Nonruminants such as swine and poultry are typically raised in confinement because of the large number of animals produced and the need for supplemental feed when they are raised on pastures.

Application and Performance: Rotational grazing is applicable to all beef and dairy operations that have sufficient land. During intensive rotational grazing, each paddock is grazed quickly (1 or 2 days) and then allowed to regrow, ungrazed, until ready for another grazing. The recovery period depends on the forage type, the forage growth rate, and the climate, and may vary from 10 to 60 days (USDA, 1997). This practice is labor- and land-intensive as cows must be moved daily to new paddocks. All paddocks used in this system require fencing and a sufficient water supply. Many operations using intensive rotational grazing move their fencing from one paddock to another and have a water system (i.e., pump and tank) installed in each predefined paddock area.

The number of required paddocks is determined by the grazing and recovery periods for the forage. For example, if a pasture-type paddock is grazed for 1 day and recovers for 21 days, 22 paddocks are needed (USDA, 1997). The total amount of land required depends on a number of factors including the dry matter content of the pasture forage, use of supplemental feed, and the number of head requiring grazing. Generally, this averages out to one or two head per acre of pasture land for both beef and dairy cattle (Hannawale, 2000). Successful intensive rotational grazing, however, requires thorough planning and constant monitoring. All paddocks should be monitored once a week. High-producing milk cows (those producing over 80 lbs/day) need a large forage allowance to maintain a high level of intake. Therefore, they need to graze in pastures that have sufficient available forage or be fed stored feed (USDA, 1997). It is also expected that beef cattle would need sufficient forage or stored feed to achieve expected weight gains.

The climate in many regions is not suitable for year round rotational grazing. Operations in these regions must maintain barns and/or dry lots for the cows when they are not being grazed or outwinter their cows. Outwintering is the practice of managing cows outside during the winter months. This is not a common practice because farmers must provide additional feed as cows expend more energy outside in the winter, provide windbreaks for cattle, conduct more frequent and diligent health checks on the cows, and keep the cows clean and dry so that they can stay warm (CIAS, 2000).

There are two basic management approaches to outwintering: rotation through paddocks and sacrifice paddocks. Some farms use a combination of these practices to manage their cows during the winter. During winter months, farmers may rotate cattle, hay, and round bale feeders throughout the paddocks. The main differences between this approach and standard rotational grazing practices are that the cows are not rotated as often and supplemental feed is provided to the animals. Deep snow, however, can cause problems for farmers rotating their animals in the winter because it limits the mobility of round bale feeders. The outwintering practice of "sacrifice paddocks" consists of managing animals in one pasture during the entire winter. There are several disadvantages and advantages associated with this practice. If the paddock surface is not frozen during the entire winter, compaction, plugging (tearing up of the soil), and puddling can occur. Due to the large amounts of manure deposited in these paddocks during the winter, the sacrificial paddocks must be renovated in the spring. This spring renovation may consist of dragging or scraping the paddocks to remove excess manure and then seeding to reestablish a vegetative cover. Some farmers place sacrifice paddocks strategically in areas where an undesirable plant grows or where they plan to reseed the pasture or cultivate for a crop (CIAS, 2000).

EPA conducted an analysis to estimate the manure reduction achievable with intensive rotational grazing at model beef and dairy operations (ERG, 2000a). Outwintering was not assumed to occur in this analysis. During the months that the cows from the model dairies and feedlots were assumed not to be on pasture, the amount of manure that must be managed is assumed to be equal to the amount produced at equal size confined dairy operations and beef feedlots. Table 8-5 presents the estimated range of months that intensive rotational grazing systems might be used at dairy farms and beef feedlots located in each of the five geographical regions included in this analysis.

Table 8-5. Amount of Time That Grazing Systems May Be Used at Dairy Farms and Beef Feedlots, by Geographic Region

Region	Annual Use of Grazing Systems (months)
Pacific	3 - 12
Central	3 -12
Midwest	3 - 6
Mid-Atlantic	3 - 9
South	9 - 12

It is estimated that approximately 15 percent of the manure generated by dairy cows is excreted in the milking center and 85 percent is excreted in the housing areas (i.e., barns, dry lots, pastures) (USDA NRCS, 1996). It is also estimated that 23 percent to 28 percent of the wastewater volume generated from a flushing dairy operation comes from the milking center and 72 percent to 77 percent (median of 75 percent) of the wastewater comes from flushing the barns (USEPA, 2000). All wastewater from a hose-and-scrape dairy system is generated at the milking center. Thus, dairies using intensive rotational grazing systems would manage 85 percent less solid manure and approximately 75 percent less wastewater (for flushing operations) than confined systems, during the months that the cows are on pasture.

All of the manure generated at beef feedlots using intensive rotational grazing systems would be excreted on the pasture during the months that the cows are grazing. No significant amounts of process wastewater are generated at beef feedlots. Thus, beef feedlots using intensive rotational grazing systems would manage 100 percent less solid waste during the months that the cows are on pasture.

Two model farm sizes were analyzed for dairy farms, assuming an average size of 454 (for medium-sized dairies) and 1,419 milking cows (for large-sized dairies). Both of these size groups are significantly larger than the 100 head or smaller operations expected to use intensive rotational grazing systems. Therefore, the specific model farm calculations are viewed as significantly overestimating the amount of collected manure and wastewater that could be reduced at typical intensive rotational grazing operations versus confined operations. For this reason, estimates on collected manure and wastewater reduction are presented on a per-head basis and model farm basis for the two dairy farm types (flushing, hose and scrape) included in EPA's Effluent Limitations Guidelines (ELG) analysis for each of the five geographical regions.

Three model farm sizes were analyzed for beef feedlots, assuming an average size of 844 (for medium-sized feedlots), 2,628 (for large-sized feedlots), and 43,805 beef slaughter steer (for very large feedlots). Due to the slow weight gain associated with grazing operations for beef cattle and required number of pasture acres, beef feedlots of these sizes are not expected to use intensive rotational grazing systems. However, estimates on collected manure reductions are presented on a per-head basis and model farm basis for the three sizes of beef feedlots included in EPA's ELG analysis for each of the five geographical regions.

Table 8-6 presents the expected reduction in collected manure and wastewater for flush and hose-and-scrape dairy operations, by head, and by region. Table 8-7 presents the expected reduction in collected manure and wastewater for dairy operations by model farm, and by region. Table 8-8 presents the expected reduction in collected manure for beef feedlots, by head, and by region. Table 8-9 presents the expected reduction in collected manure for beef feedlots by model farm, and by region.

Table 8-6. Expected Reduction in Collected Solid Manure and Wastewater at Dairies Using Intensive Rotational Grazing, per Head

Farm Type	Region	Manure Reduction (lb/yr/head)	Wastewater Reduction (gal/yr/head)
Flush	Pacific	10,200 - 41,500	9,000 - 36,500
	Central	10,200 - 41,500	9,000 - 36,500
	Midwest	10,200 - 20,500	9,000 - 18,000
	Mid-Atlantic	10,200 - 30,700	9,000 - 27,000
	South	30,700 - 41,500	27,000 - 36,500
Hose and Scrape	Pacific	10,200 - 41,500	0
	Central	10,200 - 41,500	0
	Midwest	10,200 - 20,500	0
	Mid-Atlantic	10,200 - 30,700	0
	South	30,700 - 41,500	0

Table 8-7. Expected Reduction in Collected Solid Manure and Wastewater at Dairies Using Intensive Rotational Grazing, per Model Farm

Farm Size (head)	Farm Type	Region	Manure Reduction (lb/yr/farm)	Wastewater Reduction (gal/yr/farm)
454	Flush	Pacific	4,630,800 - 18,841,000	4,086,000 - 16,571,000
		Central	4,630,800 - 18,841,000	4,086,000 - 16,571,000
		Midwest	4,630,800 - 9,307,000	4,086,000 - 8,172,000
		Mid-Atlantic	4,630,800 - 13,937,800	4,086,000 - 12,258,000
		South	13,937,800 - 18,841,000	12,258,000 -16,571,000
454	Hose & Scrape	Pacific	4,630,800 - 18,841,000	0
		Central	4,630,800 - 18,841,000	0
		Midwest	4,630,800 - 9,307,000	0
		Mid-Atlantic	4,630,800 - 13,937,800	0
		South	13,937,800 - 18,841,000	0
1,419	Flush	Pacific	14,473,800 - 58,888,500	12,771,000 - 51,793,500
		Central	14,473,800 - 58,888,500	12,771,000 - 51,793,500
		Midwest	14,473,800 - 29,089,500	12,771,000 - 25,542,000
		Mid-Atlantic	14,473,800 - 43,563,300	12,771,000 - 38,313,000
		South	43,563,300 - 58,888,500	38,313,000 - 51,793,500
1,419	Hose and Scrape	Pacific	14,473,800 - 58,888,500	0
		Central	14,473,800 - 58,888,500	0
		Midwest	14,473,800 - 29,089,500	0
		Mid-Atlantic	14,473,800 - 43,563,300	0
		South	43,563,300 - 58,888,500	0

Table 8-8. Expected Reduction in Collected Solid Manure at Beef Feedlots Using Intensive Rotational Grazing, per Head

Region	Manure Reduction (lb/yr/head)
Pacific	5,040 - 20,167
Central	5,040 - 20,167
Midwest	5,040 - 10,080
Mid-Atlantic	5,040 - 15,120
South	15,120 - 20,167

Table 8-9. Expected Reduction in Collected Solid Manure at Beef Feedlots Using Intensive Rotational Grazing, per Model Farm

Farm Size (head)	Region	Manure Reduction (lb/yr/farm)
844	Pacific	4,255,170 - 17,020,680
	Central	4,255,170 - 17,020,680
	Midwest	4,255,170 - 8,510,340
	Mid-Atlantic	4,255,170 - 12,765,510
	South	12,765,510 - 17,020,680
2,628	Pacific	13,249,500 - 52,998,000
	Central	13,249,500 - 52,998,000
	Midwest	13,249,500 - 26,499,000
	Mid-Atlantic	13,249,500 - 39,748,500
	South	39,748,500 - 52,998,000
43,805	Pacific	220,849,640 - 883,398,550
	Central	220,849,640 - 883,398,550
	Midwest	220,849,640 - 441,699,280
	Mid-Atlantic	220,849,640 - 662,548,910
	South	662,548,910 - 883,398,550

Advantages and Limitations: Compared with traditional grazing, intensive rotational grazing has been identified as environmentally friendly and, when managed correctly, is often considered better than conventional or continuous grazing. The benefits associated with intensive rotational grazing versus conventional grazing include:

- Higher live-weight gain per acre. Intensive rotational grazing systems result in high stocking density, which increases competition for feed between animals, forcing them to spend more time eating and less time wandering (AAC, 2000).

- Higher net economic return. Dairy farmers using pasture as a feed source will produce more feed value with intensive rotational grazing than with continuous grazing (CIAS, 2000). Competition also forces animals to be less selective when grazing. They will eat species of plants that they would ignore in other grazing systems. This reduces less desirable plant species in the pasture and produces a better economic return (AAC, 2000).

- Better land. Pasture land used in rotational grazing is often better maintained than typical pasture land. Intensive rotational grazing encourages grass growth and development of healthy sod, which in turn reduces erosion. Intensive rotational grazing in shoreline areas may help stabilize stream banks and could be used to maintain and improve riparian habitats (PPRC, 1996).

- Less manure handling. In continuous grazing systems, pastures require frequent maintenance to break up large clumps of manure. In a good rotational system, however, manure is more evenly distributed and will break up and disappear faster. Rotational grazing systems may still require manure maintenance near watering areas and paths to and from the paddock areas (Emmicx, 2000).

Grazing systems are not directly comparable with confined feeding operations, as one system can not readily switch to the other. However, assuming all things are equal, intensive rotational grazing systems might have some advantages over confined feeding operations:

- Reduced cost. Pasture stocking systems are typically less expensive to invest in than livestock facilities and farm equipment required to harvest crops. Feeding costs may also be lowered.

- Improved cow health. Dairy farmers practicing intensive rotational grazing typically have a lower cull rate than confined dairy farmers, because the cows have less hoof damage, and they are more closely observed by the farmer as they are moved from one paddock to another (USDA, 1997).

- Less manure handling. Intensive rotational grazing operations have less recoverable solid manure to manage than confined operations.

- <u>Better rate of return</u>. Research indicates that grazing systems are more economically flexible than the confinement systems. For example, farmers investing in a well-planned grazing operation will likely be able to recover most of their investment in assets if they leave farming in a few years. But farmers investing from scratch in a confinement operation would at best recover half their investments if they decide to leave farming (CIAS, 2000).

The disadvantages associated with intensive rotational grazing compared with either conventional grazing or confined dairy operations include:

- <u>Limited applicability</u>. Implementation of intensive rotational grazing systems is dependent upon available acreage, herd size, land resources (i.e., tillable versus steep or rocky), water availability, proximity of pasture area to milking center (for dairy operations), and feed storage capabilities. Typical confined dairy systems and beef feedlots are often not designed to allow cows easy access to the available cropland or pastureland. Large distances between the milking center and pastureland will increase the dairy cow's expended energy and, therefore, increase forage demands.

  In most of the country, limited growing seasons prevent many operations from implementing a year-round intensive rotational grazing system. Southern states such as Florida can place cows on pasture 12 months of the year, but the extreme heat presents other problems for cows exposed to the elements. Grazing operations in southern states typically install shade structures and increase water availability to cows, which in turn increases the costs and labor associated with intensive rotational grazing systems. Because most operations cannot provide year-round grazing, they still must maintain barns and dry lot areas for their cows when they are not grazing, and operations often prefer not to have to maintain two management systems.

- <u>Reduced milk production levels</u>. Studies indicate that dairy farmers using intensive rotational grazing have a lower milk production average than confined dairy farms (CIAS, 2000). Lower milk production can offset the benefit of lower feed costs, especially if rations are not properly balanced once pasture becomes the primary feed source during warm months.

- <u>Reduced weight gain</u>. Beef cattle managed in an intensive rotational grazing system would gain less weight per day than beef cattle managed on a feedlot unless they were supplied with extensive supplemental feed.

- <u>Increased likelihood of infectious diseases</u>. Some infectious diseases are more likely to occur in pastured animals due to direct or indirect transmission from wild animals or the presence of an infective organism in pasture soil or water (Hutchinson, 1998).

- <u>Limited flexibility</u>. Intensive rotational grazing systems have limited flexibility in planning how many animals can be pastured in any one paddock. Available forage in a paddock can vary from one cycle to another, because of weather and other conditions that affect forage growth rates. As a result, a paddock that was sized for a certain number of cows under adequate rainfall conditions will not be able to accommodate the same number of cows under drought conditions (USDA, 1997).

Operational Factors: As mentioned earlier, most dairy operations and beef feedlots cannot maintain year-round intensive rotational grazing systems. These systems are typically operated between 3 and 9 months of the year–with 12 months most likely in the southern states. Although outwintering is a possibility for year round grazing in more northern states, it is not a common practice.

Demonstration Status: Due to the labor, fencing, water, and land requirements of intensive rotational grazing, typically only small dairy operations (those with less than 100 head) use this practice (Hannawale, 2000; USDA NRCS, 2000; CIAS, 2000). Few beef feedlots practice intensive rotational grazing. Climate and associated growing seasons make it very difficult for operations to use an intensive rotational grazing system throughout the entire year.

Practice: Pasture-Based Systems at Swine Operations

Description: There are three main types of outdoor management systems at swine operations: pasture, open lots, and buildings with outside access. In pasture systems, crops are grown and the animals are allowed to forage for their own food. Open lots are generally nonvegetative areas where the animals are allowed to roam. These open lots are typically available to animals that are housed in buildings with outside access. The focus of this discussion is the pasture systems.

Application and Performance: This practice is applicable to any swine operation that has sufficient land. However, the practicality of the practice decreases with operation size. Wheaton and Rea (1999) found that the use of a good pasture containing such crops as alfalfa, clover, and grasses can support about 8 to 10 sows. Stocking rates, however, will depend upon soil fertility, quality of pasture, and time of year. The recommended stocking rates are (Wheaton and Rea, 1999):

- Sows with litters — 6 to 8 head per acre
- Pigs from weaning to 100 pounds — 15 to 30 head per acre
- Pigs from 100 pounds to market — 10 to 20 head per acre
- Gestating sows — 8 to 12 head per acre

Wheaton and Rea (1999) also found that pastured swine must receive two to three pounds of grain daily plus minerals and salt for proper weight gain. Adequate shade and water must also be provided to pastured swine. Swine can be very tough on pastures and soil. Therefore, it is recommended that producers rotate swine after each season and use the pasture for other animals or harvest hay for about 2 years before using it again for swine (Wheaton and Rea, 1999). All the waste produced by the animals while they are pastured is incorporated into the sod, and therefore requires minimal waste disposal.

Advantages and Limitations: A pasture-based system offers a number of advantages and disadvantages over confinement housing to swine producers. The advantages include (Wheaton and Rea, 1999):

- Lower feed costs on good pasture;
- Exercise and nutrients for breeding sows;
- Lower capital investment per production unit;
- Good use of land not suitable for machine harvest;
- Better isolation and disease control;
- Decreased waste management handling; and
- Decreased cannibalism.

The disadvantages include (Wheaton and Rea, 1999):

- Increased labor for animal handling, feeding, and watering;
- Increased risk of internal parasites;
- Increase labor for farrowing;
- Increase animal production time to reach desired market weight; and
- Lack of environmental controls.

Operational Factors: The increased labor costs associated with pasture-based swine operations are partially offset by decreased waste handling costs and reduced feed costs.

Demonstration Status: Data from the USDA's Animal and Plant Health Inspection Service - Veterinary Service indicate pasture-based systems are used at 7.6 percent of farrowing operations, 1.5 percent of nurseries, and 6.7 percent of finishing operations (USDA APHIS, 1995). The percentage of pigs raised on such operations is about five times less than the number of operations, indicating these operations are generally smaller than other types of swine operations. NAHMS confirmed this with additional analysis of the *Swine '95* data, and indicated 7 to 8 percent of swine farms with fewer than 750 total head use pasture systems, but less than 1 percent of swine operations larger than 750 head use pasture systems (USDA NAHMS, 1999).

Practice: Pasture-Based Systems at Poultry Operations

Description: Pastured poultry refers to broilers, layers, and turkeys that are raised on pasture and feed. There are three basic methods for raising poultry on pasture: pasture pens, free range, and day range (Lee, 2000). Pasture pens are bottomless pens that hold layers, broilers, or turkeys, and are moved daily or as needed to give the poultry fresh pasture. This is the most commonly used pasture poultry method at present. To accommodate layers, nest boxes are fixed to the side of the pen. Approximately 30 to 40 hens can be housed in one typical pasture pen. Free range generally means a fenced pasture surrounding the barn or poultry shelter, and day range is similar to free range except that the birds are sheltered at night from predators and weather.

Application and Performance: The use of pasture pens has been documented at operations with 1,000 birds but is believed to be used most commonly at operations with fewer than 1,000 birds. Lee (2000) also indicates that pastured poultry operations require up to twice the amount of feed as confined poultry does to achieve the same weight gain and/or production goal. All wastes produced while the birds are on pasture is incorporated into the sod, and therefore results in minimal waste requiring disposal.

Advantages and Limitations: Some of the advantages associated with pastured poultry versus confinement housing are:

- Pasture pens are easy and inexpensive to build;
- Controlled moves will harvest grass and help spread manure uniformly across the field;
- Perimeter fencing is not required;
- Diseases associated with confinement housing may be less likely to occur;
- Waste management handling is reduced; and
- Pasture-raised birds may have a higher market value (Lee, 2000).

The limitations associated with pastured poultry include the following:

- The small pens hold relatively few poultry, compared with their cost;
- Pens can trap heat, leading to heat stress;
- The roof height of the pens is too low for turkeys to stretch and raise their heads to full height;
- Pens may be difficult to move;
- Pens offer only minimal protection from weather; and
- Birds often have to bed down at night in manure-soaked grass (Lee, 2000).

Operational Factors: Pasture-based poultry operations require increased labor for animal handling, feeding, and watering (Lee, 2000). This increased labor is partially offset by a decrease in waste management.

Demonstration Status: No data could be found to indicate the number of pasture-based poultry operations. However, the use of pasture pens is rarely observed at operations with more than 1,000 birds. Thus few if any pastured poultry operations confine sufficient numbers of birds to be defined as CAFOs on the basis of operation size.

8.2 Manure/Waste Handling, Storage, and Treatment Technologies

Waste from animal feeding operations includes manure, bedding material, and animal carcasses. There are a variety of methods for handling, storing, and treating waste. Waste is handled in a solid form and through the use of water. As stated in earlier chapters, some facilities use water to move the waste away from the animals and then separate the solids from the liquids prior to storage, treatment, and disposal. Storage and treatment of waste is done in the both the solid and liquid/slurry forms.

8.2.1 Waste Handling Technologies and Practices

Different practices are used to handle or move liquid and solid wastes, and the choice of practices depends on the type of housing configuration. Housing configurations include total confinement, which is the most common and used almost exclusively in the poultry industry and at larger swine operations, open buildings with or without outside access, and lots or pastures with a hut or with no buildings.

Practice: Handling of Waste in Solid Form

Description: The use of hoop houses for swine and high-rise hog houses to handle manure in a dry form was discussed in section 8.1. In facilities with open lots, manure accumulates on the ground as a solid that can be diluted by rainfall (mostly for beef and dairy; swine and poultry are mostly totally confined) or by spillage from watering areas. Whether the lot is paved, partially paved, or unpaved, manure is typically handled as a solid or slurry and is scraped with tractor scrapers or front-end loaders and stored in a pile (see Figure 8-2). There are several options for separating solid manure from the animals at confinement facilities. Solid, unslatted floors, both paved and unpaved, can be hand-scraped or scraped with a tractor or front-end loader into a pile, pit, or other storage facility. Sloped floors further aid in manure collection as animal traffic works the manure downslope. Other facilities use uncovered alley or gutter systems combined with hand scraping, automatic scraping, or sloped floors to collect manure. Scraped manure from underslat gutters, alleys, or shallow pits can be held temporarily in a pit or a deep collection gutter at one end of the building, from which it can be applied to the land or transferred to a more permanent storage structure.

Application and Performance: Solid systems are best suited for open lot facilities, especially in areas that have a dry climate because exposed manure is less likely to be diluted by excess rainfall. The choice of solid or liquid handling systems, however, has been historically based on operator preference with respect to capital investment, labor requirements, and available equipment and facilities.

Advantages and Limitations: Solid handling systems offer both advantages and disadvantages to facility operators. For instance, solid systems use equipment that is already present at the facility, such as tractors and front-end loaders. Tractors and front-end loaders are flexible, have fewer mechanical problems, are less subject to corrosion, and work well on frozen manure, but they

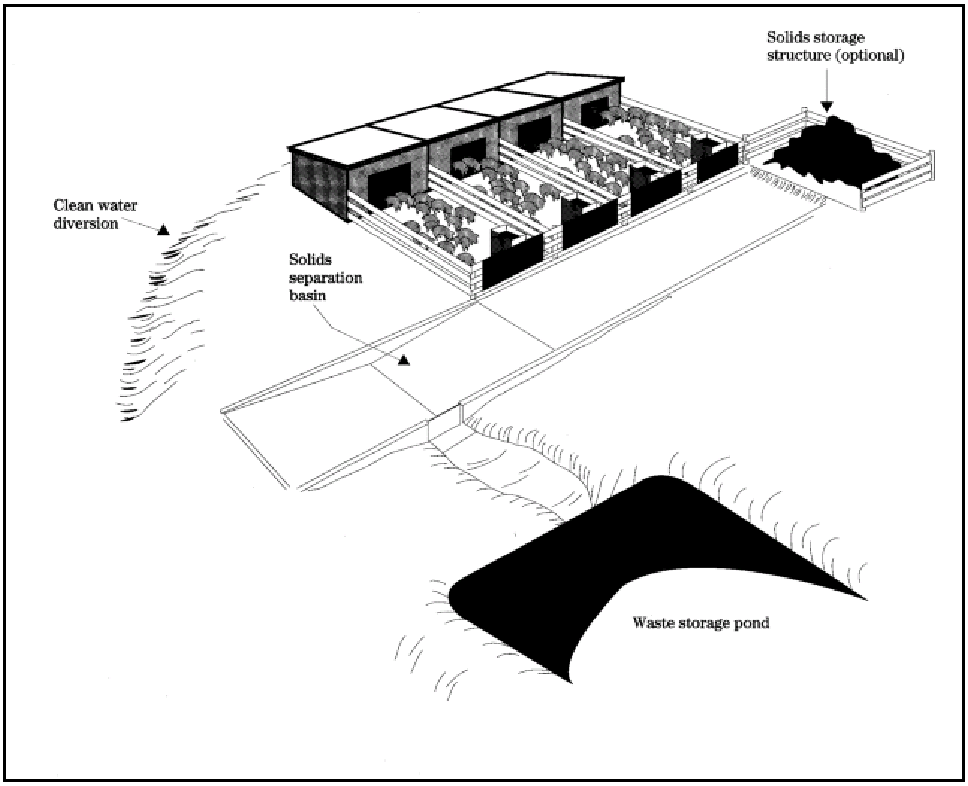

Figure 8-2. Manure Scraped and Handled as a Solid on a Paved Lot Operation (from USDA NRCS, 1996)

require more labor than automatic scrapers. Solid systems are not as automated as liquid systems; although they involve little or no capital investment and require less maintenance, they require much more labor than mechanical scraper systems or flushing systems. An advantage to solid systems is that the volume of manure handled is much less than the volume associated with liquid systems, which translates into smaller storage facility requirements. Bedding can be used without concern for pumping or agitating equipment problems (which are a concern for liquid handling systems).

Operational Factors: The extent of paving on an open lot determines the care with which manure is removed. Unpaved lots develop an impervious layer from bacterial activity and hoof action, and this layer protects against soil loss and percolation of liquids. Also, scraping of unpaved surfaces incorporates sand and soil into the manure, which can cause problems with storage or treatment of the manure. If scraped manure is to be stacked, it may be necessary to add an appreciable amount of bedding to attain a more solid consistency.

Demonstration Status: Solid handling systems are fairly common at smaller swine operations. According to *Swine '95* (USDA APHIS, 1996), removal of manure by hand is used most often in all types of operations (farrowing 38.2 percent, nursery 29.9 percent, and grower-finisher 27.2 percent). Mechanical scrapers and tractors are also used for solids handling (farrowing 12.0 percent, nursery 17.6 percent, and grower-finisher 24.9 percent).

Poultry waste is mostly handled as a dry litter, the exception being layer operations, particularly in the South region (USDA NAHMS, 2000a).

Manure is often handled in solid form at smaller dairy farms. According to *Dairy '96* (USDA APHIS, 1996A), gutter cleaners are used most often to remove manure from dairy cow housing areas (63.2 percent). Mechanical scrapers or tractors are frequently used to clean alleys (57.7 percent). A number of dairies store manure in solid form: 79.2 percent of dairies with fewer than 100 cows and 59.5 percent of dairies with 200 or more cows are reported to use some form of solid waste storage (USDA APHIS, 1996B).

Scraping is the most common method of collecting solid and semisolid manure from beef barns and open lots. Solids can be moved with a tractor scraper and front-end loader. Mechanical scrapers are typically used in the pit under barns with slotted floors. Scraping is common for medium and large feedlots. (Loudon, 1985)

Practice: Teardrop, V- and Y-Shaped Pits With Scraper

Description: Confinement facilities have several manure collection options for separating manure liquids from manure solids. Several underfloor gutter systems that are applicable only to swine will be discussed. No comparable manure collection systems that separate liquids and solids are known for other animal species.

The reason for separating swine manure into solids and liquids is to concentrate pollutants and nutrients. Kroodsma (1985) installed a plastic 0.78 mm filter net under the floor of a pig house in which eight pigs were fed by wet feeders so that no excess water fell into the manure. Solids fell onto the screen and liquids passed through. The results showed that the relatively undisturbed feces contained about 80 percent of the biological oxygen demand (BOD), chemical oxygen demand (COD), total solids (TS), phosphorus (P), calcium (Ca), magnesium (Mg), and copper (Cu). Sixty per cent of the total kjeldahl nitrogen (TKN) and forty percent of the potassium (K) were also retained in the filter net. Thus, if solids can be recovered relatively intact, parameters such as nutrients will be concentrated.

Two gutter configurations that may be useful for swine operations are Y-shaped and V-shaped gutters under slatted floors (Tengman, et al., undated draft). The sloping sides of the gutters facilitate retention of solids and allow liquids to drain to the center collection area. Scrapers pull the solids to one end of the barn for solids handling, while liquids flow with gravity in the opposite direction for management in a liquid manure system.

V-shaped gutters are easier to build than Y-shaped gutters and may be easier to clean. Manure movement in v-shaped gutters is not substantially different than in y-shaped gutters. The sideslope of Y- or V-shaped gutters should be 1:1 for farrowing operations and 3/4:1 for nurseries. A slope of 1:240 to 1:480 is recommended for the liquid gutter (Tengman, et al., undated draft).

Manure that is scraped from underslat gutters, alleys, or shallow pits can be held temporarily in a pit or a deep collection gutter at one end of the building, from which it can be applied to the land or transferred to a more permanent storage structure.

Application and Performance: The choice of a manure handling system is based primarily on operator preference with respect to capital investment, labor requirements, and available equipment and facilities. Demonstration of the economic viability or the value of concentrating nutrients using the Y-shaped gutter and V-shaped gutter is apparently lacking. No performance data was found from full-scale demonstration of the segregation of constituents, including pathogens, metals, growth hormones, and antibiotics.

Advantages and Limitations: The advantage in using a Y-shaped or V-shaped scrape collection system would be the concentration of nutrients in the solids. Nutrients concentrated in solid form are cheaper to haul than in slurry form because water, which would increase the weight and volume, is not added. Disadvantages include reduced air quality in hog buildings over manure solids smeared on the collection slope, repair of cable scrapers in small spaces under slatted floors with hogs present, the need for the operator to manage both a compost or solids stacking operation with solids handling equipment and a liquid storage and application system with liquid handling equipment.

Operational Factors: Climate, temperature, and rainfall generally do not affect scraper systems in hog barns. If scraped manure solids are to be stacked or composted, it may be necessary to add an appreciable amount of bedding to attain a more solid consistency.

Demonstration Status: Underslat manure scrape and gutter systems to direct manure liquids and solids to different handling systems have been developed, but they are not commonly used.

Practice: Handling of Waste in Liquid Form

Description: Liquid handling systems are the alternative to scraping and hauling manure. They are especially common in confinement housing operations because it is easier to install automated systems inside new or existing structures and it is more difficult to maneuver tractors or front-end loaders for scraping in small pens and tight corners. Excreted manure can be collected in shallow, narrow, open gutters or alleys, or it can collect under slats in gutters or pits for periodic flushing to a more permanent storage or treatment facility. The manure can also be directly applied to land without extended storage or treatment.

Slotted floors are an efficient method for removing manure from animal areas. Floors tend to be typically partially slotted over a pit or gutter. Feeding and resting areas are located on solid floors, and watering areas are placed over slotted floors. Manure is worked through the slats by hoof action and is stored beneath the slats until it is pumped or flushed to a lagoon. Fresh water can be used for flushing or water from a secondary lagoon can be recycled as flush water. An example of a slotted floor system is shown in Figure 8-3.

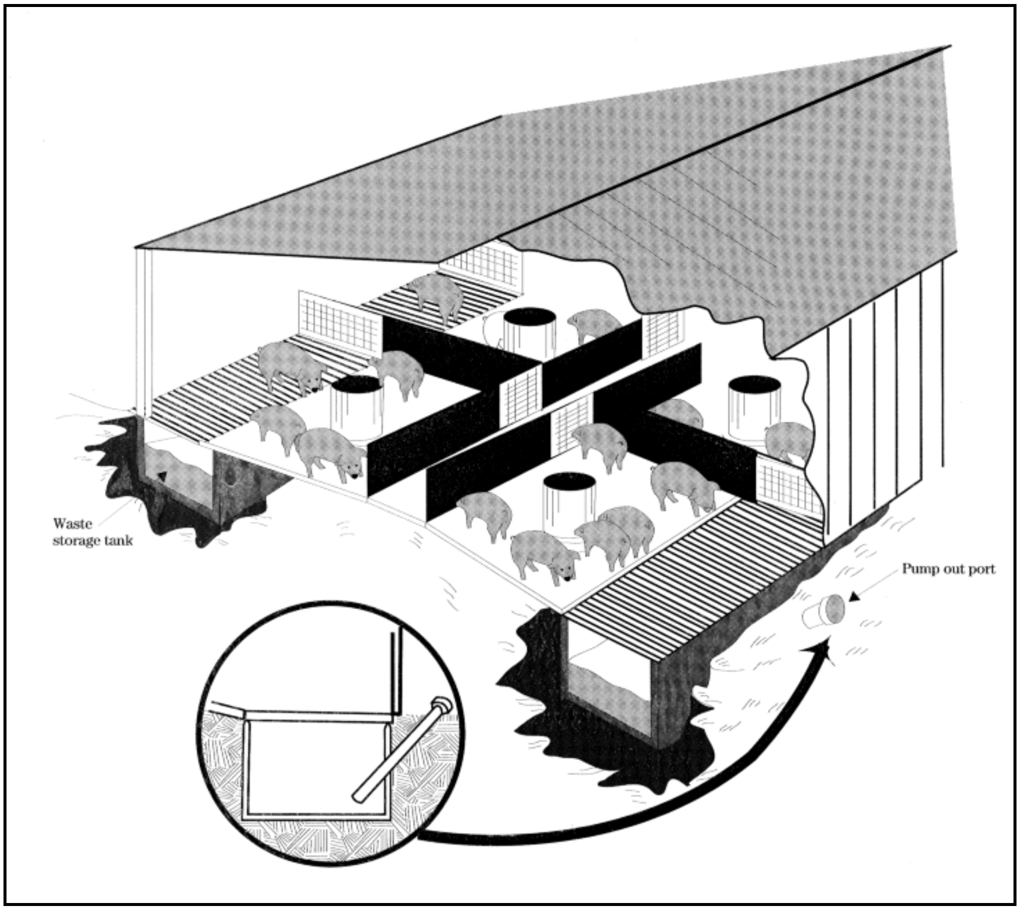

Figure 8-3. Fed hogs in confined area with concrete floor and tank storage liquid manure handling (from USDA NRCS, 1996).

Application and Performance: Liquid manure systems are most frequently used for large animal facilities, where the automation of waste management systems is very important. They may also be preferred where water is abundant or when rainfall on open lots causes considerable dilution of manure solids. Liquid systems are especially appropriate when spray irrigation of nutrient-laden waters is the preferred method for fertilizing and watering crops.

Advantages and Limitations: Flushing systems with liquid manure handling are less labor-intensive and more automated than solid handling systems, but the volume of manure and water to be stored, treated, and disposed of is greater. Flushing systems require large volumes of water to be pumped and stored in a sump until discharged by gravity flow or pumped to a lagoon. Consequently, where water is a valuable commodity, liquid systems might not be economical. This limitation can be offset by recycling flush water from treatment lagoons. Equipment needed for liquid systems, including sumps, pumps, agitators, choppers, and sprayers, brings with it high capital, operating, and maintenance costs, although savings may be seen in decreased labor costs. Manure consistency is very important in liquid handling systems because the equipment can be damaged by fibrous material (bedding), sand, or other foreign materials. Periodic cleanout of solids is necessary to maintain the capacity and proper functioning of storage structures and handling equipment.

Operational Factors: Slats can be made of wood, concrete, steel, aluminum, or plastic. Concrete is the most sturdy material, is the least corrodible, and handles the weight of larger animals, but it requires extra supports and the initial costs are higher than the costs of other materials. Wood is the least expensive material, but it can be chipped by the animals and needs to be replaced at least every 2 to 4 years. Plain steel and aluminum slats are subject to corrosion, but they can be galvanized or coated with paint or plastic to extend their life. Plastic slats, metal grates, expanded metal mesh, and stainless steel slotted planks are appropriate for swine farrowing and nursery operations that house smaller pigs. Openings between slats should be greater than 3/4 inch, up to 1 3/4 inches for swine operations.

Demonstration Status: The *Swine '95* report (USDA APHIS, 1996) demonstrates that liquid systems, although not the most common type on a facility-by-facility basis, are still used fairly frequently. Flushing under slats accounts for 5.3 percent of farrowing, 9.4 percent of nursery, and 2.4 percent of grower-finisher operations, whereas flushing with open gutter systems accounts for 3.0, 2.1, and 3.4 percent of each operation type, respectively. Liquid handling systems are becoming increasingly popular as larger operations become more prevalent, necessitating automated systems for manure handling.

Poultry waste is mostly handled as a dry litter, the exception being layer operations, particularly those in the South region. Approximately 40 percent of the laying operations in the South use a flush system with a lagoon (USDA NAHMS, 2000a).

Dairy '96 (USDA APHIS, 1996A) reports that a small number of dairy farms, 2.8 percent, use water to remove manure from alleys. However, over 90 percent of operations with 200 or more cows are reported to use liquid manure storage systems (USDA APHIS, 1996B). According to the NAHMS survey results (Garber, 1999), approximately 50% of all facilities with greater than 500 mature dairy cows employ flushing as a means of cleaning the housing area.

A flushing system dilutes manure from beef feedlots with water to allow for automated handling. The system uses a large volume of water to flush manure down a sloped gutter to storage, where the liquid waste can be transferred to a storage lagoon or basin. This system is not common for large beef feedlots; however, this type of system is widely used at veal operations (Loudon, 1985). Based on EPA site visits, about 67 percent of veal operations flush manure to liquid lagoon storage systems.

Practice: Berms and Storm Water Diversions

Description: "Clean" storm water runoff from land surrounding livestock facilities can be diverted from barns, open animal concentration areas, and waste storage or treatment facilities to prevent mixing with wastewater. This is accomplished through earthen perimeter controls and roof runoff management techniques.

Earthen perimeter controls usually consist of a berm, dike, or channel constructed along the perimeter of a site. Simply defined, an earthen perimeter control is a ridge of compacted soil, often accompanied by a ditch or swale with a vegetated lining, located at the top or base of a sloping area. Depending on their location and the topography of the landscape, earthen perimeter controls can achieve one of three main goals: preventing surface runoff from entering a site, diverting manure-laden runoff created on site to off-site waste trapping devices, and intercepting "clean" storm water runoff and transporting it away from lagoons or belowground tanks. Therefore, diversions are used to protect areas from runoff and divert water from areas where it is in excess to locations where it can be stored, used, or released. Thus, it prevents the mixing of "clean" storm water with manure-laden wastewater, reducing the volume of wast water to be treated.

Roof runoff management techniques such as gutters and downspouts direct rainfall from roofs away from areas with concentrated manure. Because these devices prevent storm water from mixing with contaminated water, they also reduce the volume of wastewater to be treated.

Application and Performance: Earthen perimeter controls or diversions are applicable where it is desirable to divert flows away from barns, open animal concentration areas, and waste storage or treatment facilities. They can be erected at the top of a sloping area or in the middle of a slope to divert storm water runoff around a feeding or manure storage site. However, unvegetated, earthen channels should not be used in regions of high precipitation because of potential erosion problems.

The design capacity of a channel is calculated using Manning's equation and is based on precipitation, slope, wetted perimeter, water cross-sectional area, and surface roughness. Water velocity is also a consideration in designing diversions to minimize erosion. Other types of diversions that can be used for runoff control include grassed waterways, which are natural or constructed channels that provide stable runoff conveyance, and lined waterways or outlets, which are lined channels or outlets reinforced with erosion-resistant linings of concrete, stone, or other permanent materials to provide additional stability.

Advantages and Limitations: When properly placed and maintained, earthen perimeter controls are effective for controlling the velocity and direction of storm water runoff. Used by themselves, they do not have any ability to remove pollutants and thus must be used in combination with an appropriate sediment or waste trapping device at the outfall of the diversion channel. With these diversion techniques, storm water runoff is prevented from mixing with contaminated manure-laden wastewater and thus the volume of water for treatment is decreased;.however, the concentrated runoff in the channel or ditch has increased erosion potential. To such erosion, diversion dikes must be directed to sediment trapping devices where erosion sediment can settle out of the runoff before being discharged. In addition, if a diversion dike crosses a vehicle roadway or entrance, its effectiveness may be reduced. Wherever possible, diversion dikes should be designed to avoid crossing vehicle pathways.

Operational Factors: The siting of earthen perimeter controls depends on the topography of the area surrounding a specific site. When determining the appropriate size and design of these diversion channels, the shape of the surrounding landscape and drainage patterns should be considered. Also, the amount of runoff to be diverted, the velocity of runoff in the diversion, and the erodibility of soils on the slope and within the diversion channel or swale are essential design considerations.

Both diversion channels and roof management devices must be maintained to remain effective. If vegetation is allowed to grow in diversions, the roughness increases and the channel velocity decreases which can cause channel overflow. Therefore, vegetation should be periodically mowed. In addition, the dike should be maintained at the original height, and any decrease in height due to settling or erosion should be remedied.

Roof management devices such as gutters and downspouts must be cleaned and inspected regularly to prevent clogging and to ensure its effectiveness.

Demonstration Status: The use of earthen perimeter techniques such as berms, diversions, and channels and the use of roof management techniques to divert storm water away from barns, open animal concentration areas, and waste storage or treatment facilities are well-accepted practices that prevent “clean” wastewater from mixing with manure-laden wastewater, thus reducing the volume of wastewater to be treated.

8.2.2 Waste Storage Technologies and Practices

The USDA NRCS recommends that storage structures be designed to handle the volume of manure produced between emptying events. The minimum storage period is based on the timing required for environmentally safe waste utilization considering climate, crops, soil, equipment, and local, state, and federal regulations. The design storage volume for liquid manure should account for manure, wastewater, precipitation and runoff (if uncovered), and other wastes that will accumulate during the storage period, such as residual solids that are not removed when liquids are pumped. Other general considerations are inlet designs, outlets or pumping access, and safety (such as fencing, odor and gas control, reinforcement against earth movements and hydrostatic pressure, use of a cover, and amount of freeboard).

Practice: Anaerobic Lagoons

Description: Anaerobic lagoons are earthen basins that provide storage for animal wastes while decomposing and liquefying manure solids. Anaerobic processes degrade high biochemical oxygen demand (BOD) wastes into stable end products without the use of free oxygen. Anaerobic lagoons are designed based on volatile solids loading rates (VSLR). Volatile solids are the wastes that will decompose. The volume of the lagoon consists of the following (see Figure 8-4):

1. Minimum Treatment Volume—The total daily volatile solids from all waste sources divided by the volatile solids loading rate for a particular region. The minimum treatment volume is based on the volatile solids loading rate, which varies with temperature and therefore with geographic location. Recommended volatile solids loading rates in the United States vary from 3 to 7 pounds per 1,000 ft^3 per day.

2. Sludge Volume—Volume of accumulated sludge between cleanouts. A fraction of the manure solids settles to the bottom of the lagoon and accumulates as sludge. The amount of sludge accumulation depends on the type and amount of animal waste.

3. Manure and Wastewater Volume—The volume of manure and wastewater transferred from feedlot operational facilities to the lagoon during the storage period. Lagoons are typically designed to store from 90 to 365 days of manure and wastewater.

4. Net Precipitation—Precipitation minus the evaporation during the storage period.

5. Design Storm—Typically a 25-year, 24-hour storm event.

6. Freeboard—A minimum of 1 foot of freeboard. Freeboard is the extra depth added to the pond as a safety factor.

7. Runoff—The runoff volume from lagoon berms. In general, lagoons should not receive runoff because runoff can shock the lagoon with an overload of volatile solids. Some runoff will enter the lagoons from the berms surrounding them.

Anaerobic lagoons should be at least 6 to 10 feet deep, although 8- to 20-foot depths are typical. Deeper lagoons require a smaller surface area, and they more thoroughly mix lagoon contents as a result of rising gas bubbles and minimize odors. Lagoons are typically constructed by excavating a pit and building berms around the perimeter. The berms are constructed with an extra 5 percent in height to allow for settling. The sides of the lagoon should be sloped with a 2:1 or 3:1 (horizontal:vertical) ratio. Lagoons can be designed as single-stage or multiple-stage (usually two stages). Two-stage lagoons require greater total volume but produce a higher quality lagoon effluent.

Lagoon covers can be used to control odor and collect biogas produced from the natural decomposition of manure. Covers are usually made of a synthetic material, and are designed to float on the surface of the lagoon. Often, because of the large size of the lagoon, the cover is constructed in multiple modules. Each module has flotation devices at the corners to help support the cover, and is tied down at the edge of the pond or lagoon. Covers typically have drains constructed in them to allow rainwater to drain through to the lagoon.

Lagoons are sometimes used in combination with a solids separator, typically for dairy waste. Solids separators help control the buildup of nondegradable material such as straw or other bedding materials. These materials can form a crust on the surface of the lagoon, which decreases its activity.

Application and Performance: Anaerobic lagoons provide effective biological treatment of animal wastes. Anaerobic lagoons can handle high pollutant loads while minimizing manure odors. Nondegradable solids settle to the bottom as sludge, which is periodically removed. The liquid is applied to cropland as fertilizer or irrigation water or is transported off site. Properly managed lagoons will have a musty odor. Anaerobic processes decompose faster than aerobic processes, providing effective treatment of wastes with high BOD, such as animal waste. Anaerobic lagoons are larger than storage ponds because additional volume is needed to provide biological treatment; however, since a constant oxygen concentration is not required, anaerobic lagoons are generally smaller than aerobic lagoons.

Lagoons reduce the concentrations of both N and P in the liquid effluent. Phosphorus settles to the bottom of the lagoon and is removed with the lagoon sludge. Approximately 60 percent of the influent N is lost through volatilization to ammonia (Fulhage, Van Horn). Microbial activity converts the organic N to ammonia N. Ammonia N can be further reduced to elemental nitrogen (N_2) and released into the atmosphere. Lagoon effluent can be used for land application or flushing of animal barns, or can be transported off site. The sludge can also be applied to land provided the soil is not saturated with nutrients. Information on the reduction of BOD, pathogens, and metals in lagoons is not available. Reductions in chemical oxygen demand, total solids, volatile solids, total N, P, and potassium are presented in Table 8-10.

Table 8-10. Anaerobic Unit Process Performance

Anaerobic Treatment	**HRT**	**COD**	**TS**	**VS**	**TN**	**P**	**K**
	days	Percent Reduction					
Pull plug pits	4-30	—	0-30	0-30	0-20	0-20	0-15
Underfloor pit storage	30-180	—	30-40	20-30	5-20	5-15	5-15
Open top tank	30-180	—	—	—	25-30	10-20	10-20
Open pond	30-180	—	—	—	70-80	50-65	40-50
Heated digester effluent prior to storage	12-20	35-70	25-50	40-70	0	0	0
Covered first cell of two cell lagoon	30-90	70-90	75-95	80-90	25-35	50-80	30-50
One-cell lagoon	>365	70-90	75-95	75-85	60-80	50-70	30-50
Two-cell lagoon	210+	90-95	80-95	90-98	50-80	85-90	30-50
HRT=hydraulic retention time; COD=chemical oxygen demand; TS=total solids; VS=volatile solids; TN=total nitrogen; P=phosphorus; K= potassium; — =data not available.							

Source: Moser and Martin, 1999

Advantages and Limitations: Anaerobic lagoons offer several advantages over other methods of storage and treatment. Anaerobic lagoons can handle high pollutant loads and provide a large volume for long-term storage. They stabilize manure wastes and reduce N content through biological degradation. Lagoons allow manure to be handled as a liquid, which reduces labor costs. If lagoons are located at a lower elevation than the animal barns, gravity can be used to transport the waste to the lagoon, which further reduces labor. Mild climates are most suitable for lagoons; cold weather reduces the biological activity of the microorganisms that degrade the wastes. Lagoons can experience spring and fall turnover, in which the more odorous bottom material rises to the surface. Foul odors can also result if biological activity is reduced or if there is a sudden change in temperature or pollutant loading rate.

Operational Factors: To avoid ground water and soil contamination, several factors must be considered. The lagoon should be located on soils with low to moderate permeability or on soils that can form a seal through sedimentation and biological action (NRCS). Impervious barriers or liners are used to reduce seepage through the lagoon bottom and sides and are described in the following practice.

Lagoon inlets should be designed from materials that resist erosion, plugging, and freezing. Vegetation around the pond should be maintained to help stabilize embankments.

Lagoons must be properly maintained for effective treatment. The minimum treatment volume of the lagoon must be maintained. Lagoons work best when the influent flow is a steady, gradual flow rather than a large slug flow. The pH of the lagoon should be monitored. The optimum pH for lagoon treatment is about 6.5, which maximizes the activity level of the bacteria. Lime can be added to the lagoon to increase pH to this level. Also, since the rate of volatile solids decomposition is a function of temperature, the acceptable volatile solids loading rate varies with climate. The loading rate should be monitored to ensure that it is appropriate to the region in which the lagoon is located.

Demonstration Status: Anaerobic lagoons without covers are used at 20.9 percent of all grower-finisher swine operations. Of these, swine operations with 10,000 or more head use uncovered lagoons most frequently (81.8 percent) (USDA APHIS, 1996). Lagoons are used on egg-laying farms in warmer climates. Beef facilities typically use storage ponds rather than lagoons. NAHMS estimates that 1.1 percent of dairies with more than 200 head use anaerobic lagoons with a cover and 46.7 percent use anaerobic lagoons without a cover (USDA APHIS, 1996b). The use of lined lagoons is dependent on site-specific conditions.

Practice: Lagoon Liners

Description: Lagoon liners are impervious barriers used to reduce seepage through the lagoon bottom and sides.

Application and Performance: Soil that is at least 10 percent clay can be compacted with a sheepsfoot roller to create a suitable impervious barrier. If the soil is not at least 10 percent clay, a liner or soil amendment should be used. There are also site conditions that may require seepage

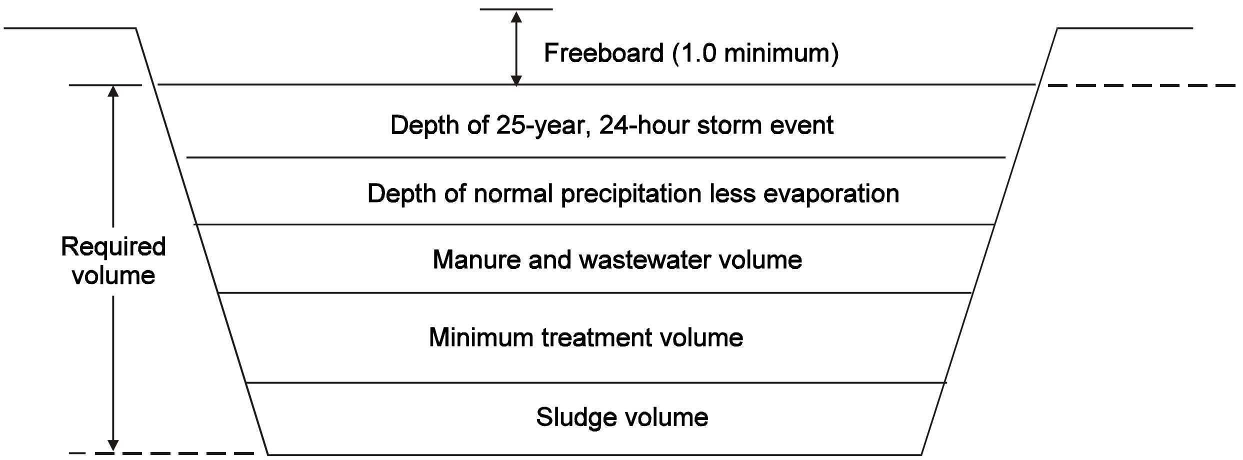

Figure 8-4. Cross Section of Anaerobic Lagoons
(Source: USDA NRCS, 1998)

reduction beyond what is provided by compacting the natural soil. These conditions may include a shallow underlying aquifer, an underlying aquifer that is ecologically important or used as a domestic water source, or highly permeable underlying bedrock or soil. There are three options available to provide additional seepage reduction. First, the soil can be mixed with bentonite or a soil dispersant and then compacted. Clay can be imported from another area and compacted along the bottom and side walls. Last, concrete or synthetic materials such as geomembranes or geosynthetic clay liners can be used.

Advantages and Limitations: Concrete and synthetic liners are usually the most expensive.

Operational Factors: The method chosen to line the lagoon depends on the type of soil, site geography and location, available materials, and economics.

Demonstration Status: The use of lined lagoons depends on site-specific conditions.

Practice: Storage Ponds

Description: Waste storage ponds are earthen basins used to store wastes temporarily, including runoff, solids (e.g. manure), and wastewater. The total volume of the pond consists of the following (see Figure 8-5):

1. Sludge Volume—Volume of accumulated sludge between cleanouts. A fraction of the manure solids settles to the bottom of the pond and accumulates as sludge. The amount of sludge accumulation depends on the type and amount of animal waste.

2. Manure and Wastewater Volume—The volume of manure and wastewater from feedlot operational facilities transferred to the pond during the storage period. Ponds are typically designed to store from 90 to 270 days of manure and wastewater. The percentage of solids in the influent will depend on animal type and the waste management system.

3. Runoff—The runoff from the sites (usually the drylot area at animal feeding operations).

4. Net Precipitation—Precipitation minus the evaporation for the storage period.

5. Design Storm—Typically a 25-year, 24-hour storm event.

6. Freeboard—A minimum of 1 foot of freeboard. Freeboard is the extra depth added to the pond as a safety factor.

Ponds are typically rectangular in shape and are constructed by excavating a pit and building berms around the perimeter. The berms are constructed with an extra 5 percent in height to allow for settling. The sides of the pond are typically sloped with a 1.5:1 or 3:1 (horizontal:vertical) ratio.

Ponds are typically used in combination with a solids separator. Solids separators help control buildup of material such as straw or other bedding materials on the surface of the pond.

Pond covers can be used to control odor and collect biogas produced from the natural degradation of manure. Covers are usually made of a synthetic material, and are designed to float on the surface of the impoundment. Often, because of the large size of the pond, the cover is constructed in multiple modules. Each module has flotation devices at the corners to help support the cover, and is tied down at the edge of the pond. Covers typically have drains constructed in them to allow rainwater to drain through to the pond.

Application and Performance: Waste storage ponds are frequently used at animal feeding operations to contain wastewater and runoff from contaminated areas. Manure, process water, and runoff are routed to these storage ponds, where the mixture is held until it can be used for

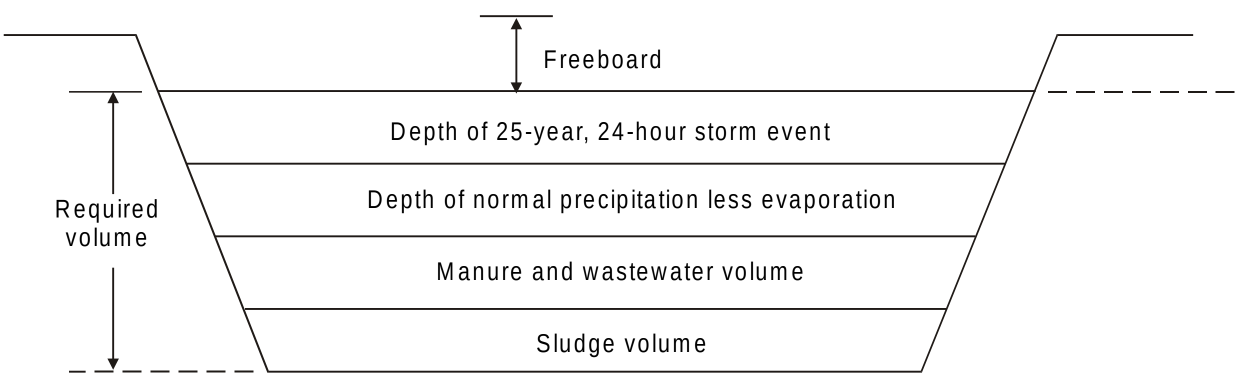

Figure 8-5. Cross Section of Waste Storage Pond (Source: USDA 1996)

irrigation or transported off site. Solids settle to the bottom as sludge, which is periodically removed. The liquid is applied to cropland as fertilizer or irrigation water, or is transported off site.

Storage ponds hold wastewater and manure and are not intended to actively treat the waste. Because they do not require additional volume for treatment, storage ponds are smaller in size than treatment lagoons.

Ponds reduce the concentrations of both N and P in the liquid effluent. Phosphorus settles to the bottom of the pond and is removed with the sludge. Influent N is reduced through volatilization to ammonia. Pond effluent can be used for land application or flushing animal barns, or it can be transported off site. The sludge can also be applied to the land provided the soil is not saturated with P.

Advantages and Limitations: Storage ponds provide a large volume for long-term waste storage and allow manure to be handled as a liquid. If ponds are located at a lower elevation than the animal barns, gravity can be used to transport the waste to the pond, which minimizes labor. Although ponds are an effective means of storing waste, no treatment is provided. Because ponds are open to the air, odor can be a problem.

Operational Factors: To avoid ground water and soil contamination, several factors must be taken into consideration. Impervious barriers or liners are used to reduce seepage through the pond bottom and sides. Soil that is at least 10 percent clay can be compacted with a sheepsfoot roller to create a suitable impervious barrier. If the soil is not at least 10 percent clay, a liner or soil amendment should be used. There are also site conditions that may require seepage reduction beyond what is provided by compacting the natural soil. Conditions may include a shallow underlying aquifer, an underlying aquifer that is ecologically important or used as a domestic water source, or highly permeable underlying bedrock or soil. There are three options available to provide additional seepage reduction. First, the soil can be mixed with bentonite or a soil dispersant and then compacted. Clay can be imported from another area and compacted along the bottom and side walls. Last, concrete or synthetic materials such as geomembranes or geosynthetic clay liners can be used. Concrete and synthetic liners are usually the most expensive. The method chosen to line the pond depends on the type of soil, site geography and location, available materials, and economics.

Pond inlets should be designed from materials that resist erosion, plugging, and freezing. Vegetation around the pond should be maintained to help stabilize embankments.

Demonstration Status: Ponds are a common method of waste storage for swine, beef, and dairy facilities and are used on poultry farms in warmer climates. Beef feedlots tend to use storage ponds for collection of runoff from the drylots. EPA estimates that 50 percent of the medium-size (300-1000 head) beef feedlots in all regions and 100 percent of the large-size (>1,000 head) beef feedlots in all regions have a storage pond for runoff. NAHMS estimates 27.8 percent of dairies use earthen storage basins (USDA APHIS, 1999). The use of lined ponds depends on site-specific conditions.

Practice: Pit Storage

Description: Manure pits are a common method for storing animal wastes. They can be located inside the building underneath slats or solid floors, or outside and separated from the building. Typical storage periods range from 5 to 12 months, after which manure is removed from the pit and transferred to a treatment system or applied to land. There are several design options for pit storage. For example, shallow pits under slats provide temporary storage and require more frequent manure removal to longer-term storage or for land application. Pit recharge systems, which are common in the Midwest, involve regularly draining the pit contents to a lagoon and recharging the pit with fresh or recycled water. The regular dissolution of solids keeps the pits free of excessive buildup while providing temporary storage for manure. Pit recharge systems typically have level floors with an average depth of 12 inches of recharge water, 12 inches allowed for waste accumulation, and 12 inches of air space between the pit surface and the slatted floor.

Application and Performance: Because agitating and pumping equipment does not handle solid or fibrous materials well, manure with greater than 15 percent solids will require dilution. Chopper-type agitators may be needed to break up bedding or other fibrous materials that might be present in the pit.

Advantages and Limitations: Below-floor storage systems provide ease of collection and minimize volume while maximizing fertilizer value, but they may cause a buildup of odors and gases and can be difficult to agitate and pump out. Remote storage avoids odor and gas buildup in animal housing areas and provide options for methane production and solids separation, but entails additional costs for transfer from the housing facilities to storage.

Operational Factors: Pits must have access for pumping equipment, and outside pits must be covered or fenced to prevent accidental entry into the pit. They should be designed to withstand anticipated hydrostatic, earth, and live loads as well as uplifting in high-water-table areas. Before the pit is filled with manure, water is typically added to prevent solids from sticking to the pit floor. Depths range from 3 to 4 inches under slatted floors and 6 to 12 inches if manure is scraped and hauled to the pit. Sand should not be used as a bedding material because it is incompatible with pumping systems. The pits should always be free of nails, lumber, or other foreign material that can damage equipment.

Demonstration Status: Pit holding is mostly done at swine operations. *Swine '95* (USDA-APHIS, 1996) reports that pit holding accounts for 25.5, 33.7, and 23.2 percent of farrowing, nursery, and grower-finisher operations, respectively.

Below-floor slurry or deep pit storage is reported in *Dairy '96* (USDA APHIS, 1996b) at 7.9 percent of all dairy operations. Based on EPA site visits, about 33 percent of veal operations are believed to utilize pit storage systems. Beef feedlots do not typically utilize pit storage.

Practice*: *Belowground or Aboveground Storage Tanks

Description: Belowground and aboveground storage tanks are used as an alternative to under-building pit storage and earthen basins. Both aboveground and belowground tanks are commonly constructed of concrete stave, reinforced monolithic concrete, lap or butt joint coated steel, or spiral wound coated steel with concrete floors. Current assembly practices for aboveground storage facilities are primarily circular silo types and round concrete designs, but the structures may also be rectangular. Belowground storage can be located totally or partially below grade. All storage tanks must be engineered to withstand operational constraints, including internal and external hydrostatic pressure, flotation and drainage, live loads from equipment, and loads from covers and supports. Belowground tanks should be surrounded by fences or guardrails to prevent people, livestock, or equipment from accidently entering the tank.

When located directly adjacent to the animal housing facility, belowground tanks are easily filled by scraping directly into the tank. In those situations where the storage tank is not adjacent to the animal housing facility, a collection pit or sump is necessary for loading. In these systems a large piston or pneumatic manure pump forces waste through a large-diameter underground pipe. Aboveground tanks at a lower grade than the livestock housing facility can often be gravity-fed through a similar underground pipe. The tank can be loaded from the top or bottom. Bottom loading in aboveground tanks is most appropriate for manure that forms a surface crust, such as cattle manure. The inlet pipe is usually located 1 to 3 feet above the bottom of the tank to prevent blockages from solids. An advantage to bottom loading is that it pushes solids away from the inlet pipe and distributes them more evenly. Top loading is suitable and most common for manures that do not crust (i.e., liquid swine manure); however, top loading in an aboveground system requires that manure be pumped against gravity. Figure 8-6 shows a typical aboveground storage tank.

Application and Performance: Aboveground or belowground tanks are suitable for operations handling slurry (semisolid) or liquid manure. This generally excludes open-lot waste which is inconsistent in composition and has a higher percentage of solids. Furthermore, because of the high cost of storage volume, prefabricated storage tanks are generally used to contain only waste, but not runoff, from the livestock facility.

Belowground and aboveground storage tanks are appropriate and preferred alternatives in situations where the production site has karst terrain, space constraints, or aesthetics issues associated with earthen basins. Storing manure in prefabricated or formed storage tanks is especially advantageous on sites with porous soils or fragmented bedrock. Such locations may be unfit for earthen basins and lagoons out of concern that seepage and ground water contamination may occur. Construction of formed storage tanks often includes installation of a liner beneath the concrete to prevent seepage. Aboveground formed storage facilities allow visual monitoring for leaking. Aboveground tanks may exhibit unsightly leaks at seams, bolt holes, or joints, but these are usually quickly sealed with manure. In these storage systems the joint between the foundation and sidewall is the greatest concern. Leaching and ground water contamination can occur if the tank is not sealed properly.

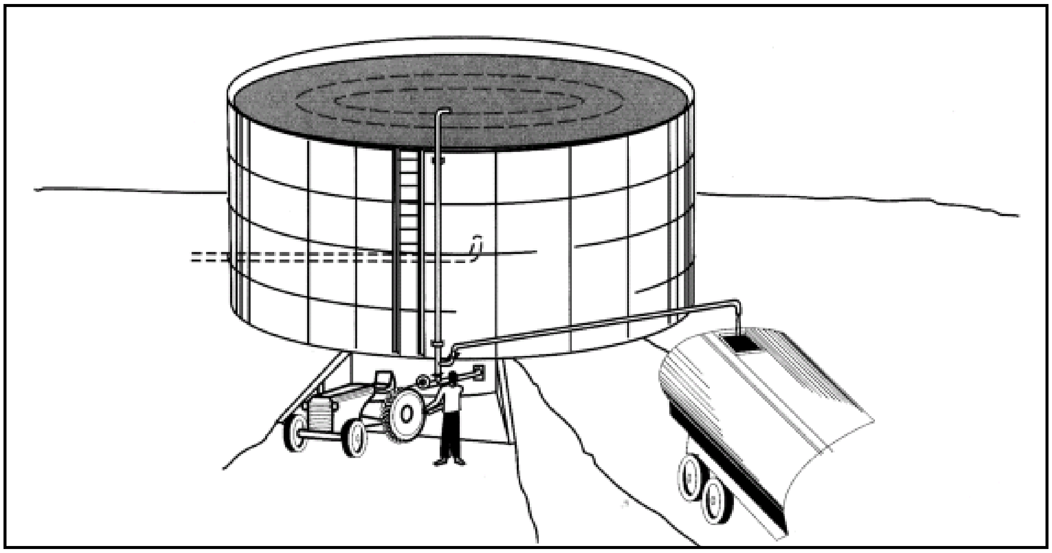

Figure 8-6. Aboveground Waste Storage Tank (from USDA NRCS, 1996).

Proper operational practices to maintain adequate storage tank capacity between land applications are critical. The holding volume of a storage tank consists of five fractions: residual volume, manure/waste storage volume (bedding, wasted feed, water added for manure handling), wash water volume, net rainfall and evaporation change, and freeboard capacity.

In general, large amounts of water are not added during the handling of manure that is stored in an aboveground or belowground storage tank. Installation costs usually dictate that capacity be limited to manure storage requirements. Thus, water conservation is often practiced by facilities that use aboveground or belowground storage tanks. For these facilities, recycling of wastewater is not an option because the manure is generally in slurry form with more than 4 percent solids.

Aboveground and belowground storage tanks are simply storage facilities, and they do not facilitate treatment of the manure. Thus, there is little to no effect on the reduction of nutrients, pathogens, solids, heavy metals, growth hormones, or antibiotics. Nitrogen in liquid manure is predominately in the inorganic form. This allows for some ammonia volatilization into the atmosphere and a reduction in the total amount of N.

Advantages and Limitations: When these systems are used, manure agitation is necessary before the contents of the storage structure are pumped into a tanker wagon for land application. Agitation ensures uniform consistency of manure and prevents the buildup of solids, thus maintaining the storage capacity of the tank. Agitation results in a more even distribution of nutrients in the manure prior to land application. It can be accomplished with high-horsepower, propeller-type agitators or by recirculating with a high-capacity pump. The length of time the manure needs to be agitated depends on the size of the storage tank, the volume of manure it contains, the percent of solids in the manure, and the type of agitator. Manure with up to 15 percent solids can be agitated and pumped. Because of the potential for agitation and pumping problems, only small amounts of chopped bedding are recommended for use in systems using storage tanks. Some types of agitators have choppers to reduce the particle size of bedding and solids. Dilution with additional water may be necessary to reduce agitation problems. One design variation places the pump in a sump outside the tank, using it for both agitation and pumpouts.

Manure in a storage tank undergoes some anaerobic decomposition, releasing odorous and potentially toxic gases, such as ammonia and hydrogen sulfide. Methane is also produced. Covers can be installed to interrupt the flow of gases up from the liquid surface into the atmosphere. Types of covers range from polyethylene, concrete, or geotextile to biocovers such as chopped straw. Various covers have been shown to reduce odors by up to 90 percent. Furthermore, particular types of covers can be used as methane reservoirs to collect and contain gases from the digestion process for disposal by flaring or converting to electrical power. Moreover, certain covers can prevent rainwater dilution and accumulation of airborne silts and debris. Finally, it is generally accepted that some types of covers control N volatilization into the atmosphere and maintain the N content of the manure.

The installation costs associated with prefabricated storage tanks are high when compared with other liquid manure-handling systems. Glass-lined steel tanks are typically associated with the highest cost. The useful life of the tanks depends on the specific manufacturer and the operator's maintenance practices. Once they have been installed, aboveground and belowground storage tanks have a low labor requirement, especially when designed as a gravity feed system (Purdue Research Foundation, 1994).

Operational Factors: Specific storage structure designs will vary by state because of climate and regulatory requirements. Pumping manure during freezing conditions can be a problem unless all pipes are installed below the freezing level in the ground. Design considerations in these systems include check valves if bottom loading is used, pumping power with respect to the maximum head, and pipe friction from the pump to the storage.

Demonstration Status: Belowground and aboveground storage tanks are in use nationwide in swine, poultry, and dairy operations. They are appropriate for use in all slurry-based manure handling systems, including those with shallow-pit flush systems, belt or scrape designs, or open-gutter flush systems.

Practice: Solid Poultry Manure Storage in Dedicated Structures

Description: In the broiler and turkey segments of the poultry industry, specially designed pole-type structures are typically used for the temporary storage of solid poultry manure; however, horizontal (bunker) silo-type structures are also used. Manure produced in "high-rise" houses for caged laying hens does not require a separate storage facility if handled as a solid.

A typical pole-type storage structure is 18 to 20 feet high and 40 feet wide. The length depends on the storage capacity desired but is usually a minimum of 40 feet. The structure will have a floor of either compacted soil or concrete, the latter being more desirable but much more expensive. The floor elevation should be at a height above grade that is adequate to prevent any surface runoff from entering the structure. A properly sited structure will be oriented parallel to

the direction of the prevailing wind. Equipment access will be through the lee side, which will have no wall. The other three sides of the structure will have walls extending from the floor to a height of 6 to 8 feet. Experience has shown that a higher wall on the windward side of the building excludes precipitation more effectively. Walls may be constructed using pressure-treated lumber or reinforced concrete. Wooden trusses covered with steel sheets are most commonly used for roofing, although plywood roof decking covered with composition shingles is also an option. Manure is usually stacked to a height of 5 to 8 feet. Figure 8-7 shows three types of permanently covered solid manure storage structures.
Horizontal silo-type storage structures are also used for the temporary storage of solid poultry manure. These storage structures can be constructed using either post-and-plank or reinforced concrete walls on three sides. Equipment access will be through the lee side which will have no wall. Concrete walls can be poured in place or made with prefabricated sections that are manufactured for horizontal silo construction. Wall height can be from as low as 3 to 4 feet to as high as 8 to 10 feet if prefabricated concrete sections are used. Usually, there is a concrete floor.

Again, floor elevation should be sufficiently above grade to prevent surface runoff from entering the structure. With this type of storage structure, 6-mil or heavier plastic is typically used to cover the stored manure, but tarpaulins have also been used. As with horizontal silos, old tires are commonly used to secure the cover, although ropes or cables can also be used. Manure is usually stacked to a height of 5 to 8 feet.

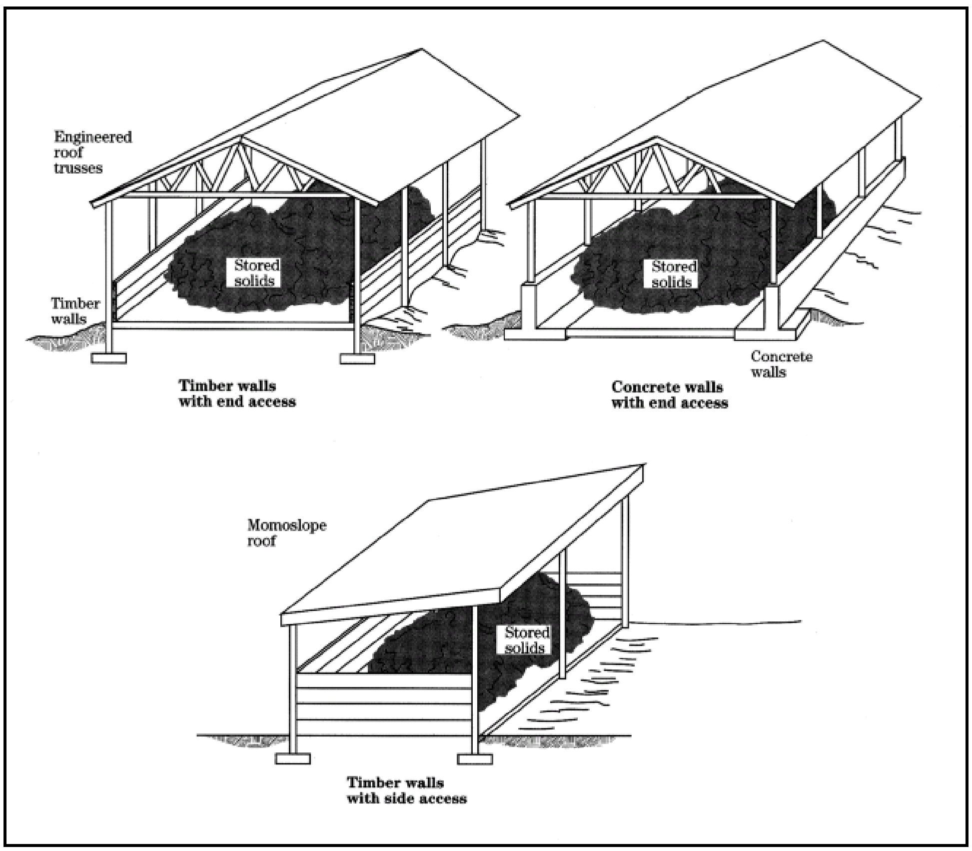

Figure 8-7. Roofed Solid Manure Storage (from USDA NRCS, 1996).

In the broiler industry, total cleanouts of production facilities occur only after a minimum of 1 year of production. A total cleanout frequency of 2 to 3 years is not uncommon. Total cleanouts may be more frequent for brood chambers, but the frequency depends on the cost and availability of bedding material, the incidence of disease, the concentration of gaseous ammonia within the production facility, and the policy of the integrator. Caked manure, also known as crust, is removed after every flock, typically a period of 49 days for 4- to 5-pound broilers. Usually, storage structures are designed only for the storage of this caked manure because most broiler growers view the cost of a structure large enough to store manure and litter from a total cleanout as prohibitively high. Because caked manure production varies with the type of bedding material, type of watering system, and climatic conditions, storage requirements may vary from farm to farm. Also, cake production increases with bedding age. Local experience is usually relied upon to estimate storage requirements.

In the turkey industry, total cleanouts of brooder facilities occur after every flock to control disease, but grow-out facilities typically are totally cleaned out only once a year. Again, most turkey growers consider the cost of storage of the manure and bedding from a total cleanout of grow- out facilities to be prohibitively high. Therefore, structures are typically sized only for the storage of manure and bedding from brooder houses.

Application and Performance: The temporary storage of solid poultry manure in a dedicated structure is applicable to all poultry operations at which birds are maintained on a bedding material. Thus, this practice is applicable to all broiler and turkey operations and the small fraction of egg-producing operations that do not house birds in cages. The combination of manure and bedding generated in these operations has a moisture content of less than 50 percent, usually 25 to 35 percent, and is handled as a solid. This practice is not necessary for caged laying hens in high-rise housing because the production facility has a manure storage capacity of 1 or more years.

When sized and managed correctly, storage of solid poultry manure in a dedicated structure will allow for the most efficient use of plant nutrients in the manure for crop production. This eliminates the potential for contamination of surface and ground waters resulting from open stacking of manure or spreading during the fall, winter, and early spring and after crop establishment, when there is no potential for crop uptake. When the stored manure is effectively protected from precipitation, odor and fly problems are minimal. Odor can be a problem, however, when the manure is removed from the storage structure and spread on cropland.

The storage of caked broiler litter and turkey brooder house manure and bedding reduces the potential impact of these materials on surface and ground water quality; however, a substantial fraction of the manure and bedding produced by these segments of the poultry industry is not stored because the associated cost is viewed as prohibitive. The material resulting from the total cleanout of broiler houses and turkey grow-out facilities is often stored temporarily in open piles or spread at inappropriate times of the year. Thus, storage, as currently practiced, probably is not as effective in reducing water quality impacts as is presently thought.

Advantages and Limitations: A correctly sized and managed storage structure allows application to cropland when nutrients will be most efficiently used, thus minimizing negative impacts on surface and ground waters as noted above. If application to cropland is not a disposal alternative, storage can facilitate off-site disposal other than application to cropland.

The principal disadvantage of storing solid poultry manure in a dedicated structure is the cost of the structure and additional material handling costs. Currently, sources of government assistance are available (e.g., cost-share funds available from local soil and water conservation districts) to partially offset construction costs and encourage the adoption of this practice.

Operational Factors: Spontaneous combustion in stored poultry manure has been a problem and has led to the recommendation that stacking height be limited to 5 to 8 feet to avoid excessive compaction. Fires in solid poultry manure storage structures, like silo fires, are extremely difficult to extinguish and often lead to the total loss of the structure.

Demonstration Status: Permanent covered structures for storage of solid manure are used extensively in the broiler and turkey segments of the poultry industry. In a 1996 survey of broiler growers on the Delmarva Peninsula, 232 of 562 respondents indicated that they used a permanent storage structure (Michel et al., 1996).

Practice: Concrete Pads

Description: Concrete pads are used as semi-impermeable surfaces upon which to place waste. The waste pile is often open to the environment, but it can be covered with a roof or plastic sheeting to minimize exposure to the elements. Pads are often sloped to a central location to allow for drainage of rainwater and runoff.

The design for concrete pads varies according to the type of waste it receives (wet or dry) Waste that includes settled solids from a settling basin or solids separator has a high moisture content. In this case, the concrete pad typically has at least two bucking walls to contain the waste and to facilitate the loading and unloading of waste onto the pile. The design height of the waste pile does not exceed about 4 feet, because of the semi-liquid state of the waste. For operations with drier waste, the concrete pad typically does not have bucking walls, and the maximum height of the manure pile is 15 feet, because the manure is drier and can be stacked more easily.

Figure 8-8 illustrates the design of a concrete pad (MWPS,1993; USDA NRCS, 1996). Concrete pads are between 4 and 6 inches thick and are made of reinforced concrete to support the weight of a loading truck. The concrete pad is underlain by 4 inches of sand and 6 inches of gravel. The pad is sloped to divert storm water runoff from the pile to the on-site waste management facility, such as a lagoon or a pond. Bucking walls, made of reinforced concrete, are 8 inches thick and 3 to 4 feet tall.

Application and Performance: Concrete pads are used at animal feeding operations to provide a surface on which to store solid and semi-solid wastes that would otherwise be stockpiled directly on the feedlot surface. Manure scraped from dry lots and housing facilities and solids separated from the waste stream in a solids separator can be stored on a concrete pad.

The pads provide a centralized location for the operation to accumulate excess manure for later use on site (e.g. bedding, land application) or transportation off site. A centralized location for stockpiling the waste also allows the operation to better control storm water runoff (and associated pollutants). Rainwater that comes into contact with the waste is collected on the

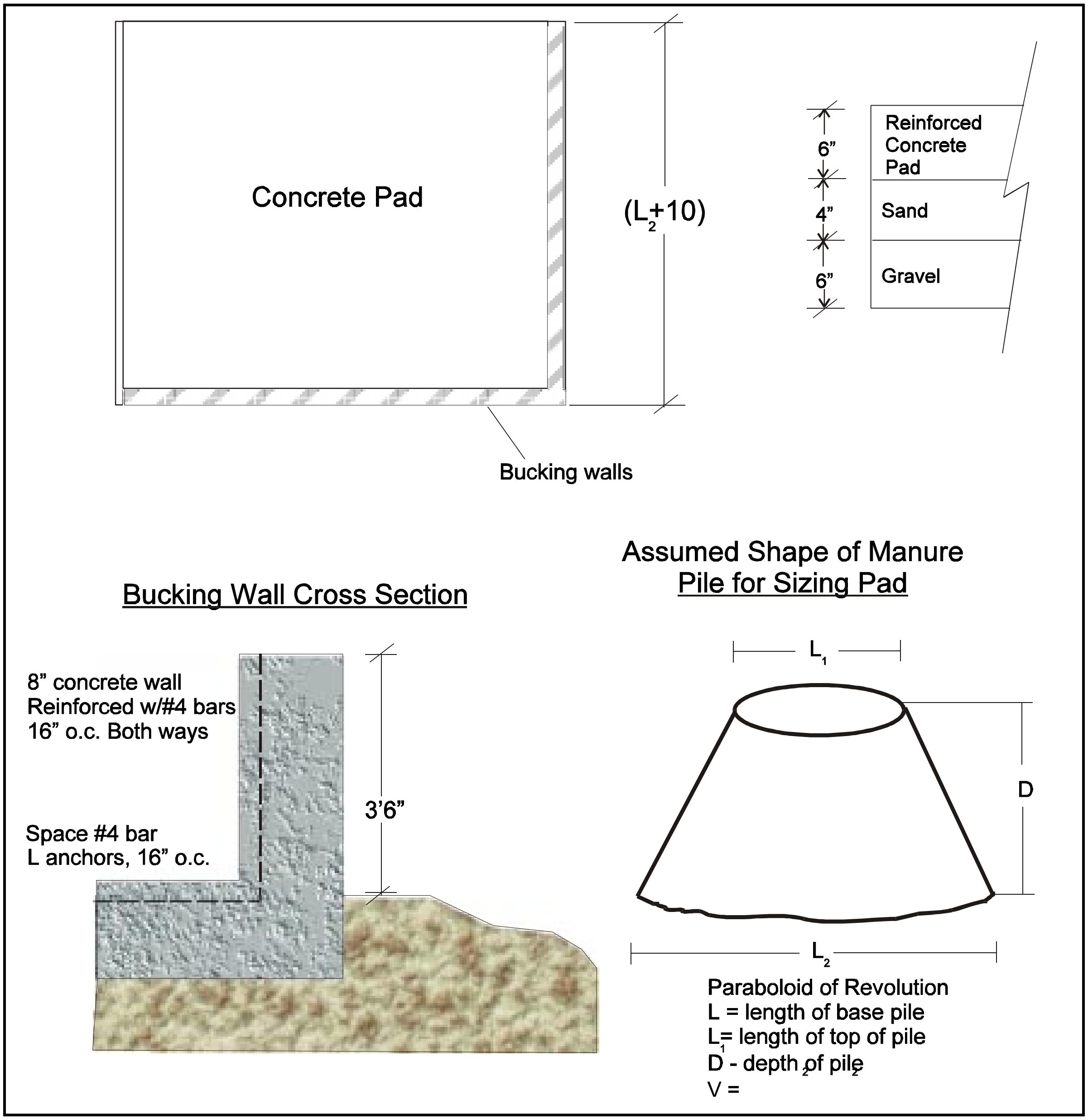

Figure 8-8 Concrete Pad Design

concrete pad and is directed to a pond or lagoon and is thereby prevented from being released on the feedlot. The pad also provides an impermeable base that minimizes or prohibits seepage of rainfall, leaching pollutants or nutrients from the waste and infiltrating into the soil beneath it. The waste is not treated once it is on the concrete pad; the pad serves as a pollution prevention measure. However, with regular handling of the waste, the N loads in the waste will be released into the atmosphere through volatilization, and both N and P may be contained in runoff from the pile after storm events. Pathogen content, metals, growth hormones, and antibiotics loads are not expected to decrease significantly on the concrete pad unless the pile ages considerably.

Advantages and Limitations: An advantage to using a concrete pad for storage is to control runoff and prevent waste from contaminating the surrounding environment. When rainwater or precipitation comes into contact with the pile, the water may percolate through the pile, carrying pollutants along the way. The water may exit the pile as runoff and carry pollutants to surface waters or seep into the ground. The concrete pad and bucking walls minimize this potential seepage into and runoff onto the ground around the pile.

Depending on the duration of storage required, however, these pads can take up a very large area. An operation may not have sufficient area to install a concrete pad large enough to store waste in one place. It can also be expensive to construct a concrete pad large enough to accommodate the amount of waste that would accumulate over an appropriate storage time.

Waste stored on a concrete pad will still need to be further managed, either by land application or by transportation off site. There may be some odors from the pile on a concrete pad, but no more than would be expected from any manure stored in a pile.

Operational Factors: Operations that frequently transport their waste will require less storage volume than operations that have less frequent hauling schedules. Operations requiring less storage capacity will require a smaller pad area, resulting in lower capital costs.

Demonstration Status: Concrete pads are used relatively infrequently in the livestock industry. They are more commonly used in dairies than in poultry, beef or swine operations, because dairy waste is semi solid and bucking walls are needed to contain the waste effectively, given the higher moisture content. Waste from swine operations is generally too wet to stack on a pad, and beef and poultry waste is usually piled directly on the feedlot.

8.2.3 Waste Treatment Technologies and Practices

8.2.3.1 Treatment of Animal Wastes and Wastewater

Some treatment systems store waste as well as change the chemical or physical characteristics of the waste. Anaerobic lagoons are the most common form of treatment for animal feeding operations. Other technologies use oxidation to break down organic matter. These include aerated lagoons and oxidation ditches for liquids and composting for solids.

Practice: Anaerobic Digesters for Methane Production and Recovery

Description: An anaerobic digester is a vessel that is sized both to receive a daily volume of organic waste and to grow and maintain a steady-state population of methane bacteria to degrade that waste. Methane bacteria are slow growing, environmentally sensitive bacteria that grow without oxygen and require a pH greater than 6.5 to convert organic acids into biogas over time. Anaerobic digestion can be simplified and grouped into two steps. The first step is easy to recognize because the decomposition products are volatile organic acids that have disagreeable odors. During the second step, methane bacteria consume the products of the first step and produce biogas—a mixture of carbon dioxide and methane—a usable fuel by-product. A properly operating digester will produce a gas with minimal odor because methane bacteria from the second step reach a population large enough to rapidly consume the products of the first step. There are three basic temperature regimes for anaerobic digestion: psychrophilic, mesophilic, and thermophilic. Psychrophilic, or low-temperature, digestion is the natural decomposition path for manures at temperatures found in lagoons. These temperatures vary from about 38 to 85 °F (3 to 29 °C). The hydraulic retention time (HRT) required for stable operation varies from 90 days at low temperatures to 30 days at higher temperatures. Methane production will vary seasonally with the variation in lagoon temperature.

Maintaining a constant elevated temperature enhances methane production. Mesophilic digestion cultivates bacteria that have peak activity between 90 and 105 °F (32 to 40 °C). Mesophilic digesters operate at a retention period of 12 to 20 days. Thermophilic digesters promote bacteria that grow at between 135 to 155 °F (57 to 68 °C); these digesters operate with a retention time of 6 to 12 days.

Although there are many types of anaerobic digesters, only covered lagoons operating at ambient temperatures, complete-mix digesters, and plug-flow digesters can be considered commercially available, because they are the only ones that have been implemented successfully at 10 or more sites.

A cover can be floated on the surface of a properly sized anaerobic lagoon to recover methane. Ideally, the cover is floated on the primary lagoon of a two-cell lagoon system, with the primary lagoon maintained as a constant volume treatment lagoon and the second cell used to provide storage of treated effluent until the effluent can be properly applied to land. The lagoons are not heated, and the lagoon temperature and biogas production vary with ambient temperatures. Coarse solids, such as hay and silage fibers in cow manure, must be separated in a pretreatment step and kept from the lagoon. If dairy solids are not separated, they will float to the top and form a crust. The crust will thicken, reducing biogas production and eventually filling the lagoon.

A complete-mix digester is a biological treatment unit that anaerobically decomposes animal manures using controlled temperature, constant volume, and mixing. These digesters can accommodate the widest variety of wastes. Complete-mix digesters are usually aboveground, heated, insulated, round tanks; however, the complete-mix design has also been adapted to function in a heated, mixed, covered earthen basin. Mixing can be accomplished with gas recirculation, mechanical propellers, or liquid circulation. In Europe, some mixed digesters are operated at thermophilic temperatures; however, most of these are regional digesters that are built and operated by digester professionals. A complete-mix digester can be designed to maximize biogas production as an energy source or to optimize volatile solids (VS) reduction with less regard for surplus energy. Either process is part of a manure management system, and supplemental effluent storage is required.

Plug-flow digesters are heated, unmixed, rectangular tanks. New waste is pumped into one end of the digester, thereby displacing an equal portion of older material horizontally through the digester and pushing the oldest material out through the opposite end. Lusk (1998) refers to a slurry-loop digester as a separate digester category, but this system, which is built in the shape of a horseshoe, functions by displacement in the same manner as a plug-flow digester.

Biogas formed in a digester bubbles to the surface and may be collected by a fixed rigid top, a flexible inflatable top, or a floating cover, depending on the type of digester. Biogas from a stable digester is saturated and contains 60 to 80 percent methane, with the balance as carbon dioxide and trace amounts of hydrogen sulfide (1,800 to 5,000 ppm H_2S). A collection system directs the virtually odorless biogas to gas handling components. Biogas may be filtered for mercaptan and moisture removal before being pumped or compressed to operating pressure and then metered to equipment for use. Biogas that is pressurized and metered can be used as fuel for heating, adsorption cooling, electrical generation, or cogeneration.

Application and Performance: Properly designed anaerobic lagoons are used to produce biogas from dilute wastes with less than 2 percent total solids (98 percent moisture), including flushed dairy manure, dairy parlor washwater, and flushed hog manure. Complete-mix digesters can be used to decompose animal manures with 3 to 10 percent total solids. Plug-flow digesters are used to digest thick wastes (11 to 13 percent total solids) from ruminant animals, including dairy and beef animals. The plug-flow system operates best with scrape-collected, fresh dairy manure that contains low levels of dirt, gravel, stones, or straw.

Anaerobic digestion is one of the few manure treatment options that reduce the environmental impact of manure and produce a commodity—energy—that can be used or sold continuously. Digesters are used to stabilize manures to produce methane, while at the same time reducing odors.

Approximately 35 percent of the volatile solids from dairy manure and 60 percent of the volatile solids from swine or beef manure can be converted to biogas and removed from the manure liquid.

Table 8-11 summarizes the performance expected from anaerobic digesters. Anaerobic digesters will reduce biological oxygen demand (BOD) and total suspended solids (TSS) by 80 to 90 percent, and virtually eliminates odor. The digester will have minimal effect on the nutrient content of the digested manure passing through plug-flow or complete-mix digesters. Half or

Table 8-11. Anaerobic Unit Process Performance

Digester type	Percentage Reduction						
	HRT (days)	**COD**	**TS**	**VS**	**TN**	**P**	**K**
Complete-mix	12-20	35-70	25-50	40-70	0	0	0
Plug-flow	18-22	35-70	20-45	25-40	0	0	0
Covered first cell of two-cell lagoon	30-90	70-90	75-95	80-90	25-35	50-80	30-50

Source: Moser and Martin, 1999.

more of the organic N (Org-N) is converted into ammonia (NH_3-N). In lagoons, the concentrations of nutrients are reduced through settling, volatilization, and precipitation. With a cover in place, ammonia volatilization losses are eliminated, leaving only settling and precipitation as pathways for N loss. A small amount of the P and K will settle as sludge in most digesters.

The reductions of P, K, or other nonvolatile elements reported in the literature for covered lagoons are not really reductions at all. The material settles and accumulates in the lagoon, awaiting later management. Vanderholm (1975) reported P losses of up to 58 percent. Bortone et al. (1992) suggest that P accumulation in anaerobic lagoons may be due to high pH driving phosphate precipitation as $Ca(PO_4)_2$ and $Mg(PO_4)_2$. This is consistent with and supported by P mass losses documented in most lagoon studies. Water-soluble cations, such as sodium, potassium, and ammonium N, tended to be distributed evenly throughout the lagoon. Humenik et al. (1972) found that 92 to 93 percent of the copper and zinc in anaerobic swine lagoon influent was removed and assumed to be settled and accumulated in sludge.

Pathogen reduction is greater than 99 percent in mesophilic and thermophilic digesters with a 20-day HRT. Digesters are also very effective in reducing weed seeds.

Advantages and Limitations: Some advantages of anaerobic digestion include the opportunity to reduce energy bills, produce a stabilized manure, recover a salable digested solid by-product, reduce odor and fly breeding, and produce a protein-rich feed from the digested slurry.

The energy from biogas can be used on site as a fuel or sold to a local utility company. On-site uses include the heating of the digester itself, fuel for boilers or electric generators, hot water production, and refrigeration. The equipment listed in Table 8-12 can use biogas in lieu of low-pressure natural gas or propane.

Table 8-12. Biogas Use Options

Electrical generator	electricity for use or sale, heat recovery optional
Refrigeration compressors	cooling, heat recovery optional
Irrigation pumps	pumping, heat recovery optional
Hot water boiler	for space heat, hot water for process and cleanup
Hot air furnace	for space heat
Direct fire room heater	for space heat
Adsorption chiller	for cold water production, heat recovery optional

Dairy waste digesters partially decompose fibrous solids to a uniform particle size that is easily separated with a mechanical separator. The recovered solids are valuable for reuse as cow bedding or can be sold as a bagged or wholesale soil product.

Limitations include the costs associated with building and operating the digester. Furthermore, nutrient concentrations in the semisolid anaerobic digestion product are not reduced substantially unless they are then stored for several months. Therefore, the amount of land needed for land application of manure is greater than that needed for uncovered lagoons and other treatment practices.

Operational Factors: The successful operation of a properly designed digester is dependent upon two variables: feed rate and temperature. All other operational issues are related to ancillary equipment maintenance. Once a properly designed digester is operating, it will usually continue to function unless management oversight is lacking. Reactor capacity is maintained through periodic removal of settled solids and grit.

A sudden drop in biogas production or pH (from accumulation of organic acids) will indicate digester upset. Factors that decrease the efficiency of microbial processes and might result in digester upset include a change in temperature or feed rations, a change in manure loading rates, or the addition of large quantities of bacterial toxins. A normal ratio of alkalinity to volatile acids during a stable or steady-state anaerobic decomposition is 10:1. The known operating range is 4:1 to 20:1. (Metcalf and Eddy, 1979). An increase in volatile acids resulting in an alkalinity to volatile acid ratio of 5:1 indicates the onset of failure of methane-producing anaerobic digestion (unbalanced decomposition) (Chynoweth, 1998).

The level of hydrogen sulfide in the produced biogas can be controlled through either scrubbing or managed operation of equipment. Scrubbing is necessary for some gas uses but is generally expensive and maintenance intensive.

Demonstration Status: Anaerobic lagoons with covers were used at 1.8 percent of grower/finisher operations in 1995 (USDA APHIS, 1999). Approximately 30 pig lagoons have been covered in the United States for odor control or methane recovery (RCM, 1999). The oldest continuously operating covered swine waste lagoon is at Roy Sharp's Royal Farms in Tulare, California. This system, which was installed in 1981, has been producing electricity with the recovered methane since 1983. Not all covered lagoon projects have beneficial uses for recovered methane; some farms either flare or release the gas.

The oldest complete-mix pig manure digester in the United States was built in 1972. Approximately 10 units are in operation today, 6 of which were built within the last 4 years. Many digesters are not operational, typically because the farm is no longer in the pig business. At least 16 operating plug-flow and slurry-loop digesters are currently operating in the United States (Lusk, 1998; RCM, 2000).

Practice: Single-Cell Lagoon With Biogas Generation

Description: In this practice, a cover is floated on the surface of a properly sized anaerobic lagoon to recover biogas (70 percent methane and 30 percent carbon dioxide). Anaerobic lagoons can produce biogas from any type of animal manure. The most successful arrangement consists of two lagoons connected in series to separate biological treatment for biogas production and storage for land application. A variable-volume, one-cell lagoon designed for both treatment and storage can be covered for biogas recovery; however, a single-cell lagoon cover presents design challenges due to the varying level of the lagoon surface.

In the early 1960s, the floating cover industry expanded beyond covering water reservoirs into floating covers for industrial wastewater lagoons. Covering industrial organic wastewater lagoons began as an odor control technique. Within the discovery that economic quantities of biogas could be recovered, cover systems were refined to collect and direct biogas back to the factory producing the organic waste. Lagoon design was optimized to provide both good BOD/COD reduction and a supply of usable biogas. Today, hundreds of industrial anaerobic lagoons have floating covers that optimize anaerobic digestion, control odor, and recover biogas. The industries that use such covers include pork processors and rendering plants in the United States. Lessons learned in the development of floating covers are incorporated into today's designs for animal waste facilities.

Psychrophilic, or low-temperature, digestion is the natural decomposition path for manures at the temperatures found in lagoons. These temperatures vary from about 38 to 85 °F (3 to 29 °C). The retention time required for stable operation varies from 120 days at low temperatures to 30 days at the higher temperatures. Methane production varies seasonally with lagoon temperature. More methane is produced from warmer lagoons than from colder lagoons.

The Natural Resources Conservation Service (1998) developed NRCS Interim Practice Standard 360, Covered Anaerobic Lagoon, to guide floating cover design, installation, and operation. Many types of materials have been used to cover agricultural lagoons. Floating covers are not limited in dimension. A floating cover allows for some gas storage. Cover materials must have a bulk density near that of water and must be UV-resistant, hydrophobic, tear- and puncture-resistant, and nontoxic to aquatic aerobes and anaerobes.

Several types of material are used to construct floating covers, including high-density polyethylene, XR-5, polypropylene, and hypalon. Material is selected based on material properties (such as UV resistance), price, availability, installation, and service. Installation teams with appropriate equipment travel and install covers.

Biogas formed in a digester bubbles to the surface and is collected and directed by the cover to a gas use. Biogas from a stable covered lagoon is virtually odorless and saturated. It contains 70 to 85 percent methane; the balance is carbon dioxide and trace amounts of hydrogen sulfide (1,000 to 3,000 ppm H_2S). Biogas can be harmful if inhaled directly, corrosive to equipment, and potentially explosive in a confined space when mixed with air. When properly managed, the off-gas is as safe as any other fuel (e.g., propane) used on the farm. Safety concerns are more completely addressed in the *Handbook of Biogas Utilization* (Ross, 1996).

Biogas may be filtered for mercaptan and moisture removal. Biogas is usually pumped or compressed to operating pressure and then metered to the gas use equipment. Biogas can be used as fuel for heating, electrical generation, or cogeneration. Alternatively, it can simply be flared for odor control.

Application and Performance: Covered lagoons are used to recover biogas and control. Covers can be installed to completely cover the lagoon and capture clean rainwater. The uncontaminated rainwater can be safely pumped off, reducing the volume of lagoon liquid to be managed later.

Off-gases collected by an impermeable cover on an anaerobic manure facility are neither explosive nor combustible until mixed with air in proper proportions to support combustion. No reports of any explosions of biogas systems at animal production facilities were found.

Table 8-13 summarizes the performance expected from covered lagoons. Anaerobic digestion in a covered lagoon will reduce BOD and TSS by 80 to 90 percent. Odor is virtually eliminated. The concentrations of nutrients are reduced through settling and precipitation in lagoons. Ammonia volatilization losses are virtually eliminated with a cover in place, leaving only settling and precipitation as pathways for N loss.

During anaerobic digestion, microbial activity converts half or more of the organic N (Org-N) to soluble ammonia (NH_3-N). Cheng (1999) found that 30 percent of the total Kjeldahl N (TKN, which includes ammonia and organic N) entering the covered first cell of a two-cell lagoon was retained in that cell, probably as organic N in slowly degradable organics in the sludge. A similar loss due to settling could be expected in a covered single-cell lagoon. A covered single-cell lagoon will not lose NH_3-N to the atmosphere; however NH_3-N will be volatilized from the uncovered second cell of a two-cell lagoon. Cheng (1999) also reported that approximately 50 percent of the influent TKN was subsequently lost from the uncovered second cell of the system.

Reported reductions of P, K, or other nonvolatile elements through a covered lagoon are not really reductions at all. The material settles and accumulates in the lagoon awaiting later management. This is consistent with and supported by P mass losses documented in most lagoon studies. Humenik et al. (1972) found that 92 to 93 percent of the copper and zinc in anaerobic swine lagoon influent was removed and assumed to be settled and accumulated in sludge.

Table 8-13. Anaerobic Unit Process Performance

		Percentage Reduction					
Digester type	HRT Days	COD	TS	VS	TN	P	K
Covered lagoon	30 – 90	70-90	75-95	80-90	25-35	50-80	30-50

Source: Moser, 1999.

Cheng (1999) found pathogen reduction through a North Carolina covered lagoon to be 2 to 3 orders of magnitude. J. Martin (1999) determined that relationships between temperature and the time required for a one $\log_{10}$ reduction in densities of pathogens were consistently exponential in form. Although there is substantial variation between organisms regarding the time required for a one $\log_{10}$ reduction in density at ambient temperatures, this work suggests that variation in die-off rates among species decreases markedly as temperature increases. For example, the predicted time required for a one $\log_{10}$ reduction in fecal streptococcus density decreases from 63.7 days at 15 °C to 0.2 day at 50 °C. For *S. aureus*, the decrease is from 10.6 days at 15 °C to 0.1 day at 50 °C. Thus, for both storage and treatment at ambient temperature, an extended period of time is predicted for any significant reduction. A single-cell covered lagoon has a longer residence time than the covered first cell of a two-cell lagoon and should therefore have a greater reduction of pathogens. However, during pumpout of a single-cell lagoon, fresh influent can be short-circuited to the pumpout, carrying pathogens with it, whereas the covered first cell of a two-cell lagoon produces a consistent pathogen reduction without short-circuiting because the first cell's pathogen destroying retention time is not affected when the second cell is pumped down.

Advantages and Limitations: The advantages of covered anaerobic lagoons are the reduction of lagoon odor, exclusion of rainfall from the lagoon, recovery of usable energy, reduction of ammonia volatilization, and reduction of methane emissions. There are also significant labor savings involved in handling manure as a liquid and being able to apply lagoon waters to the land through irrigation. Solids are broken down through microbial activity, and organic matter is stabilized when anaerobic digestion is complete, reducing the potential for production of noxious by-products. A bank-anchored cover prevents the growth of weeds where the cover is placed. Finally, treated lagoon water can be recycled for flush water in confinement houses, resulting in cost savings in areas where water is scarce.

Limitations of covered anaerobic lagoons include the cost of installing a cover, which in 1999 varied from \$0.37 to \$1.65 per square foot (Martin, 1999), and the occasional need for cover maintenance such as rip repair, and rainfall pump-off. The lagoons themselves can be large, depending on the size of the hog operation, and can require a significant amount of cover material. Spills and leaks to surface and ground water can occur if the lagoon capacity is exceeded, or if structural damage occurs to berms, seals, or liners. The treatment capacity of most lagoons is diminished by sludge accumulation, and sludge has to be removed and managed.

Operational Factors: Lagoons should be located on soils of low permeability or soils that seal through biological action or sedimentation, and proper liners should be used to avoid contamination of ground water. Proper sizing and management are necessary to effectively operate a covered anaerobic lagoon and maintain biogas production. The minimum covered lagoon capacity should include treatment volume, sludge storage, freeboard, and, if necessary, storage for seasonal rainfall and a 25-year, 24-hour rainfall event.

Temperature is a key factor in planning the treatment capacity of a covered lagoon. The lagoons are not heated, and the lagoon temperature and biogas production vary with ambient temperatures. Warm climates require smaller lagoons and have less variation in seasonal gas production. Colder temperatures will reduce winter methane production. To compensate for reduced temperatures, loading rates are decreased and hydraulic retention time is increased. A larger lagoon requires a larger, more costly cover than a smaller lagoon in a warmer climate.

The floating cover must be designed and operated in such a way as to keep it from billowing in windy conditions. Coarse solids, such as hay and silage fibers in cow manure, must be separated in a pretreatment step and kept from the lagoon. If dairy solids are not separated, they float and form a crust. The crust will thicken, reducing biogas production and eventually filling the lagoon.

Proper lagoon inspection and maintenance are necessary to ensure that lagoon liners and covers are not harmed by agitating and pumping, berms and embankments are stable, and the required freeboard and rainfall storage are provided. Sampling and analysis of the lagoon water are suggested to determine its nutrient content and appropriate land application rates.

Anaerobic lagoons accumulate sludge over time, diminishing treatment capacity. Lagoons must be cleaned out once every 5 to 15 years, and the sludge can be applied to land other than the spray fields receiving the lagoon liquid. Because crop P requirements are less than those for N, it takes more land to apply the sludge from lagoon cleanout than to apply liquid wastewater.

Demonstration Status: Floating-cover technology is well developed and readily available. Covering lagoons for odor control has been demonstrated in all sectors of the animal production industry. The installation of floating covers specifically for methane recovery is a less common, but well-known practice. There are at least 10 covered lagoon systems with biogas collection and combustion in the pig and dairy industries (Lusk, 1998; RCM, 2000).

Practice: Aerobic Treatment of Liquids

Description: Conventional aerobic digestion is a process used frequently at small municipal and industrial wastewater treatment plants for biosolids stabilization. It is a suspended growth process operating at ambient temperature in the stationary or endogenous respiration phase of the microbial growth curve. In the stationary phase, the exogenous supply of energy is inadequate to support any net microbial growth. Endogenous respiration occurs when the exogenous supply of energy also is inadequate to satisfy cell maintenance requirements, and a net decrease in microbial mass occurs. Operating parameters include a relatively long period of aeration, ranging from severa daysl to more than 30 days, depending on the degree of stabilization desired. Given the relatively long period of aeration, activated sludge recycling is not necessary and hydraulic detention and solids retention times are equal in continuous-flow systems. This is a major difference between aerobic digestion and the various variants of the activated sludge process, including extended aeration (see "Secondary Biological Treatment" below). When aerobic digestion is used for biosolids stabilization, either the fill-and-draw or the continuous mode of operation can be used. With the fill-and-draw mode of operation, an option is to periodically cease aeration temporarily to allow settling and then decant the clarified liquid before resuming aeration. This approach also allows the reactor to be used as a biosolids thickener.

With conventional aerobic digestion, substantial reductions in total and volatile solids, biochemical and chemical oxygen demand, and organic N can be realized. Total N reduction can also be substantial, with either ammonia stripping or nitrification-denitrification serving as the primary mechanism, depending on the dissolved oxygen concentration of the mixed liquor. Actual process performance depends on a number of variables, including solids retention time, temperature, and adequacy of oxygen transfer and mixing.

An aeration basin typically is used for the aerobic digestion of municipal and industrial wastewater biosolids. In contrast, several reactor types, including oxidation ditches and mechanically aerated lagoons, as well as aeration basins, have been used for the aerobic digestion of animal manures. Under commercial conditions, the oxidation ditch has been the most commonly used because it can be located in the animal housing unit under cages for laying hens or under slatted floors for swine. This eliminates the need for transport of manure to the treatment system.

It should be noted that since the oxidation ditch was originally developed to employ the activated sludge process used in municipal wastewater treatment, the term "activated sludge" has been used incorrectly on occasion to describe the aerobic digestion of swine, poultry, and other animal wastes. Aerobic digestion, not the activated sludge process, is employed in oxidation ditches, mechanically aerated lagoons, and aeration basins. Table 8-14 presents technologies that use aerobic digestion or the activated sludge process.

Application and Performance: Conventional aerobic digestion is an option for all swine and poultry operations where manure is handled as a liquid or slurry, and it can be used with flushing systems using either mixed liquor or clarified effluent as flush water. With proper process design and operation, a 75 to 85 percent reduction in 5-day biochemical oxygen demand (BOD_5) appears achievable, with a concurrent 45 to 55 percent reduction in chemical oxygen demand (COD), and a 20 to 40 percent reduction in total solids (TS) (Martin, 1999). In addition, a 70 to 80 percent reduction of the N in both poultry and swine wastes via nitrification-denitrification also appears possible. Total P is not reduced, but the soluble fraction may increase. As with aerobic digestion

Table 8-14. Operational Characteristics of Aerobic Digestion and Activated Sludge Processes

Process Modification	Flow Model	Aeration System	BOD Removal Efficiency (percent)	Remarks
Conventional	Plug flow	Diffused-air, mechanical aerators	85-95	Use for low-strength domestic wastes. Process is susceptible to shock loads.
Complete mix	Continuous-flow stirred-tank reactor	Diffused-air, mechanical aerators	85-95	Use for general application. Process is resistant to shock loads, but is susceptible to filamentous growths.
Step feed	Plug flow	Diffused air	85-95	Use for general application for a wide range of wastes.
Modified aeration	Plug flow	Diffused air	60-75	Use for intermediate degree of treatment where cell tissue in the effluent is not objectionable.
Contact stabilization	Plug flow	Diffused-air, mechanical aerators	80-90	Use for expansion of existing systems and package plants.
Extended aeration	Plug flow	Diffused-air, mechanical aerators	75-95	Use for small communities, package plants, and where nitrified element is required. Process is flexible.
High-rate aeration	Continuous-flow stirred-tank reactor	Mechanical aerators	75-90	Use for general applications with turbine aerators to transfer oxygen and control floc size.
Kraus process	Plug flow	Diffused air	85-95	Use for low-N, high-strength wastes.
High-purity oxygen	Continuous-flow stirred-tank reactors in series	Mechanical aerators (sparger turbines)	85-95	Use for general application with high-strength waste and where on-site space is limited. Process is resistant to slug loads.
Oxidation ditch	Plug flow	Mechanical aerators (horizontal axis type)	75-95	Use for small communities or where large area of land is available. Process is flexible.
Sequencing batch reactor	Intermittent-flow stirred-tank reactor	Diffused air	85-95	Use for small communities where land is limited. Process is flexible and can remove N and P.
Deep-shaft reactor	Plug flow	Diffused air	85-95	Use for general application with high-strength wastes. Process is resistant to slug loads.
Single-stage nitrification	Continuous-flow stirred-tank reactors or plug flow	Mechanical aerators, diffused-air	85-95	Use for general application for N control where inhibitory industrial wastes are not present.
Separate stage nitrification	Continuous-flow stirred-tank reactors or plug flow	Mechanical aerators, diffused-air	85-95	Use for upgrading existing systems, where N standards are stringent, or where inhibitory industrial wastes are present and can be removed in earlier stages.

Source: Metcalf and Eddy, 1991.

of biosolids, some reduction in pathogen densities may also occur depending on process temperature.

Advantages and Limitations: In addition to the potential for substantial reductions in oxygen-demanding organics and N, one of the principal advantages of aerobic digestion of poultry and swine manures is the potential for a high degree of odor control. Another advantage is the elimination of fly and other vermin problems.

Limitations include high energy requirements for aeration and mixing (e.g., pumps, blowers, or mixers for mechanical aeration). In addition, aerobic lagoons without mechanical aeration are generally shallow, requiring a very large land area to meet oxygen demands. The absence of a reduction in the volume of waste requiring ultimate disposal is another limitation. In certain situations, waste volume will be increased significantly. For example, use of an undercage oxidation ditch versus a high-rise type system to manage the waste from laying hens will increase substantially the waste volume requiring ultimate disposal. Also, management, maintenance, and repair requirements for aerobic digestion systems can be significant. For example, liquids and solids must be separated in a pretreatment step when aerated lagoons are used.

Operational Factors: Establishing and maintaining an adequate microbial population in aerobic digestion reactors is critical to ensure optimal process performance. Failure to do so will lead to excessive foam production, which has suffocated of animals on slatted floors above in-building oxidation ditches. Failure to remove slowly biodegradable solids on a regular basis to maintain a mixed liquor total solids concentration of about 1 percent in fill-and-draw systems will lead to a substantial reduction in oxygen transfer efficiency and mixing. This results in reduced treatment efficiency and the potential for generation of noxious odors and release of poisonous gases, particularly hydrogen sulfide. Because ambient temperature determines process temperature, seasonal variation in process performance occurs.

Demonstration Status: Aerobic digestion has not been adapted to any significant degree by the poultry, dairy, or swine industries, although a number of research and demonstration scale studies were conducted in the late 1960s and early 1970s. Problems related to process and facilities design, together with the significant increase in electricity costs in the early to mid-1970s, led to a loss of interest in this animal waste treatment alternative. It is possible that no aerobic digestion systems for animal wastes are currently in operation in the poultry and swine industries.

Lagoons are the most popular method of treatment for livestock manure. Aerobic lagoons are commonly used for secondary treatment and storage of anaerobic lagoon wastes. Despite the advantages, however, aerobic lagoons are considered uneconomical for livestock manure treatment.

Practice: Autoheated Aerobic Digestion

Description: Autoheated aerobic digestion uses heat released during the microbial oxidation of organic matter to raise process temperature above ambient levels. This is accomplished by minimizing both sensible and evaporative heat losses through the use of insulated reactors and aeration systems with high-efficiency oxygen transfer. Mesophilic temperatures, 86 ºF (30 ºC) or higher, typically can be maintained even in cold climates, and thermophilic temperatures as high as 131 to 149 ºF (55 to 65 ºC) can be attained. Both ammonia stripping and nitrification-denitrification can be mechanisms of N loss at mesophilic temperatures; nitrification-denitrification is typically the principal mechanism if the aeration rate is adequate to support nitrification. Because both *Nitrosomas* and *Nitrobacter*, the bacteria that convert ammonium ions into nitrate, are mesophiles, N loss at thermophilic temperatures is limited to ammonia stripping. Typically, autoheated digestion reactors are operated as draw-and-fill reactors to minimize influent short-circuiting, especially when maximizing pathogen reduction is a treatment objective.

Application and Performance: Autoheated aerobic digestion is appropriate for all livestock and poultry operations where manure is handled as a slurry that has a minimum total solids concentration of at least 1 to 2 percent, wet basis. At lower influent total solids concentrations, such as those characteristic of flushing systems, achieving process temperatures significantly above ambient levels is problematic because of an insufficient biological heat production potential relative to sensible and evaporative heat losses. As influent total solids concentration increases, the potential for achieving thermophilic temperatures also increases. Influent total solids concentrations of between 3 and 5 percent are necessary to attain thermophilic temperatures.

With proper process design and operation, the previously discussed reductions in biochemical oxygen demand (BOD_5), chemical oxygen demand, total solids, and total N that can be realized with conventional aerobic digestion also can be realized with autoheated aerobic digestion (Martin, 1999a). Autoheated aerobic digestion can also provide significant reductions in pathogen densities in a relatively short 1- to 2-day period of treatment. Reductions realized are a function of process temperature. At a process temperature of 122 °F (50 °C) or greater, a minimum of at least a one $\log_{10}$ reduction in the density of most pathogens is highly probable, with two to three $\log_{10}$ reductions likely (Martin, 1999b).

Advantages and Limitations: With respect to waste stabilization and odor control, the potential benefits of conventional and autoheated aerobic digestion are comparable. The principal advantages of autoheated aerobic digestion relative to conventional aerobic digestion from a process performance perspective are (1) higher reaction rates that translate into shorter detention times to attain a given degree of stabilization and (2) more rapid reduction in densities of pathogens. The time required to achieve comparable reductions in BOD_5, chemical oxygen demand, total solids, and total N is much shorter in autoheated than in conventional aerobic digestion. With autoheated aerobic digestion, these reductions occur within 1 to 3 days at thermophilic temperatures, whereas 15 days or more are required with conventional aerobic digestion at ambient temperatures. This translates directly into smaller reactor volume requirements.

The ability to provide rapid and substantial (at least a one $\log_{10}$) reductions in pathogen densities is one of the more attractive characteristics of autoheated aerobic digestion. This ability has been demonstrated in several studies of autoheated aerobic digestion of biosolids from municipal wastewater treatment, including a study by Martin et al. (1990).

The high energy requirements for aeration and mixing are limitations of autoheated aerobic digestion. In addition, waste volume is not reduced through the treatment process. However, the requirement of a less dilute influent waste stream, as compared with conventional aerobic digestion, for example, to provide the necessary biological heat production potential translates into reduced ultimate disposal requirements.

Operational Factors: A foam layer covering the mixed liquor in autoheated aerobic digestion reactors is a common characteristic and serves to reduce both sensible and evaporative heat losses. It is necessary to control the depth of this foam layer to ensure that an overflow of foam from the reactor does not occur. Typically, mechanical foam cutters are used. Although autoheated aerobic digestion is less sensitive to fluctuations in ambient temperature than are other treatment processes, such as conventional aerobic digestion, some reduction in treatment efficiency can occur, especially during extended periods of extremely cold weather.

Demonstration Status: The feasibility of using autoheated aerobic digestion to stabilize swine manure has been demonstrated in several studies (Martin, 1999b). Feasibility also has been demonstrated in several studies with cattle manure, including studies by Terwilliger and Crauer (1975) and Cummings and Jewell (1977); however, there does not appear to have been any comparable demonstration of feasibility with poultry wastes. Given the similarities in the composition of swine and poultry wastes, it is highly probable that autoheated aerobic digestion of poultry wastes is also technically feasible. Although no data are available, it is probable that this waste treatment technology is not currently being used in any segment of animal agriculture, primarily because of the associated energy cost.

Practice: Secondary Biological Treatment

Description: The activated sludge process is a widely used technology for treating wastewater that has high organic content. The process was first used in the early 1900s and has since gained popularity for treatment of municipal and industrial wastewater. Many versions of this process are in use today, but the fundamental principles are similar. Basically, the activated sludge process treats organic wastes by maintaining an activated mass of microorganisms that aerobically decomposes and stabilizes the waste.

Primary clarification or solids settling is the first step in the activated sludge process. Next, the organic waste is introduced into a reactor. Maintained in suspension in the reactor is a biological culture that converts the waste through oxidation and synthesis. The aerobic environment in the reactor is achieved using diffused or mechanical aeration, which also maintains a completely mixed state. After a specified period, known as the hydraulic retention time (HRT), the mixture in the reactor is passed to a settling tank. A portion of the solids from the settling tank is recycled to the reactor to maintain a balance of microorganisms. Periodically, solids from the settling tank are "wasted" or discharged to maintain a specific concentration of microorganisms in the system. The solids are discharged according to a calculated solids retention time (SRT), which is based on the influent characteristics and the desired effluent quality. The overflow from the settling tank is discharged from the system.

Application and Performance: The activated sludge process is very flexible and can be used to treat almost any type of biological waste. It can be adapted to provide high levels of treatment under a wide range of operating conditions. Properly designed, installed, and operated activated sludge systems can reduce the potential pollution impact of feedlot waste because this technology has been shown to reduce carbon-, N-, and P-rich compounds.

In the activated sludge process, N is treated biologically through nitrification-denitrification. The supply of air facilitates nitrification, which is the oxidation of ammonia to nitrite and then nitrate. Denitrification takes place in an anoxic environment, in which the bacteria reduce the nitrate to nitrogen gas (N_2), which is released into the atmosphere. The activated sludge process can nitrify and denitrify in single- and double-stage systems.

Phosphorus is removed biologically when an anaerobic zone is followed by an aerobic zone, causing the microorganisms to absorb P at an above-normal rate. The activated sludge technology most effective for removing P is the sequencing batch reactor (see “Sequencing Batch Reactors,” below).

N and P can both be removed in the same system. The SBR is also most effective for targeting removal of both N and P because of its ability to alternate aerobic and anaerobic conditions to control precisely the level of treatment.

Advantages and Limitations: An advantage of the activated sludge process is that it removes pollutants, particularly nutrients, from the liquid portion of the waste. Nutrient removal can allow more feedlot wastewater to be applied to land without overloading it with N and P. Furthermore, concentrating the nutrients in a sludge portion can potentially reduce transportation volumes and costs of shipping excess waste.

A disadvantage of an activated sludge system compared with an anaerobic lagoon is the relatively high capital and operating costs and the complexity of the control system. In addition, because pollutants will remain in the sludge, stabilization and pathogen reduction are necessary before disposing of it.

Because the activated sludge process does not reduce pathogens sufficiently, another way to reduce pathogens in both the liquid and solid portions of a waste may be appropriate prior to discharge or land application. The liquid effluent from an activated sludge system can be disinfected by using chlorination, ultraviolet radiation, or ozonation, which are the final steps in many municipal treatment systems.

Operational Factors: Many parameters can affect the performance of an activated sludge system. Organic loading must be monitored carefully to ensure that the microorganisms can be sustained in proper concentrations to produce a desired effluent quality. The principal factors in the control of the activated sludge process are:

- Maintaining dissolved oxygen levels in the aeration tank (reactor);
- Regulating the amount of recycled activated sludge from the settling tank to the reactor; and
- Controlling the waste-activated sludge concentration in the reactor.

Ambient temperature can also affect treatment efficiency of an activated sludge system. Temperature influences the metabolic activities of the microbial population, gas-transfer rates, and settling characteristics of biological solids. In cold climates, a larger reactor volume may be necessary to achieve treatment goals because nitrification rates decrease significantly at lower temperatures.

Demonstration Status: Although activated sludge technologies have not been demonstrated on a full-scale basis in the animal feedlot industry, the process may treat such waste effectively. Studies have been performed on dairy and swine waste to determine the level of treatment achievable in an SBR (see "Sequencing Batch Reactors," below). The SBR is simpler, more flexible, and perhaps more cost-effective than other activated sludge options for use in the feedlots industry.

Practice: Sequencing Batch Reactors

Description: A sequencing batch reactor (SBR) is an activated sludge treatment system in which the processes are carried out sequentially in the same tank (reactor). The SBR system may consist of one reactor, or more than one reactor operated in parallel. The activated sludge process treats organic wastes by maintaining an aerobic bacterial culture, which decomposes and stabilizes the waste. An SBR has five basic phases of operation, which are described below.

<u>Fill Phase</u>: During the fill phase, influent enters the reactor and mechanical mixing begins. The mixing action resuspends the settled biomass from the bottom of the reactor, creating a completely mixed condition and an anoxic environment. As wastewater continues entering the reactor, oxygen may also be delivered, converting the environment from anoxic to aerobic. Depending on the desired effluent quality, the oxygen supply can be operated in an "on/off" cycle, thus alternating the aerobic and anoxic conditions and accomplishing nitrification and denitrification.

<u>React Phase</u>: During the react phase, wastewater no longer enters the reactor. Influent to the system is instead either stored for later treatment in a single-reactor system or diverted to another reactor to begin treatment in a system with multiple reactors. Mechanical mixing continues throughout this phase. The oxygen supply may be operated in a cyclical manner, as described in the fill phase, to accomplish additional denitrification if necessary. Activated sludge systems, such as SBRs, depend upon developing and sustaining a mixed culture of bacteria and other microbes (i.e., the biomass) to accomplish the treatment objectives.

Settle Phase: During the settle phase, the oxygen supply system and mechanical mixer do not operate. This phase provides a quiescent environment in the reactor and allows gravity solids separation to occur, much like in a conventional clarifier.

Draw Phase: Following the treatment of a batch, it is necessary to remove from the reactor the same volume of water that was added during the fill phase. After a sufficient settling phase, the liquid near the top of the reactor is decanted to a predetermined level and discharged or recycled.

Idle Phase: The idle phase is a time period between batches during which the system does not operate. The duration of this unnecessary phase depends on the hydraulic aspects of the reactor. However, as a result of biological degradation and accumulation of inert materials from the wastewater, solids must be discharged from the reactor periodically to maintain a desirable level of mixed liquor suspended solids. This "sludge wasting" is done during the idle phase, or immediately following the draw phase.

Application and Performance: SBR technology could be applied to reduce the potential pollution impact of liquid manure waste from dairies because this technology has been shown to reduce carbon-, N-, and P-rich compounds. Removing these pollutants from the liquid portion of the waste could allow for greater hydraulic application to lands without exceeding crop nutrient needs. Concentrating the nutrients in the sludge portion could potentially reduce transportation volumes and cost of shipping excess waste. Although a proven technology for treatment of nutrients in municipal wastewater, available data does not exist showing SBRs to be effective in pathogen reduction.

Given the processes it employs, SBR treatment may allow treated dairy wastewater to be either applied to land or discharged to a stream if a sufficient level of treatment can be achieved. Further, the sludge from the wasting procedure could be applied to land, composted, or sent off site for disposal. Aqua-Aerobic Systems of Rockford, Illinois, (Aqua-Aerobics, 2000) estimates a sludge production rate of approximately 1.3 pounds of waste activated sludge per pound of BOD_5 entering the system. The use of SBRs to treat dairy waste has been studied in the laboratory at both Cornell University and the University of California at Davis. Both studies have shown SBR technology to be effective in reducing pollutants in the liquid portion of dairy waste, although neither report included specific information on sludge characteristics or P removals (Johnson and Montemagno, 1999; Zhang et al., 1999).

In the Cornell study, diluted dairy manure was treated in bench-scale reactors (Johnson and Montemagno, 1999). Experiments were conducted to determine the operating strategy best suited for the diluted dairy manure. The study resulted in removals of 98 percent of ammonia (NH_3), 95 percent of chemical oxygen demand (COD), 40 percent of nitrate/nitrite (NO_3/NO_2), and 91 percent of inorganic N.

The University of California at Davis studied how SBR performance was affected by hydraulic retention time (HRT), solids retention time (SRT), organic loading, and influent characteristics of dairy wastewater (Zhang et al., 1999). The highest removal efficiencies from the liquid portion of the waste were for an influent COD concentration of 20,000 milligrams per liter (a COD concentration of 10,000 mg/L was also studied) and an HRT of 3 days (HRTs of 1 to 3 days were studied). With these parameters, laboratory personnel observed removal efficiencies of 85.1 percent for NH_3 and 86.7 percent for COD.

In addition, studies on SBR treatment of swine waste in Canada and of veal waste in Europehave demonstrated high removal rates of COD, N, and P (Reeves, 1999).

Advantages and Limitations: Technology currently used at dairies includes solids settling basins followed by treatment and storage of waste in an anaerobic lagoon. Lagoon effluent and solids are applied to cropland in accordance with their nutrient content, and excess water or solids are then transported off site. The SBR could replace treatment in an anaerobic lagoon, but there would still be a need for solids separation in advance of SBR treatment, as well as a pond or tank to equalize the wastewater flow. In fact, Aqua-Aerobics (2000) has indicated that solids removal and dilution of the raw slurry would be necessary to make treatment in the SBR. Following the SBR, it is possible that some type of effluent storage would be required for periods when direct irrigation is not possible or necessary.

Use of an SBR is expected to be advantageous at dairies that apply a portion of their waste to land. The reduced level of nutrients in the liquid portion would allow for application of a greater volume of liquid waste, thereby reducing the volume of waste that must be transported off site and possibly eliminating liquid waste transport. An SBR is also beneficial in the handling of the solids portion of the waste because no periodic dredging is required as is the case with anaerobic lagoons. Disadvantages of an SBR system are the relatively high capital and operating costs, as well as the need to manage the nutrients that remain in the sludge.

Because the activated sludge process is not a generally accepted method of pathogen reduction, another means of reducing pathogens in both the liquid and solid portions of the dairy waste may be appropriate. Disinfection of the liquid effluent from the SBR could be accomplished through use of chlorination, ultraviolet radiation, or ozonation which are used as the final step in many municipal treatment systems. Composting has also been demonstrated as a means of reducing pathogens in organic solid waste and could be implemented for use with the SBR sludge.

Operational Factors: The five phases of SBR operation may be used in a variety of combinations in order to optimize treatment to address specific influent characteristics and effluent goals. N in the activated sludge process is treated biologically through the nitrification-denitrification process. The nitrification-denitrification process in the SBR is controlled through the timing and cyclical pattern of aeration during the react phase. The supply of air causes nitrification, which is the oxidation of ammonia to nitrite and then nitrate. To accomplish denitrification, the air supply is shut off, creating an anoxic environment in which the bacteria ultimately reduce the nitrate to nitrogen gas (N_2), which is released to the atmosphere. The cycle can be repeated to achieve additional levels of denitrification. Some portion of the N in the influent to the SBR may also volatilize prior to treatment, and a portion may also be taken up by microorganisms that are present in the waste activated sludge (Zhang et al., 1999).

P is removed when an anaerobic zone (or phase) is followed by an aerobic zone, causing the microorganisms to take up P at an above-normal rate. The waste activated sludge containing the microorganisms is periodically "wasted" as described above. As such, the bulk of the P will be concentrated ultimately in the sludge portion with a minimal amount remaining in the liquid effluent.

N and P can both be removed in the same system. This dual removal is accomplished by beginning the fill phase without aeration, which creates an anoxic condition allowing for some denitrification as well as release of P from the cell mass to the liquid medium. there follows a period of aerated mixing, which will continue into the react phase, allowing for nitrification and uptake of P. The settle phase, in which no aeration occurs, is extended sufficiently to allow for additional denitrification. Again, these phases can be repeated or executed for varying durations in order to accomplish specific treatment goals.

Demonstration Status: Although the SBR technology has not been demonstrated on a full-scale basis in the dairy industry, SBRs are currently being evaluated for use at dairies because they generate a high volume of wastewater. Dairy wastewater treated in the SBR includes a combination of parlor and barn flush/hose water and runoff.

Cornell University is currently studying two pilot-scale SBR systems to further investigate the treatability of dairy waste (Johnson and Montemagno, 1999). No results from the pilot-scale study are yet available, although preliminary results for nutrient removal have been favorable and a full-scale system is being planned.

Practice: Solids Buildup in the Covered First Cell of a Two-Cell Lagoon

Description: This section addresses sludge accumulation, removal, and management in the first cell of a two-cell lagoon. The first cell may or may not be covered for methane recovery. Some sludge will be carried from the first cell to the second cell; however, the quantity is not significant compared with potential accumulations in the first cell. No quantitative information was found regarding the differences in the rate of accumulation of sludge in the first cell versus accumulation in a single-cell lagoon. The removal and management of sludge from the first cell of a two-cell lagoon will be the same as described for sludge cleaning from a single cell lagoon.

For the purpose of this section, sludge is material settled on the bottom of a lagoon receiving waste from any animal; it has a total solids content greater than 10 percent, generally has a high angle of repose when dewatered, and will not readily flow to a pump. Sludge includes organic material not decomposed by lagoon bacteria, and inorganic material such as sand and precipitates. Sludge accumulation can eventually fill a lagoon.

Accumulated sludge is removed to restore lagoon treatment and storage capacities. Two general methods of sludge removal, slurry and solid, are described below. When managed as a slurry, sludge is resuspended with agitation and pumped to tankers or irrigation guns for land application. Slurry management is desirable when the sludge mixture can be pumped to an irrigation gun or hauled a short distance. Sludge removed from covered lagoons is removed as a slurry.

Sludge managed as a solid is excavated from the lagoon or pumped from the bottom as slurry to a drying area. Solid sludge is cheaper to haul than slurry because water, which increases the weight and volume, is not added. Solid sludge can be spread with conventional manure spreaders or dumped on fields and spread out and disced into the soil. In drier areas of the country, a lagoon may be withdrawn from service as a parallel lagoon is restored to service. The lagoon liquids are pumped off to field application and the sludge is allowed to dry. After 4 to 12 months, excavators, backhoes or bulldozers scrape, push, pull, or lift the material into trucks or wagons for hauling and spreading. Some lagoons are designed to be desludged by dragline bucket excavators while still in operation. Draglines work along the banks of these long, narrow lagoons, excavating sludge and either dropping it into trucks for hauling or depositing it on the lagoon embankment to dry for later hauling.

Application and Performance: Lagoon cleanout is applicable to all two-cell lagoons, regardless of location. Reported reductions of P, K, and other nonvolatile elements through a lagoon are not really reductions at all because these materials settle. Nitrogen is considered volatile in the ammonia form, but some organic N associated with heavier and nondegradable organics also settles into the lagoon sludge and stays, resulting in a high-organic N fraction of total Kjeldahl N (TKN) in settled solids. The settled materials accumulate in the lagoon awaiting later disposal. Compared with lagoon liquids, lagoon sludges have higher concentrations of all pollutants that are not completely soluble. All reported data suggest that the sludge is more stable than raw manure based on its reduced volatile solids/total solids ratio (VS/TS). Volatile solids are a portion of the total solids that can be biologically destroyed, and as they are destroyed, the VS/TS ratio declines.

As anaerobic digestion of manure changes the solution chemistry in a lagoon, materials such as ammonia and P form precipitates with Ca and Mg. Fulhage and Hoehne (1999) and Bicudo et al. (1999) both report concentrations of Ca, Mg, P, and K in lagoon sludge at 10 to 30 times that found in raw manure. Fulhage and Hoehne also reported that Cu and Zn settle and concentrate to 40 to 100 times the concentration found in lagoon liquid.

Martin (1999), in a review and analysis of factors affecting pathogen destruction, found that time and temperature controlled the die-off rate of pathogens. Sludge that has been in a lagoon for 10 years is expected to have very low concentrations of pathogens, and those would be associated with the most recent 90 to 180 days of settling.

Advantages and Limitations: The advantage of lagoon cleanout is that removal of sludge restores the volume of a first-cell lagoon that is necessary for design treatment capacity. One of the limitations is that sludge disposal is ignored in most nutrient management plans. Sludge is a concentrated, nutrient-rich material. The nutrients in the sludge, if applied to the same cropland historically receiving lagoon liquids, could easily exceed the planned application rate of nutrients. Phosphorus and other relatively insoluble nutrients are more concentrated than N in sludge and become the basis of planning proper use of the sludge.

Ideally, sludge will be managed as a high-value fertilizer in the year it is applied. As the sludge has a higher nutrient and, hence, cash value than liquid manure, hauling to remote farms and fields to replace commercial fertilizer application is possible and desirable. Proper management of applied sludge will result in successful crops and minimal loss of nutrients to surface or ground waters.

The cover is a limiting factor in covered lagoon cleanout. At least a portion of the cover is removed to allow equipment access. Removing a complete cover is usually not practical. Lacking complete access, covered lagoon cleanouts will not remove all of the sludge present. Therefore, more frequent cleanouts would be expected. Most covered lagoons have been developed with cleanout intervals of 10-15 years.

Operational Factors: The USDA allows for sludge accumulation by incorporating a sludge accumulation volume (SAV) in its lagoon design calculations. Table 8-15 shows USDA's ratios of sludge accumulated per pound of total solids (TS) added to the lagoon. The higher the rate of sludge accumulation assumed in a design, the larger the lagoon volume required. There are no published data to compare sludge accumulation in the first cell of a two-cell lagoon versus accumulation in a single-cell lagoon. Anecdotal observations suggest that a first cell does not accumulate sludge faster than a single-cell lagoon as long as the first cell is sized to contain all of the treatment volume and sludge accumulation volume (SAV). In theory, a constant volume first cell should accumulate less sludge over time than a single-cell lagoon because the constant volume lagoon has a consistently higher microbial concentration than a single-cell lagoon. The higher concentration should result in the ability to consume new manure organic solids before they can settle to become sludge. Also in theory, a covered first cell would accumulate less sludge due to higher biological activity because a covered lagoon is a few degrees warmer than an uncovered lagoon.

Table 8-15. Lagoon Sludge Accumulation Ratios (USDA NRCS 1996)

Animal Type	Sludge Accumulation Ratio
Layers	0.0295 ft^3/lb TS
Pullets	0.0455 ft^3/lb TS
Swine	0.0485 ft^3/lb TS
Dairy cattle	0.0729 ft^3/lb TS

Information from various studies suggests that the USDA values may overestimate actual sludge accumulation rates. Table 8-16 shows a range of long-term sludge accumulation rates reported by various researchers. Field studies by both Fulhage and Hoehne (1999) and Bicudo et al. (1999) show lower accumulation rates than developed by Barth and Kroes (1985) and USDA NRCS (1996).

Table 8-16. Lagoon Sludge Accumulation Rates Estimated for Pig Manure

Source	Sludge Accumulation Rate
Fulhage (1990)	0.002 m^3/kg LAW*
Bicudo (1999)	0.003 m^3/kg LAW*
Barth (1985)	0.008 m^3/kg LAW*
USDA (1992)**	0.012 m^3/kg LAW*

* LAW = live animal weight ** as calculated by Bicudo et al. (1999).

It is important to note that the accumulation rate of sludge is influenced by lagoon design, influent characteristics, site factors, and management factors. Lagoon design factors such as lagoon volume, surface fetch, and lagoon depth increase or decrease potential lagoon mixing. More lagoon mixing encourages greater solids destruction by increasing the opportunity for bacteria to encounter and degrade solids. Influent factors, including animal type and feed, determine the biodegradability of manure solids. Highly degradable manure solids are more completely destroyed, thus accumulating as sludge to a lesser degree. Site temperature and incident rainfall impact the biological performance of the lagoon. High temperature increases biological activity and solids destruction. High rainfall can fill the lagoon and reduce retention time, thus slowing biological destruction of solids. Management factors also affect sludge accumulation. Increasing animal population, adding materials such as straw or sand used for animal bedding, or adding process water will reduce the ability of a lagoon to destroy solids and, therefore, increase the rate of sludge accumulation. Properly managed solids separators can reduce the quantity of solids reaching the lagoon, hence reducing sludge accumulation

Demonstration Status: First-cell cleanouts are common and have occurred since two-cell lagoons have been used. In many areas of the country, there are companies that specialize in lagoon cleaning.

Practice: Solids Buildup in an Uncovered Lagoon

Description: For the purpose of this section, sludge is material settled on the bottom of a lagoon receiving waste from any animal; it has a total solids content greater than 10 percent, generally has a high angle of repose when dewatered, and will not readily flow to a pump. This definition is intended to distinguish sludge from a less concentrated layer of solids above the sludge surface that can be drawn off with conventional pumping. All lagoons accumulate settleable materials in a sludge layer on the bottom of the lagoon. Sludge includes organic material not decomposed by lagoon bacteria and inorganic material such as sand and precipitates. Over time the sludge accumulation decreases the active treatment volume of a lagoon and negatively impacts the lagoon performance. Reduced treatment performance increases the rate of sludge accumulation. Sludge accumulations can eventually fill a lagoon.

Accumulated sludge is removed to restore lagoon treatment and storage capacities. Two general methods of sludge removal, slurry and solid, are described below.

When managed as a slurry, sludge is resuspended with agitation and pumped to tankers or irrigation guns for land application. Slurry management is desirable when the sludge mixture can be pumped to an irrigation gun or hauled a short distance.

Sludge managed as a solid is excavated from the lagoon. Solid sludge is cheaper to haul than slurry because water, which increases the weight and volume, is not added. Solid sludge can be spread with conventional manure spreaders or dumped on fields and spread out and disced into the soil. In drier areas of the country, a lagoon may be withdrawn from service when a parallel lagoon is restored to service. The lagoon liquids are pumped off to field application, and the sludge is allowed to dry. After 4 to 12 months, excavators, backhoes, or bulldozers scrape, push, pull, or lift the material into trucks or wagons for hauling and spreading. Some lagoons are designed to be desludged by dragline bucket excavators while still in operation. Draglines work along the banks of these long, narrow lagoons, excavating sludge and either dropping it into trucks for hauling or depositing it on the lagoon embankment to dry for later hauling.

Application and Performance: Lagoon cleanout is applicable to all operations that have lagoons, regardless of location. Reported reductions of P, K, and other nonvolatile elements through a lagoon are not really reductions at all. The material settles and accumulates in the lagoon, awaiting later disposal. Compared with lagoon liquids, lagoon sludges have higher concentrations of all pollutants that are not completely soluble. All reported data suggest that the sludge is more stable than raw manure based on its reduced volatile solids to total solids ratio (VS/TS). Volatile solids are a portion of the total solids that can be biologically destroyed, and as they are destroyed, the VS/TS ratio declines. Some organic N associated with heavier and nondegradable organics also settles into the lagoon sludge and stays, resulting in a high-organic N fraction of total Kjeldahl N (TKN) in settled solids.

As anaerobic digestion of manure changes the solution chemistry in a lagoon, materials such as ammonia and P form precipitates with Ca and Mg. Both Fulhage and Hoehne (1999) and Bicudo et al. (1999) report concentrations of Ca, Mg, P, and K in lagoon sludge at 10 to 30 times that found in raw manure. Fulhage and Hoehne also reported that Cu and Zn settle and concentrate to 40 to 100 times the concentration found in lagoon liquid.

Martin (1999), in a review and analysis of factors affecting pathogen destruction, found that time and temperature controlled the die-off rate of pathogens. Sludge that has been in a lagoon for 10 years is expected to have very low concentrations of pathogens, and those would be associated with the most recent 90 to 180 days of settling.

Advantages and Limitations: The advantage of lagoon cleanout is that removal of sludge restores the volume of a lagoon that is necessary for design treatment and storage capacities. One of the limitations is that sludge disposal is ignored in most nutrient management plans. Sludge is a concentrated, nutrient-rich material. The nutrients in the sludge, if applied to the same cropland historically receiving lagoon liquids, could easily exceed the planned application rate of nutrients. Phosphorus and other relatively insoluble nutrients are more concentrated than N in sludge and become the basis of planning proper use and disposal of the sludge.

Ideally, sludge will be managed as a high value fertilizer in the year it is applied. As the sludge has a higher nutrient and, hence, cash value than liquid manure, hauling to remote farms and fields to replace commercial fertilizer application is possible and desirable. Proper management of applied sludge will result in successful crops and minimal loss of nutrients to surface or ground waters.

Operational Factors: The USDA allows for sludge accumulation by incorporating a sludge accumulation volume (SAV) in its lagoon design calculations. Table 8-15 shows USDA's ratios of sludge accumulated per pound of total solids (TS) added to the lagoon. The higher the rate of sludge accumulation assumed in a design, the larger the lagoon volume required.

Information from various studies suggests that the USDA values may overestimate actual sludge accumulation rates. Table 8-16 shows a range of long-term sludge accumulation rates reported by various researchers. Field studies by both Fulhage and Hoehne (1999) and Bicudo et al. (1999) show lower accumulation rates than were developed by Barth and Kroes (1985) and USDA NRCS (1996).

It is important to note that the accumulation rate of sludge is influenced by lagoon design, influent characteristics, site factors, and management factors. Lagoon design factors such as lagoon volume, surface fetch, and lagoon depth increase or decrease potential lagoon mixing. More lagoon mixing encourages greater solids destruction by increasing the opportunity for bacteria to encounter and degrade solids. Influent factors, including animal type and feed, determine the biodegradability of manure solids. Highly degradable manure solids are more completely destroyed, thus accumulating as sludge to a lesser degree. Site temperature and incident rainfall impact the biological performance of the lagoon. High temperature increases biological activity and solids destruction. High rainfall can fill the lagoon and reduce retention time, thus slowing biological destruction of solids. Management factors also affect sludge accumulation. Increasing the animal population, the addition of materials such as straw or sand used for animal bedding, or the addition of process water will reduce the ability of a lagoon to destroy solids and increase the rate of sludge accumulation. Properly managed solids separators can reduce the quantity of solids reaching the lagoon, thereby reducing sludge accumulation. Mixing a lagoon before land application will suspend some of the sludge solids, causing them to be pumped out sooner rather than later.

Demonstration Status: Lagoon cleanouts are common and have occurred since lagoons have been used. Companies that specialize in lagoon cleaning are found in many areas of the country.

Practice: Trickling Filters

Description: Trickling filters are currently being evaluated for use at animal feeding operations (AFOs) to address the high concentrations of organic pollutants in AFO wastewater. The technology is a type of fixed-growth aerobic biological treatment process. Wastewater enters the circular reactor and is spread over media that support biological growth. The media are typically crushed rock, plastic-sheet packing, or plastic packing of various shapes. Wastewater contaminants are removed biologically.

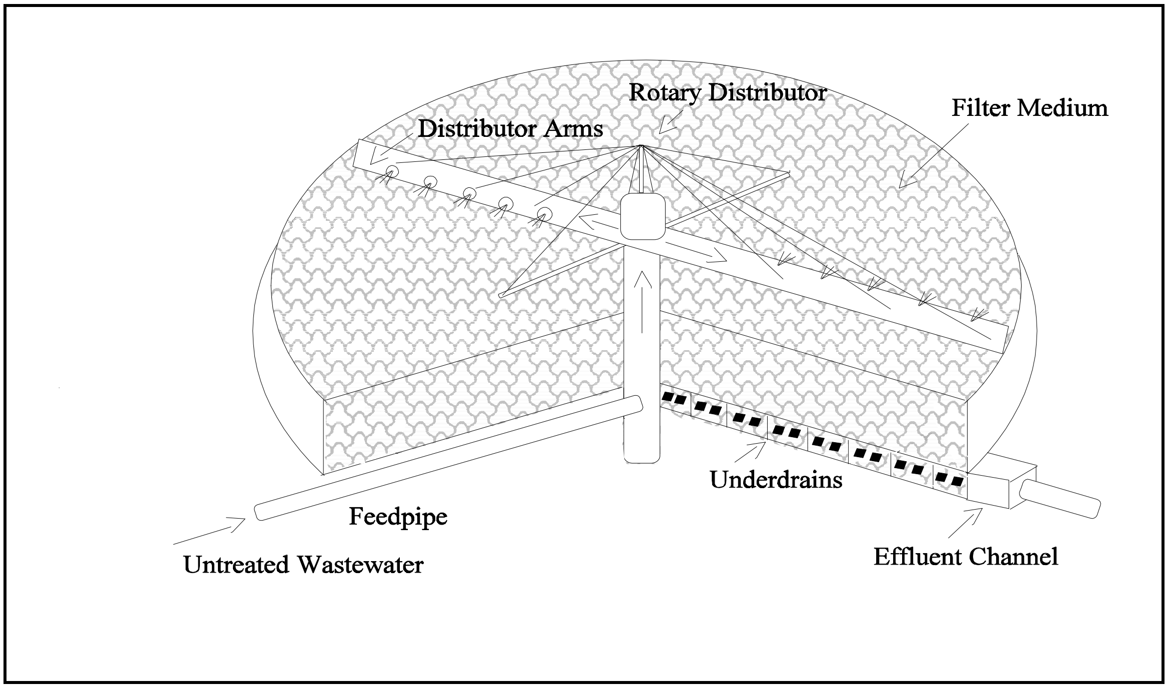

Figure 8-9. Trickling Filter

The top surface of the media bed is exposed to sunlight, is in an aerobic state, contains microorganisms that are in a rapid growth phase, and is typically covered with algae. The lower portion of the bed is in an anaerobic state and contains microorganisms that are in a state of starvation (i.e., microorganism death exceeds the rate of reproduction). The biofilm covering the filter medium is aerobic to a depth of only 0.1 to 0.2 millimeters; the microbial film beneath the surface biofilm is anaerobic. As wastewater flows over the microbial film, organic matter is metabolized and absorbed by the film. Continuous air flow is necessary throughout the media bed to prevent complete anaerobic conditions (Viessman, 1993).

Components of a trickling filter include a rotary distributor, underdrain system, and filter medium. Untreated wastewater enters the filter through a feedpipe and flows out onto the filter media via distributor nozzles, which are located throughout the distributor. The distributor spreads the wastewater at a uniform hydraulic load per unit area on the surface of the bed. The underdrain system, typically consisting of vitrified clay blocks, carries away the treated effluent. The clay blocks have entrance holes that lead to drainage channels and permit the circulation of air through the media bed. Figure 8-9 below shows a cutaway of a typical trickling filter.
Rock media beds can be up to 200 feet in diameter and 3 to 8 feet deep, with rock sizes ranging from 1 to 4 inches. Plastic media beds are narrower and deeper, ranging from 14 to 40 feet deep (Viessman, 1993). These systems look more like towers than conventional rock-media systems. It is also common to have single-stage or two-stage systems for N removal. A two-stage system allows for greater flexibility because each stage can be operated independently and optimized accordingly. Flow capacity of trickling filters can range between 200 and 26,000 gallons per day; however, units can be installed in parallel to handle larger flows (AWT Environment).

Application and Performance: Traditionally, the trickling filter medium has been crushed rock or stone; however, this type of media occupies most of the volume in a filter bed, reducing the void spaces for air passage and limiting surface area for biological growth. Many trickling filters now use a chemical-resistant plastic medium because it has a greater surface area and a large percentage of free space. These synthesized media forms offer several advantages over naturally available materials, particularly in terms of surface contact area, void space, packing density, and construction flexibility (Viessman, 1993).

Although stone-media trickling filters are not as common, they are still used in shallow filters. BOD loads, expressed in terms of pounds of BOD applied per unit of volume per day, are typically 25 to 45 pounds per 1,000 ft^3 per day for single-stage stone filters and 45 to 65 pounds per 1,000 ft^3 per day/day for two-stage stone filters (based on the total media volume of both filters). The recommended hydraulic load ranges from 0.16 gallons per minute per ft^2 to 0.48 gallons per minute per ft^2 (Viessman, 1993).

Other shallow filters use random packing (e.g., small plastic cylinders, 3.5 x 3.5 inches), with a specific surface area of 31 to 40 ft^2/ft^3 and a void space of 91 to 94 percent. Deep filters use corrugated PVC plastic sheets that are 2 feet wide, 4 feet long, and 2 feet deep stacked on top of each other in a crisscross pattern. The specific surface area ranges from 26 to 43 ft^2/ft^3 and a void space of approximately 95 percent. The BOD loads for plastic media towers are usually 50 pounds per 1,000 ft^3 per day or greater with surface hydraulic loadings of 1 gpm/ft^2 or greater (Viessman, 1993).

A single or two-stage trickling filter can remove N through biological nitrification. The nitrification process uses oxygen and microorganisms to convert ammonia to nitrite nitrogen, which is then converted to nitrate nitrogen by other microorganisms. Nitrate nitrogen is less toxic to fish and can be converted to nitrogen gas, which can be released to the atmosphere through denitrification, a separate anaerobic process following nitrification. Note that trickling filters are not capable of denitrifying.

A single-stage trickling filter removes BOD in the upper portion of the unit while nitrification occurs in the lower portion. A two-stage system removes BOD in the first stage while nitrification occurs in the second stage. Trickling filters do not typically remove P, but can be adapted to remove P from the wastewater effluent by chemical precipitation following BOD removal and nitrification (AWT Environment, ETI, 1998).

It is critical to have a properly designed trickling filter system. An improperly designed system can impact treatment performance and effluent quality. Media configuration, bed depth, hydraulic loading, and residence time all need to be carefully considered when designing a trickling filter system (Viessman, 1993).

In a study using municipal wastewater, the average BOD removal was greater than 90 percent and TSS removal was greater than 87 percent using a trickling filter. The average effluent BOD concentration was 13 mg/L, while the average effluent TSS concentration was 17 mg/L (AWT

Environment). In another similar study that included municipal and dairy waste, BOD and TSS concentrations were slightly greater, but never exceeded 100 mg/L (Bio-Systems, 1999).

In another study using municipal wastewater and an anaerobic upflow filter prior to the trickling filter, the average effluent BOD and TSS concentrations both ranged from 5 to 10 mg/L, and the total N removal ranged from 80 to 95 percent. Pathogen reduction for this particular system is expected to be good, due to the upflow filter component. The estimated cost for this system is approximately $18,000 in annualized present day (Year 2000) costs (annualized over 20 years and not including design and permitting) (City of Austin, 2000).

Information on the reduction of pathogens, antibiotics, and metals in trickling filters is not available, but it is expected to be minimal based on engineering judgment.

Advantages and Limitations: An advantage of operating a trickling filter is that it is a relatively simple and reliable technology that can be installed in areas that do not have a lot of space for a treatment system. This technology is also effective in treating high concentrations of organics and nutrients. It can be cost-effective because it entails lower operating and maintenance costs than other biological processes, including less energy and fewer skilled operators. The wasted biomass, or sludge, can be processed and disposed of, although it contains high concentrations of nutrients. Finally, it also effectively handles and recovers from nutrient shock loads (ETI, 1998).

Disadvantages of operating a trickling filter are that additional treatment may be needed to meet stringent effluent limitations, the operation generates sludge that needs to be properly disposed of, poor effluent quality results if the system is not properly operated, and regular operator attention is needed. The system is susceptible to clogging from the biomass as well as odors and flies. The high solids content of CAFO waste would most likely require solids separation prior to treatment to also prevent clogging. Only the liquid waste may be treated in this system. In addition, a high investment cost may also prevent certain farms from installing this technology (ETI, 1998).

Operational Factors: Trickling filters are typically preceded by primary clarification for solids separation and are followed by final clarification for collection of microbiological growths that slough from the media bed. They can also be preceded by other treatment units such as septic tanks or anaerobic filters. Trickling filters effectively degrade organic pollutants, but can also be designed to remove N and P from the wastewater.

Trickling filters are relatively simple to operate, are lower in cost than other biological treatment processes, and typically operate at the temperature of the wastewater as modified by that of the air, generally within the 15-25°C range. A high wastewater temperature increases biological activity, but may result in odor problems. Cold wastewater (e.g., 5-10°C) can significantly reduce the BOD removal efficiency (Viessman, 1993).

Demonstration Status: Trickling filters are most commonly used to treat municipal wastewater, although the technology is applicable to agricultural wastewater treatment. They are best used to treat wastewaters with high organic concentrations that can be easily biodegraded. EPA was not able to locate any AFO facilities that currently operate trickling filters; however, based on the information gathered, several wastewater treatment vendors market this technology to such facilities.

Practice: Fluidized Bed Incinerators

Description: Fluidized bed incinerators (FBIs) are currently being evaluated for use at CAFOs given the high volume of manure they generate. The technology is typically used for wastewater sludge treatment (e.g., municipal sludge), but may be used for wastewater treatment. The main purpose of an FBI is to break down and remove volatile and combustible components of a waste stream and to reduce moisture. Its most prominent application to CAFO industries would be for animal waste disposal and treatment, because manure has a higher solids content than wastewater from CAFO operations.

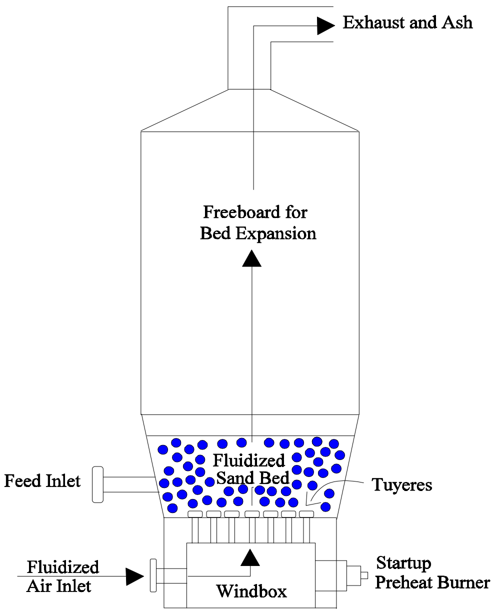

Figure 8-10. Fluidized Bed Incinerator

An FBI is a vertical, cylindrical shaped apparatus that requires media (typically sand), injected air, and an influent fuel to operate. An FBI contains three basic zones: a windbox, a sand bed, and a freeboard reactor chamber. Air enters the windbox and moves upward into the media bed through orifices called "tuyeres" at a pressure of 3 to 5 pounds per square inch. The injected air acts to fluidize the bed and to generate combustion. The term "fluidized bed" refers to the "boiling" action of the sand itself, which occurs when air is injected into the reactor. The fuel, or animal waste, directly enters the fluidized sand bed and is mixed quickly within the bed by the turbulent action. Any moisture in the animal waste evaporates quickly, and the sludge solids combust rapidly. Combustion gases and evaporated water flow upward through the freeboard area to disengage the bed material and to provide sufficient retention time to complete combustion. Gases and ash exit the bed out the top of the FBI. Exit gases may be used to preheat the injected air or may be recovered for energy. Exit ash is removed from exit gas in an air pollution device such as a venturi scrubber. Ash can either be disposed of or reused (typically as fertilizer) depending on its characteristics (Metcalf and Eddy, 1991).

Prior to injection, the sand media is kept at a minimum temperature of 1300 °F and controlled at between 1400 and 1500 °F during treatment. This temperature range varies with specific design criteria. The FBI typically ranges in size from 9 to 25 feet in diameter; the media bed is typically 2.5 feet thick, when settled (Metcalf and Eddy, 1991). The system has a capacity of up to 30 tons per hour (UNIDO, 2000). The combustion process is optimized by varying the animal waste and air flow, with exit gas retention times greater than 1 second and solids retention times greater than 30 minutes (Versar, 2000). Figure 8-10 represents a typical FBI.

Application and Performance: Animal waste enters the FBI and quickly combusts in the media bed. Organic constituents of the waste are burned to produce carbon dioxide and water, while volatile pollutants are evaporated and captured in the air control device. Solid material may be recycled through the system for further treatment. The ash contains many of the pollutants in the animal waste itself, although waste volume is reduced and most of the N in the waste is evaporated. The ash will still contain high levels of metals, P, and K.

The high temperature of the system typically eliminates the spread of pathogens, reducing biosecurity concerns. Similarly, any antibiotics or hormones remaining in the waste will also be broken down and reduced. Although FBIs operate at very high temperatures, they typically operate at lower temperatures than other types of incinerators, which results in lower air emissions, particularly of NO_x compounds and volatile organic compounds (VOCs).

Advantages and Limitations: Fluidized bed incineration is an effective and proven technology for reducing waste volume and for converting the waste to useful products (e.g., energy). Resulting ash may be used as an end- product fertilizer, or as an intermediate product used in manufacturing commercial fertilizers. Animal waste incineration eliminates aesthetic concerns (e.g., odors) as well as nuisance concerns (e.g., pest attraction) (Versar, 2000).

Although fluidized bed incineration is viewed as an efficient system, it is very sensitive to moisture content and fuel particle size. The higher the moisture content, the less efficient the system is because the moisture acts to depress the reactor temperature, thereby reducing combustion capabilities. Moisture can be reduced in animal waste by combining the waste with other biomass such as wood chips or straw. Air drying or dewatering the animal waste also reduces moisture content before treatment in the FBI. Blockages may often occur in input and output pipes triggering shut-down and maintenance (Versar, 2000).

Air emissions must also be considered when operating any type of incinerator. Organic and N compounds are easily removed from the waste; however, they are then emitted to the air, potentially creating a cross-media impact if not properly controlled. Furthermore, nutrients such as P, K, and metals typically remain in the ash and are not treated. Finally, FBIs entail high operating and maintenance costs, especially compared with other types of incinerators (Versar, 2000).

Operational Factors: As discussed above, FBIs are most sensitive to moisture content and fuel particle size. The less moist the influent fuel, the more efficient the system is. Acceptable influent moisture levels range from 15 to 20 percent moisture. Fuel particle size should also be minimized to avoid clogging the system. Another consideration is that depending on the metals concentrations and local regulations, the ash, if intended for disposal, may need to be handled as hazardous waste (Versar, 2000).

FBI costs depend on size and capacity. Capital costs can range from approximately $5 to 25 million for a 5-ton-per-hour and a 30-ton-per-hour FBI, respectively (UNIDO, 2000). FBIs are complex technologies and require operation by trained personnel. Because of this, FBIs are more economical for medium to large facilities, or when operated in cooperation with several businesses that are able to provide fuel sources. Therefore, FBIs may not be a cost-effective waste management technique for an individual farm, but, when operated on a larger scale, they may prove to be cost-effective. Capital and annual operating costs are generally higher for FBIs than for other types of incinerators because of the sensitive design parameters (e.g., moisture content and solid particle size). On the other hand, the system operates efficiently, and energy can usually be recovered from the process and may be sold to another party or used to reduce on-site operating costs.

Demonstration Status: ERG is not aware of any U.S. feedlots currently operating FBIs or sending animal waste to larger-scale municipal or private FBIs. According to information gathered for this program, FBIs are more commonly used in Europe and in Japan to treat animal waste, although some U.S. companies using waste-to-energy technology may be operating FBIs using animal waste with other fuel sources. FBIs are most commonly used in the United States to manage municipal sludge.

In a study done to assess the engineering and economic feasibility of using poultry litter as a fuel to generate electric power, researchers found that combusting poultry litter (combined with wood chips) can be an effective waste-to-energy technology (Versar, 2000). Although the study did not specifically evaluate fluidized bed incineration, the application and results are expected to be similar. The study found litter samples to have a heat content between 4,500 and 6,400 BTU per pound at approximately 16 percent moisture, which is a slightly higher content than the wood chips alone. The ash content of the litter was reported to be between 9 and 20 percent, which is significantly higher than the wood chips alone. However, although the air emissions data in this study were considered preliminary, they showed that the facility could trigger air permitting requirements. The study also found that poultry litter ash may be classified as hazardous waste under individual state regulations (Versar, 2000).

Practice: Constructed Wetlands

Description: Constructed wetlands (CWs) can be an important tool in the management of animal waste by providing effective wastewater treatment in terms of substantial removal of suspended solids, 5-day biochemical oxygen demand (BOD_5), fecal coliform, and nutrients such as N and P (CH2M Hill, 1997). The treatment process in CWs generates an effluent of better quality that can be applied on agricultural land or discharged to surface waters (CH2M Hill, 1997). Wastewater treatment in CWs occurs by a combination of mechanisms, including biochemical conversions, settling/filtration, litter accumulation, and volatilization. Removal of pollutants in CWs is facilitated by shallow water depth (which maximizes the sediment-water interface), slow flow rate (which enhances settling), high productivity, and the presence of aerobic and anaerobic environments (Cronk, 1996).

Wetland media (soil, gravel) and vegetation provide a large surface area that promotes microbial growth. Biochemical conversion of various chemical compounds through microbial activity is the main factor in the wetland treatment process. Through microbial activities, organic N is converted to ammonia (ammonification), which is used by plants as a nutrient; ammonia is converted to nitrate and nitrite (nitrification), which is used by microbes and some plants for growth; and N is volatilized (denitrification) and is lost to the atmosphere (CH2M Hill, 1997). Ammonia may be removed through volatilization, uptake by plants and microbes, or oxidized to nitrate. Volatilization of ammonia in CWs appears to be the most significant mechanism for N removal for animal waste treatment (Payne Engineering and CH2M Hill, 1997).

Phosphorus removal is achieved mainly by fixation by algae and bacteria, plant uptake, and adsorption onto sediments (Cronk, 1996) when oxidizing conditions promote the complexing of nutrients with iron and aluminum hydroxides (Richardson, 1985). Plant uptake of P is only a short-term sink because plant P is rapidly released after the death of plant tissues (Payne Engineering and CH2M Hill, 1997). Fixation of P by microbes ultimately results in the storage of P in the bottom sediments (Corbitt and Bowen, 1994), yet they may become saturated with P, resulting in an export of excess P (Richardson, 1985).

Rooted emergent aquatic plants are the dominant life form in wetlands (Brix, 1993) and are the only aquatic plants recommended for planting in CWs used for animal waste treatment (Payne Engineering and CH2M Hill, 1997). These aquatic plants have specialized structures that allow air to move in and out as well as through the length of the plant, have roots that allow adsorption of gases and nutrients directly from the water column, and are physiologically tolerant to chemical products of an anaerobic environment (Brix, 1993). For these reasons, emergent aquatic plants can survive and thrive in wetland environments. The most common emergent aquatic plants used in CWs for animal waste treatment are cattail (*Typha* spp.), bulrush (*Scirpus* spp.), and common reed (*Phragmites* spp.) (CH2M Hill and Payne Engineering, 1997).

Roles of emergent aquatic plants in the wastewater treatment process include the following: (1) providing a medium for microbial growth and a source of reduced carbon for microbial growth; (2) facilitating nitrification-denitrification reactions; (3) assimilating nutrients into their tissue; (4) facilitating entrapment of solids and breakdown of organic solids; and (5) regulating water temperature by shading the water (Payne Engineering and CH2M Hill, 1997). The vascular tissues of these plants move oxygen from overlying water to the rhizosphere and thus provide aerobic microsites (within the anaerobic zone) in the rhizosphere for the degradation of organic matter and growth of nitrifying bacteria (Brix, 1993). Dissolved nitrates, from nitrification, can then diffuse into the surrounding anaerobic zone where denitrification occurs. Furthermore, wetland macrophytes remove small amounts (<5 percent, Hammer, 1992) of nutrients, for nutritional purposes, by direct assimilation into their tissue. Removal of nutrients, however, increases slightly in CW systems that incorporate periodic harvesting of plants (Hammer, 1992) or may be considerably higher (67 percent) in specially designed systems that maximize influent-root zone contact (Breen, 1990).

The two principal types of CWs for treating wastewater are surface flow (SF) and subsurface flow (SSF) systems. The SF systems are shallow basins or channels, carefully graded to ensure uniform flow, planted with emergent vegetation, and through which water flows over the surface at relatively shallow (~30 cm) depths. The SSF systems consist of a trench or bed with, a barrier to prevent seepage, planted emergent vegetation growing in a permeable media (soil, gravel) designed such that the wastewater flows horizontally through the media, with no open surface flow. The base media and plant roots provide large surface areas for biofilm growth and thus, functions somewhat like a rock trickling filter at a municipal wastewater treatment plant (Payne Engineering and CH2M Hill, 1997).

Some authors also refer to the SF system as the free water surface system, while the SSF type is also referred to as the vegetated rock-reed filter, vegetated submerged bed system, gravel-bed system, and root-zone system. Compared with SSF systems, the SF wetlands are capable of receiving a wider range of wastewater loads, have lower construction costs, and are relatively easy to manage (Payne Engineering and CH2M Hill, 1997). Additionally, mass removal of ammonia-N, the major form of N in animal wastewater (CH2M Hill and Payne Engineering, 1997), in SSF wetlands is significantly less compared with the SF type because there is less time and oxygen to support necessary nitrification reactions (USEPA, 1993). For these reasons, the SF system is the most commonly used wetland type for treating animal waste (Payne Engineering and CH2M Hill, 1997) and is the only one recommended for animal waste treatment by the USDA Natural Resources Conservation Service (USDA NRCS, 1991).

Application and Performance: A database, developed by CH2M Hill and Payne Engineering (1997), containing design, operational, and monitoring information from 48 livestock CW systems (in the United States and Canada), indicates that CWs have been and continue to be used successfully to treat animal waste, including wastewater from dairy, cattle, swine, and poultry operations. The majority of CW sites included in the database have begun operations since 1992. SF systems constitute 84 percent of cells in the database, and the remainder consists of SSF or other wetland systems. Cattail, bulrush, and reed, in that order, dominate the aquatic vegetation planted in the surveyed CWs.

Typically, effluent from a CW treating animal waste is stored in a waste storage lagoon. Final dispersal occurs through irrigation to cropland and pastureland, though the potential for direct discharge of effluent exists. Direct discharge may, however, require a permit under the EPA's National Pollutant Discharge Elimination System.

A performance summary of CWs used for treating animal waste indicates a substantial reduction of suspended solids (53 to 81 percent), fecal coliform (92 percent), BOD_5 (59 to 80 percent), ammonia-N (46 to 60 percent), and N (44 to 63 percent) for wastewater from cattle feeding, dairy, and swine operations (CH2M Hill and Payne Engineering, 1997). In a study by Hammer et al. (1993), swine effluent was treated in five CW cells, located below lagoons, that were equipped with piping that provided a control for variable application rates and water level control within each cell. Performance data indicate notable (70 to 90 percent) pollutant removal rates and reliable treatment of swine lagoon effluent to acceptable wastewater treatment standards for BOD_5, suspended solids, N, and P during the first year of the reported study.

Removal efficiency of N is variable depending on the system design, retention time, and oxygen supply (Bastian and Hammer, 1993). Low availability of oxygen can limit nitrification, whereas a lack of a readily available carbon source may limit denitrification (Corbitt and Bowen, 1994). Fecal coliform levels are significantly reduced (>90 percent) by sedimentation, filtration, exposure to sunlight, and burial within sediments (Gersberg et al., 1990). Compared with dairy systems, higher reduction of pollutants have been reported for swine wastewater treatment in CWs, probably because loading rates have tended to be lower at swine operations (Cronk, 1996).

Advantages and Limitations: In addition to treating wastewater and generating water of better quality, CWs provide ancillary benefits such as serving as wildlife habitat, enhancing the aesthetic value of an area, and providing operational benefits to farm operators and their neighbors (CH2M Hill, 1997). CWs, in contrast to natural wetlands, can be built with a defined (desired) composition of substrate (soil, gravel) and type of vegetation and, above all, offer a degree of control over the hydraulic pathways and retention times (Brix, 1993). An SF system is less expensive to construct than an SSF system, the major cost difference being the expense of procuring and transporting the rock or gravel media (USEPA, 1993). An SSF system, however, has the advantage of presenting an odor- and insect-free environment to local residents.

Major limitations include a need for relatively large, flat land areas for operation (Hammer, 1993), a possible decrease in SF system performance during winter in temperate regions (Brix, 1993), and a reduction in functional sustainability of the SSF systems if the pore spaces become clogged (Tanner et al., 1998). Other limitations include (1) an inadequacy of current designs of SF systems to store flood waters and use stored water to supplement low stream flows in dry conditions and (2) potential pest problems and consequent human health problems from improperly designed or operated SF systems (Hammer, 1993). Moreover, because CW technology for animal waste treatment is not well established, long-term status and effects, including accumulation of elemental concentrations to toxic levels, are poorly documented. Further research is needed to better understand the nutrient removal mechanisms in CWs so that improved designs and operating criteria can be developed.

Operational Factors: Because untreated wastewater from AFOs has high concentrations of solids, organics, and nutrients that would kill most wetland vegetation, wastewater from AFOs is typically pretreated in a waste treatment lagoon or settling pond prior to discharge to a CW (Payne Engineering and CH2M Hill, 1997). Incorporating a waste treatment lagoon in the treatment process reduces concentrations of BOD_5 and solids considerably (>50 percent) and provides storage capacity for seasonal application to the wetlands (Hammer, 1993).

Figure 8-11 shows the typical components and a typical treatment sequence of a CW. Constructed wetlands may be built with cells that are parallel or in a series. Construction of cells needs to be determined by the overall topography as well as by the drainage slope of individual cells to maintain shallow water depth for the wetland plants (CH2M Hill and Payne Engineering, 1997). The land slope should be small (<0.5 percent), and the length-to-width ratios should be between 1:1 and 10:1, with an ideal ratio being 4:1 (USDA NRCS, 1991). Data for the surveyed CWs, reported by CH2M Hill and Payne Engineering (1997), indicate the following average

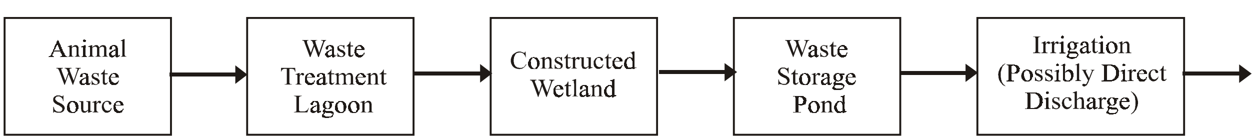

Figure 8-11. Schematic of Typical Treatment Sequence Involving a Constructed Wetland

design conditions: water depth of 38 cm; bottom slope of 0.7 percent; length-to-width ratio of 6.5:1; hydraulic loading rate of 4.7 cm/day; and a size of 0.03 hectare.

Design criteria for CWs for animal waste treatment are described in USDA NRCS (1991), including methods to determine the surface area of a proposed wetland. The NRCS *Presumptive Method* is based on an estimate of BOD_5 loss in the pretreatment process, which is used to calculate BOD_5 concentration in the pretreatment effluent. Size of the wetland is then determined based on a loading rate of 73 kg BOD_5/ha/day that would achieve a target effluent of <30 mg/L of BOD_5, <30 mg/L total suspended solids, and <10 mg/L ammonia-N. The NRCS *Field Test Method* is based on laboratory data for average influent BOD_5 concentration to the CW. The influent BOD_5 concentration, together with average temperature data, is used to determine the hydraulic residence time needed to obtain a desired effluent BOD_5 concentration.

Advances in research and technology of CW during the 1990s have provided additional information to allow modification of the USDA NRCS (1991) methods. CH2M Hill and Payne Engineering (1997) developed the *Modified Presumptive USDA-NRCS Method*, which takes into account pollutant mass loading and volume of water applied, and relates the results to a data table developed from existing CWs for animal waste treatment. The *Field Test Method #2* was also proposed by CH2M Hill and Payne Engineering (1997) based on the areal loading equation developed by Kadlec and Knight (1996), which includes rate constants specific to concentrated animal waste.

Operation and maintenance requirements for CWs include maintenance of water level in the wetland cells, monitoring water quality of influent and effluent, regular inspection of water conveyance and control structures to ensure proper flow, and maintenance of the embankments to avoid damage from rodents.

Demonstration Status: CWs have been demonstrated successfully as a management technology treatment for swine waste (Maddox and Kinglsey, 1990; Hammer et al., 1993) and dairy waste (Chen et al., 1995; Tanner et al., 1995; Schaafsma et al., 2000), and have been relatively less successful in the treatment of poultry waste (Hill and Rogers, 1997). Results of several other successful case studies, performed in several regions of North America, are reported in DuBowy and Reaves (1994), DuBowy (1996), and Payne Engineering and CH2M Hill (1997).

Practice: Vegetated Filter Strips

Description: Vegetated filter strips are an overland wastewater treatment system. They consist of strips of land located along a carefully graded and densely vegetated slope that is not used for crops or pasture. The purpose of a vegetated filter strip is to reduce the nutrient and solids content of wastewater and runoff from animal feeding operations. The filters are designed with adequate length and limited flow velocity to promote filtration, deposition, infiltration, absorption, adsorption, decomposition, and volatilization of contaminants.

The wastewater is distributed evenly along the width of a slope in alternating application and drying periods. The wastewater may be applied to the slope by means of sprinklers, sprays, or

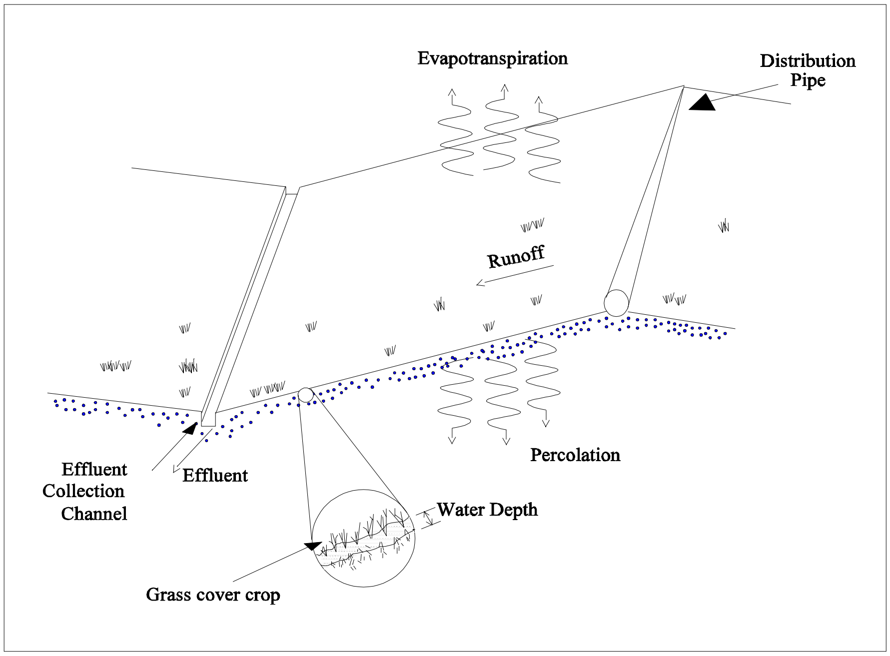

Figure 8-12. Schematic of a Vegetated Filter Strip Used to Treat AFO Wastes

gated, slotted, or perforated pipe. As the wastewater flows down the slope, suspended solids are deposited and some nutrients are absorbed into the vegetation. The effluent from the system is collected in a channel at the bottom of the slope and then discharged (see Figure 8-12).

Application and Performance: The design of a vegetated filter strip is typically based on the BOD concentration of the wastewater (Metcalf and Eddy, 1991). The total treatment area required is calculated from the hydraulic loading rate, assumed length of slope (generally 100 to 150 feet), and an operating cycle. The operating cycle and application rate can be varied to optimize the system. An operating cycle of 1 day is typical, with 8 to 12 hours of application and 12 to 16 hours of drying. Ammonia removal from primary effluent can be expected to vary inversely with the ratio of application period to drying period. A properly designed system can remove up to 95 percent of ammonia. The application rate is critical for considering BOD removal because it is important to maintain aerobic conditions that are required for microbial decomposition. Too high an application rate can create anaerobic conditions because the oxygen transfer through natural aeration from the atmosphere will be insufficient.

The vegetative cover should be dense in growth, such as a grass, and well suited to the climatic conditions. The vegetation must be dense enough to slow the wastewater flow to allow adequate treatment and prevent erosion. Consideration should also be given to the nutrient uptake potential of the vegetation to maximize nutrient removal rates.

Proper grading is also critical to the design of a vegetated filter strip to prevent the channeling of wastewater and allow for efficient treatment. Sites with an existing slope of 2 to 6 percent are best suited for vegetated filter strips to keep regrading costs to a minimum without causing water to pond.

Vegetated filter strips are also best suited to sites that have low permeability soils to prevent wastewater from infiltrating the subsurface. In areas where soils are relatively permeable, it may be necessary to amend the existing soils or install an impermeable barrier.

A study conducted to determine the effectiveness of milkhouse wastewater treatment using a vegetative filter strip at a dairy farm in Vermont (Clausen and Schwer, 1989) found that removals of total suspended solids, total P, and total Kjeldahl N were 92 percent, 86 percent, and 83 percent, respectively. However, the total P concentration in the effluent was more than 100 times greater than the average P concentration of streams draining agricultural areas in the northeast. Moreover, only 2.5 percent of the total input of P and 15 percent of the input of N were removed in the vegetation.

The EPA Chesapeake Bay Program studied the use of vegetative filter strips to reduce agricultural nonpoint source pollutant inputs to the bay (Dillaha et al., 1988). A series of nine experimental field plots were constructed, each containing a simulated feedlot source area and a vegetated filter strip of known length. A rainfall simulator was used to produce runoff, which was collected from the base of each vegetated filter strip. Analysis indicated that 81 to 91 percent of incoming sediment, 58 to 69 percent of the applied P, and 64 to 74 percent of the applied N were removed.

Advantages and Limitations: Compared with many treatment technologies, vegetated filter strips effectively reduce the nutrient and solids concentration of wastewater with relatively low construction and maintenance costs. This is particularly true for sites where available land is well suited for such a system.

However, to effectively treat high volumes of wastewater, such as from a milking parlor, excessive acreage may be required. In addition, because overland flow systems such as vegetated filter strips depend on microbiological activity at or near the surface of the soil, cold weather adversely affects their performance. Winter use of this in colder climates will therefore be limited and an appropriate amount of wastewater storage will be required. Storage is recommended when the average daily temperature is below 32°F.

Operational Factors: Maintenance of a vegetated filter strip consists of periodic removal of the vegetative growth, which contains many of the nutrients. The biomass has various potential uses—as forage, fiber, or mulch, for example. In addition, the slope needs to be periodically inspected and regraded to ensure a level flow surface and prevent channeling and erosion.

Demonstration Status: Vegetated filter strips have been used to treat milkhouse wastewater in New York and North Carolina. They have also been used to treat a variety of other wastes, including feedlot runoff.

Practice: Composting—Aerobic Treatment of Solids

Description: Composting is the aerobic biological decomposition of organic matter. It is a natural process that is enhanced and accelerated by the mixing of organic waste with other ingredients in a prescribed manner for optimum microbial growth. Composting converts an organic waste material into a stable organic product by converting N from the unstable ammonia form to a more stable organic form. The end product is safer to use than raw organic material and one that improves soil fertility, tilth, and water holding capacity. In addition, composting reduces the bulk of organic material to be spread, improves its handling properties, reduces odor, reduces fly and other vector problems, and can destroy weed seeds and pathogens. There are three basic methods of composting: windrow, static pile, and in-vessel.

Windrow composting consists of placing a mixture of raw organic materials in long, narrow piles or windrows, which are agitated or turned on a regular basis to facilitate biological stabilization. Windrows aerate primarily by natural or passive air movement (convection and gaseous diffusion). Windrow composting is suitable for large quantities of organic material. For composting dense materials like manure mixtures, windrows are usually no more than 3 feet high and 10 to 20 feet wide. The equipment used for turning, ranging from a front-end loader to an automatic mechanical turner, determines the size, shape, and spacing of the windrows.

The **static pile method** consists of mixing the compost material and then stacking the mix on perforated plastic pipe or tubing through which air is drawn or forced. Forcing air (by suction or positive pressure) through the compost pile may not be necessary with small compost piles that are highly porous or with a mix that is stacked in layers with highly porous material. If layering is not practiced, the materials to be composted must be thoroughly blended before they are placed in a pile. The exterior of the pile is typically insulated with finished compost or other material. The dimensions of the static pile are limited by the amount of aeration that can be supplied by the blowers and by the stacking characteristics of the waste. The pile height generally ranges from 8 to 15 feet, and the width is usually twice the height. The spacing between individual piles is usually equal to about half the height.

The **in-vessel method** involves the mixing of manure or other organic waste with a bulking agent in a reactor, building, container, or vessel, and may involve the addition of a controlled amount of air over a specific detention time. This method has the potential to provide a high level of process control because moisture, aeration, and temperature can be maintained in some of the more sophisticated units (USDA, 1999).

Application and Performance: Composting is an accepted process for the biological stabilization of the organic material in waste, providing an alternative to long-term liquid and semisolid manure storage. It turns waste organic material (dead poultry, manure, garbage, and so forth) into a resource that can be used as a soil amendment and fertilizer substitute. Proper composting minimizes nutrient loss while killing pathogenic organisms by process generated heat. For example, two waste products from a municipal and a dairy source were composted in the lab under controlled temperature and air flow rates (Hall and Aneshansley, 1997). Researchers found that maintaining high and constant temperatures destroys pathogens and accelerates decomposition.

In general, only manure from confined animals is available for composting. Usually, manure must be dewatered or mixed with sawdust or wood chips to lower the moisture content, which may range from 60 to 85 percent. The presence of plant nutrients such as N, P, and K; the organic content; and the absence of significant levels of heavy metals makes animal manure a very attractive raw material for producing compost. In-vessel composting has been conducted successfully with dairy cattle manure, swine manure, horse manure, and poultry and turkey litter.

Advantages and Limitations: Compost and manure are both good soil conditioners that contain some fertilizer value. On a growing number of farms, however, manure is considered more of a liability than an asset. Animal waste generators may find themselves with surpluses of manure in the winter, yet lacking manure by spring planting. Odor complaints associated with manure are common in populated areas. Other concerns include polluted runoff from manure spread on frozen ground and nitrate contamination of wells.

Composting converts the nutrients in manure into forms that are less likely to leach into ground water or be carried away by surface runoff. Compost releases its nutrients more slowly than commercial fertilizers, so it does not burn crops and can feed them over a longer period of time. The nutrient value of manure was demonstrated in a study in which five combinations of composted cattle feedyard manure and liquid phosphate were applied to provide 100 percent of the P requirement for corn (Auvermann and Marek, 1998). Five replicates were tested for each treatment. No significant difference was determined between corn yields in treatment-by-treatment comparisons, indicating that composted feedlot manure may be an adequate substitute for chemical fertilizers.

A well-managed composting operation generates few odors and flies, and the heat generated by the composting process reduces the number of weed seeds contained in the manure. Composting also reduces the weight, moisture content, and volatility of manure, making it easier to handle and store. Because of its storage qualities, compost can be held for application at convenient times of the year. Composted manure and composted manure solids can also be used as bedding material for livestock.

Different types of in-house, deep litter manure management systems were tested at a 100,000-chicken high-rise layer operation in Georgia (Thompson et al., 1998). Composting was conducted using raw manure, a manure and leaf mixture, and manure and wood chip mixture. The in-house composting was found to reduce the weight and volume of wastes more efficiently than conventional methods of stacking manure under the house. Wood chip and leaf manure both had lower moisture content and more concentrated nutrients compared with the raw manure.

Disposal is less of a problem for compost than for manure because there is usually someone willing to take the compost. One of the strongest incentives for composting is that a market exists for the product, especially in populated areas. Potential buyers include home gardeners, landscapers, vegetable farmers, garden centers, turf growers, golf courses, and ornamental crop producers. Bulk compost prices range from $7 to $50 per cubic yard, depending on the local market, compost quality, and the raw materials used.

Countering these advantages are several limitations. Managing and maintaining a composting operation takes time and money, and compost windrows and storage facilities for raw materials can take land, and possibly building space, away from other farming activities. When processing only small volumes of farm wastes, the equipment needed is probably already available on the farm, but composting may become a very capital- and labor-intensive task for larger operations. Farmers might need to invest in special composting equipment, which can cost anywhere from $7,000 to more than $100,000. The main equipment needed for composting on a moderate to large scale is machinery to construct, mix, and move material in a compost pile or windrow. A front-end loader and truck may be all that is required. Other equipment, such as chipping or shredding equipment, a windrow turner, screening equipment, aeration equipment, and a composting thermometer or temperature probe, might be needed as well.

Although the end product of composting is odor-free, the raw materials used to make compost may not be. Even the compost piles themselves, if not maintained properly, can become malodorous. Cold weather slows the composting process by lowering the temperature of the composting material. Heavy precipitation adds water to the composting mix, and snow and mud can limit access to windrows.

There is also some ambiguity as to whether manure or compost provides crops with more N. Compost can contain less than half the N of fresh manure; however, the N in manure is less stable than that in compost. Farmers must apply more compost than manure to farmland to achieve the same results because compost nutrients are released very slowly. Generally, less than 15 percent of the N in compost is released in the first year.

Last, although compost is a salable product, selling compost involves marketing. This means searching out potential buyers, advertising, packaging, managing inventory, matching the product to the customer’s desires, and maintaining consistent product quality.

In addition to these general limitations, there are specific limitations associated with composting different types of animal manure. Wastes containing excessively high water content, such as poultry manure from egg laying operations and wet manure from free-stall dairy CAFOs, may require additional processing prior to composting. The conditions for optimal composting (see Operational Factors below for greater detail) are not always met with these wastes; for example, the water content is too high (usually greater than 70 percent), the biomass is poorly aerated, and the C:N ratio is often less than 15:1. In these cases, bulking agents such as wood chips or similar wood products are added to make the mix more suitable for efficient composting, but bulking agents must be purchased if not readily available on the farm.   Table 8-17 summarizes some of the key advantages and disadvantages of composting.

Operational Factors: Because composting is a biological process, environmental factors influence organism activity, thus determining the speed of decomposition and the length of the composting cycle. The composting period typically lasts from 3 to 8 weeks for conventional composting methods under normal operating conditions. Users of some highly controlled mechanical systems claim to produce compost in as little as 1 week. The length of time depends upon many factors, including the materials used, temperature, moisture, frequency of aeration, and ultimate use of the material. Conditions that slow the process include lack of moisture, a high C:N ratio, cold weather, infrequent or insufficient aeration, and large or woody materials. A month-long "curing" period usually follows the active composting stage. Curing continues to stabilize the compost but at a much slower pace. At this stage, the compost can be stockpiled without turning or aeration and without the fear of odor problems (Rynk, 2000).

Table 8-17. Advantages and Disadvantages of Composting

Advantages of Composting	Disadvantages of Composting
Compost is an excellent soil conditioner.	Composting is labor and management intensive.
Compost is a salable product.	Selling compost involves marketing costs (advertising, packaging, management, customer service, and so forth).
Compost reduces the weight, moisture content, and activity of manure, making it easier to handle and store.	The composting site, raw materials storage, and compost storage require a large land area.
Composting converts the N content of manure into a more stable organic form. Manure that has been composted provides a better carbon/nitrogen ratio (C:N) in the soil, contains fewer weed seeds, and poses a lower risk of pollution and nuisance complaints (due to less odor and fewer flies).	Nutrients in compost are in complex form and, therefore, need to be mineralized for plant intake; thus a greater volume of compost is needed to meet crop demands.
Composting kills pathogens.	Effectiveness is weather dependent.
Compost is a suitable bedding substitute.	Large operations require expensive equipment
Land-applied compost has proven to suppress soil-borne plant diseases without the use of chemical controls.	Odors can be a recurring problem.
Some farmers have begun accepting payment (referred to as "tipping fees") to compost off-site wastes.	Acceptance of off-site organic wastes may result in the operation being classified as commercial and increase compliance costs under zoning and environmental regulations.

The characteristics of the raw organic material are the most important factors determining the quality of compost, including moisture content, C:N ratio, aeration, material particle size, and temperature. Acceptable and preferred ranges for nutrient balance (C:N ratio), moisture content, pH, and bulk density are provided in Table 8-18 (NREAS, 1992). Additional factors considered when formulating a raw organic material recipe are degradability, odor potential, and cleanness. For example, swine manure is very odorous and should not be composted on locations prone to odor complaints. Cleanness refers to the degree of contamination from unwanted materials (glass and heavy metals), chemicals (pesticides), and organisms (human pathogens). If the compost is to be sold offsite, the raw material content will greatly affect its market value.

The optimum **moisture content** for composting varies with particle size and aeration. At high moisture content, voids fill with liquids and aeration is hindered. Low moisture levels, on the other hand, retard or stop microbial activity, although some composting occurs with moisture as low as 25 percent. Depending on the raw materials, there is ultimately a 30 to 60 percent reduction in volume of the compost material, much of it due to water loss. If the water content falls below 40 to 50 percent, water should be added and mixed into the composting feedstocks. Warm weather enhances water loss from compost windrows by surface evaporation. Increased turning also results in a higher evaporation rate. This can be an advantage if a drier compost is desired, but if the evaporation rate becomes too high, water should be added to reduce potential fire hazards.

Periods of high rainfall can also be a problem for windrow composting. Windrows usually absorb water from normal rainfall or snow without saturating the materials. If the windrows become wetter than desired, more turnings are required to evaporate the added moisture. Rain can also produce muddy conditions, making it difficult to operate turning equipment. Snow can halt operation altogether until plowed from equipment paths. In addition, puddles and standing water can lead to anaerobic conditions at the base of a windrow. It is important that the composting site has adequate drainage to compensate for periods of high rainfall.

Table 8-18. Desired Characteristics of Raw Material Mixes

Characteristic	Reasonable Range	Preferred Range
Carbon to Nitrogen (C:N) Ratio	20:1-40:1	25:1-30:1
Moisture Content	40-65 percent	50-60 percent
pH	5.5-9	6.5-8.5
Bulk Density (lbs/y^3)	Less than 1,100	No preferred range

Source: NREAS, 1992.

Carbon and nitrogen serve as nutrients for the microorganisms, and for efficient composting they should be available in the right balance. A good **C:N ratio** falls between 25:1 and 35:1, although recommendations vary based upon site-specific conditions. For example, a study by Virginia Polytechnic Institute and State University concluded that the best combination of straw and raw swine manure for composting has a C:N ratio of 16:1 and a moisture level of 50 to 70 percent (Collins and Parson, 1993). Above the optimum range of C:N ratio, the materials break down at a slower rate, while a lower ratio results in excess nitrogen loss. For example, a study of poultry litter composting as a function of the C:N ratio and the pH of the starting materials showed that ammonia emissions decreased substantially as the C:N ratio increased through addition of short paper fiber (C:N ratio(> 200:1) to broiler litter (Ekinci et al., 1998). As composting progresses, the C:N ratio will fall gradually because the readily compostable carbon is metabolized by microorganisms and the nitrogen is converted to nitrate and organic forms.

In animal manure, the C:N ratio is usually 10:1 to 15:1. The C:N ratios for different manures vary: poultry litter 10:1, layer manure 5:1, cattle feedlot manure 13:1, dairy manure 18:1, swine feedlot manure 3:1, and horse stable manure 25:1. Bulking materials can be added to increase the C:N ratio in the compost pile. Typical bulking materials include grass clippings (C:N ratio of 12:1 to 25:1); hay (15:1 to 32:1); oak leaves (50:1); shrub and tree trimmings (50:1 to 70:1); straw, cornhusks, and cobs (50:1 to 100:1); pine needles (60:1 to 100:1); sawdust (150:1 to 700:1); wood chips (500:1 to 600:1); or newspaper (400:1 to 850:1). For example, dairy manure is a good substrate for composting because it breaks down quickly and supplies the microorganisms with most of the required nutrients, but it is also nitrogen-rich, excessively wet, and has a carbon-to-nitrogen ratio ranging from 12:1 to 18:1. Moisture content varies from about 75 percent for manure collected from stanchion barns to about 85 percent from free-stall operations, with the variability determined primarily by the amount of bedding used. To make dairy manure more suitable for composting, it must be mixed with bulking agents that can be easily incorporated into the composting mix by using them as bedding.

The feasibility of using sawdust and chopped fescue hay as a low-cost waste carbon source to compost with separated swine manure solids was investigated using 21-liter vessels and bin composting units (Hoehne et al., 1998). Manure and fescue hay produced the lowest C:N ratio in both small and large composting units. Temperature trends were used to indicate biological activity. Composting manure with a carbon source was recommended because the product was easy to transport, appropriate for transport through residential areas, and odor-stable, even though composting is labor intensive.

The rate of air exchange and effectiveness of **aeration** of windrows depends on the porosity of the windrow. For example, a wet, dense windrow containing manure is less porous than a windrow of leaves. Windrows that are too large may result in anaerobic zones occurring near the center and causing odors when the windrow is turned. Periodic turning of window compost piles exposes the decomposing material to the air and keeps temperatures from getting too high (exceeding 170 ^{o}F). The most important effect of turning is rebuilding the windrow's porosity. Turning fluffs up the windrow and restores pore spaces lost from decomposition and settling, thereby restoring oxygen within the pore spaces for microorganisms and improving passive air exchange. Turning also exchanges the material at the surface with material in the interior. The materials compost evenly and, as a result, more weed seeds, pathogens, and fly larvae are destroyed by the high temperatures. The minimum turning frequency varies from 2 to 10 days, depending on the type of mix, volume, and ambient air temperature. As the compost ages, the frequency of turning can be reduced.

A study in Ohio measured ammonia concentrations from dairy manure and rice hulls composted with various aeration rates (Hong et al., 1997). Temperature and ammonia concentrations peaked 48 days after aeration begins and then declined steadily, leveling off after 150 hours. The effect of intermittent aeration on composting swine waste was studied to determine changes in ammonia emissions and dry matter loss (Hong et al., 1998). Continuous and intermittent aeration treatments were tested on composting hog manure amended with sawdust in pilot-scale 200-liter vessels. Ammonia emissions were 39 percent lower from the intermittent aeration treatments, and nitrogen losses as NH_3-N were 26 percent lower for continuous aeration and 14 percent lower for intermittent aeration. Dry solids loss and other physicochemical properties were similar between the two treatments. It was concluded that intermittent aeration may be a practical method of reducing nitrogen loss and ammonia emissions when composting swine manure with sawdust.

Smaller **particle size** provides greater surface area and more access for the degrading organisms. It may be necessary to reduce by grinding the particle size of some material such as corn stalks.

Windrow turning blends raw materials and breaks up particles into smaller pieces, thus accelerating biodegredation through increased surface area.

Heat produced during the composting process raises the **temperature** of the composting materials. Because the heat produced is directly related to the biological activity, temperature is the primary gauge of the composting process. During the first few days of composting, pile temperatures increase to between 104 and 158 ^{o}F. This range enhances the growth and activity of the microorganisms. In addition, temperatures above 131 ^{o}F kill most pathogens, fly larvae, and weed seeds. The high temperature might be maintained for several days, until the microorganisms begin to deplete their food source or until moisture conditions become less than optimal. Mixing the composting feedstock brings more undecomposed food into contact with the microorganisms, replenishing their energy supply. Once the optimum moisture level is restored and the feedstocks have been remixed, the temperature increases again. After the readily decomposable material is depleted, the compost pile no longer heats upon remixing. The temperature continues to drop to ambient, and only very slow decomposition continues.

Although composting can be accomplished year-round, seasonal and weather variations often require operational adjustments. This is especially true for windrow composting. Cold weather can slow the composting process by increasing the heat loss from piles and windrows. The lower temperatures reduce the microbial activity, which decreases the amount of heat generated. To compensate for cold weather, windrows should be large enough to generate more heat than they lose to the environment, but not so large that the materials become excessively compacted. Windrows that are too small can lose heat quickly and may not achieve temperatures high enough to cause moisture to evaporate and kill pathogens and weed seeds.

Demonstration Status: Agricultural composting is experiencing a resurgence of activity, particularly in the northeastern United States. A growing number of farmers are now composting significant quantities of organic materials. These farmers have incorporated composting of a wide variety of organic wastes generated on and off farm into their normal operations. Some own large commercial enterprises; others are small "hobby" farms. A number operate otherwise traditional dairy enterprises, and several are organic vegetable growers. Some use all or most of the finished compost on the farm, and some produce compost and soil mixes as a primary agricultural product. Many use existing on-farm technology to manage the compost piles, and others have invested in specialized compost production equipment.

Several Massachusetts dairy farms have adopted composting as a manure management technique. In a study of five farms practicing composting in that state, it was found that three used the windrow method of composting, one used the passive method, and one experimented with several composting methods, finding the windrow method the most successful (Rynk, 2000). The Rosenholm-Wolfe Dairy farm in Buffalo County, Wisconsin, has successfully produced compost for the commercial market using organic solids separated from manure that had been flushed from a 250-head free-stall barn (Rosenow and Tiry, _____). The raw composting material has a C:N ratio of 30:1 and a moisture content of 60 percent, which is ideal for rapid production of a high-quality product using windrow composting.

A pilot project conducted at the Purdue Animal Science Research Center has shown that composting can be an efficient way to manage waste from dairy farms, hog farms, beef feedlots, and poultry operations at a lower cost than that associated with other waste management methods (*Purdue News,* August 1998). The composting site has 13 rows of compost material, of them each 5 feet tall, 10 feet wide, and 250 feet long. The rows are turned using a specialized windrow turner.

Three fundamental factors driving this renewed interest in composting are environmental and community constraints on traditional manure management options, increased understanding of the agronomic benefits of compost use, and rising disposal costs for such materials as municipal yard waste and food processing wastes, which might be managed for a profit in an agricultural setting. Despite growing interest, however, the environmental and possible economical benefits of composting are challenged by a variety of constraints. An agricultural composting study conducted by Cornell University (Fabian, 1993) concluded that governmental agencies need to take a number of steps to further encourage agricultural composting, including minimizing regulatory constraints on farm-composted materials, encouraging local zoning to allow compost facilities as a normal agricultural operation, providing governmental assistance for composting equipment and site preparation, developing procurement guidelines for state agencies to use compost in preference to peat and topsoil, and supporting research and demonstration programs that explore new applications for compost in the agricultural sector.

Practice: Dehydration and Pelleting

Description: Dehydration is the process by which the moisture content of manure is reduced to a level that allows the waste to be used as a commercial product, such as fertilizer for horticulture.

Applicability and Performance: Dehydration has been used on a variety of animal waste products, including poultry manure and litter. The output material (dried to about 10 percent moisture content) is an odorless, fine, granular material. With a moisture content of from 10 percent to 15 percent, a slight odor may be noted. Crude protein levels of from 17 percent to 50 percent have been reported in dried poultry waste (USEPA, 1974). The material can also be formed into pellets prior to drying. Pelleting can make the material easier to package and use as a commercial fertilizer.

Operational Factors: Manure is collected and dried from an initial moisture content of about 75 percent to a moisture content of from 10 percent to 15 percent. The drying process is usually accomplished using a commercial drier. The input requirement for most commercial driers is that the raw material be mixed with previously dried material to reduce the average moisture content of the input mixture to less than 40 percent water.

The mixture is fed into a hammer mill, where it is pulverized and injected into the drier. An afterburner is generally incorporated to control offensive odors. The resultant dried material is either stockpiled or bagged, depending on the ultimate method of disposal selected. Units reported range in size from small portable units to systems capable of processing 150,000 tons per year (USEPA, 1974).

Advantages and Limitations: The drying of animal waste is a practiced, commercial technology with the dehydrated product sold as fertilizer, primarily to the garden trade. It is an expensive process that can be economical only where the market for the product exists at the price level necessary to support the process.

Development Status: The status of dehydrating animal manure is well established. Full-scale drying operations have been established with animal manure, in some cases since the late 1960s. A number of manufacturers offer a line of dehydration equipment specifically designed for this purpose. At least one large-scale facility, currently under construction on the Delmarva Pennisula, will be used to treat broiler manure.

Practice: Centralized Incineration of Poultry Waste

Description: Centralized incineration is an alternative method of disposing of excess poultry litter. Most poultry litter has energy content and combustion qualities similar to those of other biomass and commercially used alternative fuels (e.g., wood and refuse-derived fuels from municipal trash). Under a centralized incineration approach, poultry litter that is removed from the houses is collected and transported to a centralized facility that has been designed or retrofitted to burn poultry litter. The concentration of the poultry industry in several areas of the country and the dry composition of the manure facilitates litter transport, which is critical to the success of this alternative treatment technology. The centralized incineration unit could be located at a processing plant to provide power to the plant or at a stand-alone facility that would generate power for public use.

Application and Performance: Most of the nutrients in the litter would not be destroyed by combustion, but would be captured in the combustion ash and could be managed safely and economically. Consequently, the most immediate environmental benefit from burning litter is that its nutrients would not be applied to cropland and therefore would not run off into waterways.

Advantages and Limitations: The incineration of poultry litter to generate energy offers several clear advantages over current practices. The energy recovered by burning poultry litter would displace conventional fossil fuels and thereby avoid greenhouse gas emissions. The pollution control equipment required for major fuel burning units would likely minimize other combustion emissions when the manure is burned.

Limitations of using poultry litter as fuel include variability in litter composition, litter production rates, and litter caloric content. One of the most important determinants of the suitability of any substance as a fuel is its moisture content, and there is no guarantee that litter would undergo any sort of drying process prior to combustion. Moisture in a fuel represents a reduction in its heating value because some of its energy content must be used to vaporize the moisture, reducing the fuel's effective energy output. Poultry litter has a much lower British thermal unit (Btu) content, higher moisture content, and higher ash content than conventional fuels. It can pose greater operational problems (such as corrosion) and would probably be convertible to steam at a lower efficiency than conventional fuels. Moreover, because of its much higher ash content, litter will yield far more unburned residuals than other fuels. Metals, P, and K from the litter will concentrate in the residual ash; however, bottom ash and fly ash can be sold as fertilizer, contributing to the profitability of the technology.

Metals (e.g., copper, arsenic, zinc) may be present in litter because they are added to poultry feed as a dietary supplement. Other metals may be unintentionally present in feed and bedding, or may be scraped from the floor of a poultry house when the litter is removed. Aluminum may be found in litter because alum is added to limit ammonia volatilization, and aluminum sulfate is added to bind the P in litter, reducing P in runoff when applied to land. Metals in poultry litter can affect its suitability for combustion in several ways. First, the concentration of metals could affect the nature of air emissions from a poultry-fired boiler. Second, metals might pose a problem in the ash created from litter combustion. Most toxic metals concentrate significantly in combustion ash relative to the unburned litter.

Although litter combustion has significant environmental advantages, adverse environmental impacts might result from using poultry litter as a fuel source. Air emissions and treatment residuals result from the incineration of any fuel, however, and the chemical and physical properties of litter as a fuel do not suggest that burning litter would result in significantly worse pollution emissions than would burning conventional fuels. When compared with the combustion of conventional fuels, combustion of poultry litter produces fewer tons of nitrogen oxides (NO_x), sulfur oxides (SO_x), and filterable particulate matter (PM) emissions at the boiler than coal or residual (No. 6) oil. In comparison with distillate fuel oil, litter has a less desirable emissions profile. A comparison with wood is mixed; litter shows lower emissions of carbon monoxide (CO), filterable PM, and methane, whereas wood shows lower emissions of NO_x, SO_x, and carbon dioxide (CO_2). Despite the high N content of poultry litter, burning litter should not increase NO_x emissions. NO_x emissions from combustion primarily depend on the nature of the combustion process itself (affecting the degree to which atmospheric nitrogen is oxidized) and only secondarily on the amount of N in the fuel. In fact, the high ammonia levels in poultry litter may act to reduce much of the NO_x that is formed during combustion back into elemental N. This is the reaction that underlies most of the modern NO_x control technologies (selective catalytic and noncatalytic reduction) used in utility boilers.

SO_x formation in combustion processes depends directly on the sulfur content of the fuel. Therefore, SO_x emissions from burning poultry litter should be lower than those from high-sulfur fuels (residual oil or higher-sulfur coal) and higher than those from low-sulfur fuels (distillate oil, low-sulfur coal, wood, natural gas). The relatively high alkali (potassium and sodium) content of litter and litter combustion ash may cause problems in the combustion system: a low ash melting point, which can lead to slagging and deposition of “sticky” ash on combustion surfaces, and high particulate emissions in the form of volatile alkali compounds. However, this high alkali ash content also has the likely benefit of reducing SO_x in the flue gas through a “scrubbing” effect. If the uncontrolled emissions from burning poultry litter appear likely to exceed emission standards, an appropriate air pollution control device would be installed at the unit, just as it would be at a conventional fuel-burning unit.

Costs for this technology include cleanout and storage/drying costs, as well as the cost of transporting the litter to the incineration facility. A fuel user might hire a contractor to remove litter from a poultry house and load it onto a truck for delivery, hire a contractor to load the litter and pay a grower for the litter and cleanout, or hire a contractor to get the litter from the shed and load it onto a truck, paying the grower for the litter, cleanout, and storage. In addition, fuel users may also need to install new fuel-handling and management equipment and perform some redesign of the combustion process. Burning litter effectively might entail new plant construction, such as construction of a direct-fired biomass facility, retrofitting of an existing plant for direct firing poultry litter, or retrofitting of an existing cogeneration facility or boiler to co-fire poultry litter with conventional fuels (such as oil or coal). Most operations would also require a storage structure and litter supply system. The costs of retrofitting a processing plant boiler or feed mill boiler to co-fire litter do not appear excessive. The cost savings from burning litter would continue indefinitely and would increase as fuel users find more effective and efficient ways of burning litter.

Operational Factors: One of the first steps in using poultry litter as a fuel is to estimate the amount of litter produced by a feedlot. This amount is then compared with the quantity of litter that could be spread appropriately on local cropland to meet agricultural nutrient needs. The amount by which litter production exceeds the litter needed for crop nutrient purposes is the measure of the amount available for fuel. Several approaches are in use to project the volume of litter that a poultry operation will generate. The differing results of these approaches are mostly a function of the wide range of variables that affect poultry litter production—type of bird, feed and watering programs, bird target weight, type of bedding, litter treatment for ammonia control, house type, crusting procedures, and cleanout schedules. One method uses a calculation of 10.8 lb of manure produced per broiler per year, another assumes an average of 35 lb of manure per 1,000 birds per day, and another assumes an average of 2.2 lb of litter per bird. Other more sophisticated methods apply a rate of litter produced per unit of bird weight produced. However, the most straightforward and commonly used calculation relies on an assumption of 1 ton of litter per 1,000 birds. It should be noted that since a significant portion of the weight of litter is water, having drier litter means fewer tons per bird. Therefore, the 1 ton of litter per 1,000 birds assumption should be treated strictly as a rough estimate.

The most important characteristic of litter with regard to its value as a fuel is its caloric content. Although the energy content of litter varies significantly, there is less variation after it is air-dried or oven-dried. For example, research conducted on the Btu content of several litter samples under varying moisture conditions showed that litter with a moisture content ranging from 0 percent to 30 percent having a caloric content ranging from 7,600 Btu per pound to 4,700 Btu per pound, respectively. Litter has a much lower caloric value than conventional fuels, but it has an energy content similar to that of several other commonly used alternative fuels. In addition, when litter is used as a fuel, its density affects the nature of the fuel feed systems and boiler configurations required. The density of litter also affects how the litter can be stored, handled, transported, and land-applied. Estimates of litter density vary widely, depending largely on the moisture content of the litter. Estimates range from 19 to 40 pounds per ft^3, with the average being roughly 30 pounds per ft^3.

Because poultry litter is quite variable with respect to several characteristics important to its use as a fuel, the fuel user must develop quality control and quality assurance guidelines to ensure that the litter is of consistent quality and well suited for combustion. Criteria for accepting litter may include acquiring only litter that has been covered in storage for some period of time to avoid excessive moisture and increase Btu content per ton, or mixing a large quantity of litter on site prior to burning to reduce fluctuations in quality across individual loads of litter. One plant in operation in the United Kingdom employs the following measures: (1) litter shipments are examined for moisture content with infrared equipment, and shipments with excessive moisture are rejected; (2) core samples are taken and analyzed for moisture, ash, and Btu content; (3) based on the results of the analysis, the load is sorted into one of several storage pits; and (4) an overhead crane draws from the different storage pits in a manner providing an appropriate blend of wet and dry material, giving a reasonably constant caloric value when fed to the furnace.

Demonstration Status: This technology is not currently used in the United States for poultry waste; however, existing boilers could be retrofitted to co-fire litter with conventional fuels such as oil or coal, or litter could be burned in a direct-fired biomass facility to generate electricity, steam, or heat at power plants or in boilers at poultry processing plants to supplement energy needs. Other agricultural and silvicultural wastes such as bagasse, almond shells, rice hulls, and wood wastes are burned for energy recovery in scattered utility and industrial plants in the United States. In the United Kingdom, several medium-sized, profitable electric power plants are fueled by poultry litter. This indicates that centralized incineration of poultry waste has the potential to develop into a commercially viable alternative treatment technology for poultry growers.

A British company, Fibrowatt, conceived of, developed, and operates the electricity plants in the United Kingdom that use poultry litter as fuel. Fibrowatt's three plants (two operating, one under construction) are all new and are all electricity-generating plants rather than industrial boilers for steam heat or cogeneration facilities. Fibrowatt's litter storage and handling system is proprietary. The Fibrowatt plant at Eye in Suffolk, the first plant fueled by poultry litter, came on line in July 1992. The second plant, in Glanford at Humberside, came on line in November 1993. The third and largest plant is at Thetford in Norfolk, which was scheduled to begin operations in 1998.

The basic operations at the three plants are similar. Each plant is situated in the heart of a poultry-producing region. Trucks designed to minimize odor and the risk of biocontamination transport the litter from farms to the power plants. The trucks enter an "antechamber" to the litter storage structure, and the doors of the antechamber are closed before the truck unloads. Upon arrival, the litter is sampled for nearly 40 different traits, including Btu content and moisture. The litter is stored and conditioned in a way that homogenizes the fuel. It is kept under negative pressure to control odor, and the air from the fans in the storage structure is directed to the boilers and used in combustion. The Glanford plant uses Detroit Air-jet spreader-stokers (reciprocating grate, solid-fuel combustors) to burn fuel. The Eye plant employs a stepped grate stoker. The boilers are Aalborg Ciserv three-pass, natural-circulation, single-drum water tube boilers. There are modifications to the ash removal process because the high alkali content of the litter can cause corrosion in the boiler. The steam from the boiler is passed to a turbo-alternator, and electricity is sold to the grid. The Fibrowatt plants are commercially viable in the United Kingdom because the prices Fibrowatt can charge for the electricity delivered to the grid are far higher than the prices charged in the United States. In addition, farmers are charged a disposal fee for their litter, and Fibrowatt is able to earn money on the ash produced by combustion, which the plants collect and sell as concentrated fertilizer with a guarantee analysis. Theoretically, the process could be replicated in the United States, but a full-market study would be needed.

Poultry litter is not currently used as fuel in the United States; however, research into the feasibility of burning litter for electricity, steam, or heat is under way. Maryland Environmental Services (MES) has asked the Power Plant Research Program (PPRP), an arm of the Maryland Department of Natural Resources, to help investigate the possibility of burning poultry litter at the cogeneration plant at the Eastern Correctional Institute. In February 1998, Exeter Associates published a report for MES projecting the costs of various scenarios for using poultry litter at the plant. One of the recommendations in the report was that a full engineering study be done to obtain a better estimate of the costs involved. MES submitted a request for proposals on this basis in April 1998 and received bids from several companies. Among the companies that bid were Fibrowatt and two companies that build gasifiers. As of July 1998, the gasifier company bids had been rejected and the remaining bids were still under consideration. MES is determined to turn the cogeneration plant at the Eastern Correctional Institute into a working facility and is interested in a Fibrowatt-style system, the technology of which is proven and currently operational.

Other Technologies for the Treatment of Animal Wastes

Practice: Aquatic Plant Covered Lagoons

Aquatic plant covered lagoons provide low cost wastewater treatment by removing suspended solids, BOD, N, and P in structures that are mechanically simple, relatively inexpensive to build, and low in energy and maintenance requirements (WPCF-TPCTF, 1990). Wastewater treatment occurs through a combination of mechanisms including biochemical conversion through plant-microbial reactions, plant uptake, settling, volatilization, and adsorption onto sediments. Free-floating aquatic plants such as duckweed (*Lemnaceae*) and water hyacinth (*Eichhornia crassipes*) grow rapidly (in a matter of days) and take up large amounts of nutrients from wastewaters (Reddy and De Busk, 1985). In addition, the extensive root system of water hyacinth provides a large surface area for microbial growth, which promotes degradation of organic matter and microbial transformation of N (Brix, 1993). Greater than 70 percent removal of pollutants by aquatic plant covered lagoons has been reported for domestic wastewater treatment (Orth and Sapkota, 1988; Alaerts et al., 1995; Vermaat and Hanif, 1998). Depending on the lagoon design, water depth, and retention time, effluent from hyacinth and duckweed covered lagoons can potentially meet secondary and sometimes advanced wastewater discharge standards for BOD, suspended solids, N, and P (Buddhavarapu and Hancock, 1991; Bedell and Westbrook, 1997).

In addition to providing wastewater treatment, nutrient uptake by water hyacinth and duckweed produces a protein rich biomass (Reddy and Sutton, 1984; Oron et al., 1988) that can be harvested and used as an agricultural fertilizer or a feed supplement (Oron, 1990). Furthermore, duckweed and hyacinths provide a dense cover that restricts algal growth by impeding sunlight at the water surface (Brix, 1993), reduces odor by preventing gaseous exchange, and acts as a physical barrier to reduce the breeding of mosquitoes (Buddhavarapu and Hancock, 1991). Limitations of aquatic plant covered lagoons include a need for large treatment areas, pretreatment of wastewater in settling ponds, and floating grid barriers to keep plants from drifting (Brix, 1993). Cold temperature reduces the growth rate of floating plants (Brix, 1993). Although duckweed removes fewer nutrients than do water hyacinths (Reddy and De Busk, 1985), duckweed has higher protein and lower fiber, a faster growth rate, and lower harvesting costs (Oron, 1990), and can grow at temperatures as low as 1 to 3 °C (Brix, 1993). Duckweed prefers ammonia over nitrate (Monselise and Kost, 1993), transforms nutrients to a protein-rich (25-30 percent) biomass (Oron, 1990), and selected duckweed species (*Lemna gibba*, *Lemna minor*) have been demonstrated to grow on undiluted swine lagoon effluent (Bergmann et al., 2000). For these reasons, duckweed is potentially effective in the treatment of animal waste. Further studies are needed to understand better the application and performance of aquatic plant covered lagoons for animal waste treatment.

Practice: Nitrification -Denitrification Systems—Encapsulated Nitrifiers

Description: Nitrification-denitrification refers to the biological conversion of ammonium first to nitrate, then to nitrogen gas. Many schemes for nitrification-denitrification have been researched, including the use of nitrifying bacteria encapsulated in polymer resin pellets to speed up the reaction (Vanotti and Hunt, 1998). The theory is that elevated populations of nitrifying bacteria immobilized on resin pellets that are retained in a treatment system will convert more ammonia to nitrate faster than free swimming bacteria. There is ample evidence that attached media systems that retain bacteria on their surface remove the target pollutants more effectively than bacteria that have to swim to their food and can be washed from the system.

Vanotti and Hunt demonstrated in the lab that an enriched solution of encapsulated nitrifiers in an oxygen-saturated solution at 30 ºC, with 150 ppm BOD and 250 ppm TKN, could nitrify 90 percent of the ammonia in a batch if sufficient alkalinity was added. The research also documented that a solution with encapsulated nitrifiers had more and faster nitrification than an aerated equivalent volume of anaerobic lagoon effluent with no nitrifiers added.

A pilot plant using imported pellets operating on anaerobic lagoon effluent followed the laboratory work. The effluent was first screened, and then introduced into a contact aeration treatment to reduce BOD. The aeration sludge was settled next, and then treated effluent was introduced into a nitrification tank in which another aeration blower was used to maintain a dissolved oxygen concentration of 3 milligrams per liter. The pH was maintained at 7.8 or greater with sodium hydroxide as necessary. The results of 3 months of operation were that, given adequate pretreatment, high nitrification rates of swine wastewater could be attained using enriched nitrifying populations immobilized on polymer resins.

Application and Performance: The technology specifically targets nitrification of ammonia, and could reduce the loss of ammonia-N to the atmosphere. When set up and operated properly, the treatment can convert 90 percent of the ammonia-N remaining in pretreated lagoon effluent to nitrate. A nitrified farm effluent can be denitrified easily by either returning it to an anaerobic environment resulting in release of nitrogen gas (N_2). This technology will have little if any effect on pathogens, metals, growth hormones, or antibiotics. It can be assumed that most of these constituents were removed in the process of aerating the manure to reach oxygen-saturated conditions, which would enable the encapsulated nitrifiers to function.

Advantages and Limitations: A facility to support this process would be expensive to build, operate, and maintain. It is difficult to imagine this process being used on a farm. One area not considered is the sludge generated by aerobic pretreatment. Another limitation is the anaerobic lagoon pretreatment step used to reduce initial BOD and limit sludge production.

Operational Factors: Nitrifying bacteria are temperature sensitive, but the effect of temperature was not discussed by Vanotti. Rainfall and varying concentration should not affect performance; however, seasonal temperature variation may reduce nitrification.

Demonstration Status: North Carolina State University has operated a pilot plant in Duplin County, North Carolina.

Disinfection—Ozonation and UV Radiation

Ozonation is commonly used to disinfect wastewater after biological treatment. Ozone is a highly effective germicide against a wide range of pathogenic organisms, including bacteria, protozoa, and viruses. It oxidizes a wide range of organics, can destroy cyanide wastes and phenolic compounds, and is faster-acting than most disinfectants. Moreover, unlike chlorine, ozone does not generate toxic ions in the oxidation process.

UV radiation is used primarily as a disinfectant. It inactivates organisms by causing a photochemical reaction that alters molecular components essential to cell function. It is very effective against bacteria and viruses at low dosages and produces minimal disinfection by-products. To enhance the inactivation of larger protozoa, UV radiation is often considered in conjunction with ozone.

Disinfection measures such as ozonation and UV radiation are not commonly practiced in the United States for treatment of animal wastes. Animal wastewater would require primary and/or biological treatment prior to disinfection . Ozone is generally effective for aqueous waste streams with less then 1 percent organic content. Both processes are costly and require higher levels of maintenance and operator skill. Wastewater with high concentrations or iron, calcium, turbidity, and phenols may not be appropriate for UV disinfection. The effectiveness of UV disinfection is greatly hindered by high levels of suspended solids.

Vermicomposting

Composting is the controlled decomposition of organic materials and involves both physical and chemical processes (see Composting—Aerobic Treatment of Solids). During decomposition, organic materials are broken down through the activities of various invertebrates that naturally appear in compost, such as mites, millipedes, beetles, sowbugs, earwigs, earthworms, slugs, and snails. Vermicomposting is accomplished by adding worms to enhance the decomposition process.

Vermicomposting uses “redworms” (Eisenia foetida), which perform best at temperatures between 50 and 70 ^{o}F. Bones, meats, fish, or oily fats should not be added to a worm compost box because of odors and rodent problems they could create. Successful operation requires a great amount of maintenance because the worms are highly sensitive to alterations in oxygen levels, temperature, moisture, pH, nutrients, and feed composition and volume. Heavy metals are not treated by any means of composting and can be toxic to the microorganisms and invertebrate population.

Farm-scale systems for vermicomposting have been developed. They tend to be simple systems using conventional material-handling equipment. Labor and equipment are required to add material to the bed, remove composted material, separate the compost from the worms by screening, and process the compost and worms for their respective markets (the compost as a protein additive to animal feed; the worms as fish bait). Flies are a potential problem since this process occurs at a lower temperature than the general composting process. Pathogen destruction and drying are also reduced. A drying or heating step may be required to produce the desired compost.

Chemical Amendments

Chemical amendments to poultry litter have been proven to enhance nutrient removal and odor elimination. Ammonia volatilization from poultry litter often causes high levels of atmospheric ammonia in poultry houses, which is detrimental to both farm workers and birds. Ammonia emissions from houses can also result in a loss of fertilizer nitrogen and aggravate environmental problems such as acid rain. Litter amendments, such as aluminum sulfate (alum), ferrous sulfate, and phosphoric acid, have been proven to reduce ammonia volatilization from litter dramatically. Alum has also been shown to reduce water-soluble P concentrations in litter (whereas phosphoric acid greatly increases water-soluble P levels) and alum has the ability to reduce the solubility of metals (arsenic, copper, iron, and zinc), thereby reducing metal concentrations in rainwater runoff. Ferrous sulfate is also effective in reducing soluble P in the runoff from land-applied poultry litter, but is not favored as an option for use inside poultry houses because chickens might ingest the toxic substance.

Odor control is a major concern at many CAFOs. Chemical additives such as potassium permanganate have been used to reduce levels of sulfides, mercaptans, and other odor-causing agents in manure storage structures, particularly lagoons. Large amounts of lime are often added to wastewaters (raising the pH>10) to eliminate odor by reducing microbial activity. Hydrogen peroxide is applied to liquid manure to control sulfides during waste removal and land spreading. Zeolite (a volcanic mineral), cement kiln, and power-plant alkaline by-products are frequently used to reduce volatilization and odors.

Gasification

The fuel produced by gasification is viewed today as an alternative to conventional fuel. A gasification system consists of a gasifier unit, purification system, and energy converters (burners or internal combustion engine). The gasification process thermochemically converts biomass materials (e.g., wood, crop residues, solid waste, animal waste, sewage, food processing waste) into a producer gas containing carbon dioxide, hydrogen, methane and some other inert gases. Mixed with air, the producer gas can be used in gasoline and diesel engines with little modification.

Gasification is a complex process best described in stages: drying, pyrolysis, oxidation, and reduction. Biomass fuels have moisture contents ranging from 5 to 35 percent. For efficient operation of a gasification system, the biomass moisture content must be reduced to less than 1 percent. The second stage of the process, pyrolysis, involves the thermal decomposition of the dried biomass fuels in the absence of oxygen. The next stage, oxidation, produces carbon dioxide and steam. The last stage, reduction, produces methane and residual ash and unburned carbon (char).

Gasification is one of the cleanest, most efficient combustion methods known. It eliminates dependence on fossil fuel and reduces waste dumping. It extracts many substances, such as sulfur and heavy metals, in elemental form. Factors limiting the use of this process include stringent feed size and materials handling requirements. Process efficiency is strongly influenced by the physical properties of the biomass (surface, size, and shape), as well as by moisture content, volatile matter, and carbon content (see Pyrolysis below for additional limitations).

Gasification of animal wastes is still in the developmental stages. It is currently considered a better alternative to incineration for its lower NO_x emissions. However, this treatment option is limited to the animal feed operations that have a market in which to sell the excess power or heat generated by the gasification unit. Without this advantage, such facilities would be inclined to resort to less expensive waste treatment technologies.

Pyrolysis

Pyrolysis is a major part of the gasification process described above. It is formally defined as chemical decomposition induced in organic material by heat in the absence of oxygen. Pyrolysis transforms organic materials into gaseous components, small quantities of liquid, and a solid residue (coke or char) containing fixed carbon and ash. Pyrolysis of organic materials produces combustible gases, including carbon monoxide, hydrogen and methane, and other hydrocarbons. If the off-gases are cooled, liquids condense, producing an oil/tar residue and contaminated water.

Target contaminant groups for pyrolysis are volatile organic compounds and pesticides. The process is applicable for the separation of organics from refinery wastes, coal tar wastes, wood-treating wastes, creosote-contaminated soils, hydrocarbon-contaminated soils, mixed (radioactive and hazardous) wastes, synthetic rubber processing wastes, and paint waste.

Economic factors have limited the applicability of pyrolysis to the animal waste management field. There are also a number of handling factors that limit applicability. Pyrolysis involves specific feed size and materials handling requirements. The technology requires that the biomass be dried to low moisture content (<1 percent). Slight inconsistencies in moisture content and biomass properties (both physical and chemical) greatly increase operational costs. These considerations make it difficult to apply this technology to animal waste. Pyrolysis is not effective in either destroying or physically separating inorganics from the contaminated medium. Volatile metals may be removed as a result of the higher temperatures associated with the process but are not destroyed. Biomass containing heavy metals may require stabilization.

Pyrolysis is still an emerging technology. Although the basic concepts of the process have been validated, the performance data for this technology have not been validated according to methods approved by EPA and adhering to EPA quality assurance/quality control standards. Site characterization and treatability studies are essential for further refining and screening of this process. Pyrolysis has been considered for animal waste treatment as part of the gasification technology, but is currently not in high demand because of operation and maintenance costs.

Freeze Drying and Freeze Crystallization or Snowmaking

Freeze drying involves freezing the waste, which causes the solids and liquids to separate. When the frozen sludge melts, the liquid is easily drained away for reprocessing. The remaining sludge is high in solids, completely stabilized, and capable of being spread on land with conventional agricultural equipment. The process has proven to lower waste management costs by reducing waste volume.

Freeze crystallization, or snowmaking, is a treatment process in which wastewater is turned to snow, thus readily stripping volatile gases from water. Other contaminants are precipitated from the water in a process called atomizing freeze-crystallization. Meltwaters may have a nutrient reduction of up to 60 percent, with almost 100 percent of pathogens killed (MacAlpine, 1997).

Both processes are scarcely utilized due to applicability limitations. These processes are suited only to colder climates. The freeze drying process requires significant storage capacity, and facilities must be capable of storing up to 1 year's production of sludge on site.

Practice: Photosynthetic Purification

A proprietary new animal waste treatment technology, Photosynthetic Purification, uses the nutrients in concentrated animal waste to grow algae and photosynthetic bacteria that yield a harvestable crop (Biotechna, 1998). Photosynthetic Purification technology is reported to treat high-strength, high-moisture waste streams with minimal loss of manure nutrients and generate a clean effluent that can be recycled or safely discharged. The resultant biomass can be used as a high protein animal feed supplement. Nutritional value of the biomass is at least equivalent to that of soy protein. Along with producing a valuable biomass, the main advantage of this technology is that it reduces the potential environmental impact of land application or discharge of animal waste in regions with concentrated animal feeding operations. A possible disadvantage is that animal waste will need to be transported to a processing facility.

The technology has been under development by Biotechna Environmental (2000) Corporation (BE2000) since the early 1990s. Successful tests are reported to have been carried out at pilot scale in Ireland (1994-95) and Connecticut, USA (1998). A laboratory-scale system and a full-scale commercial demonstration plant are planned. Photosynthetic Purification produces high-protein feed supplements and a range of other value added products for the feed and nonfood markets. Because of proprietary information and patent pending status, little information on this technology is currently available to the public.

Deep Stacking of Poultry Litter

Research dating back to the 1960s (Bhattacharya and Fontenot, 1965) has shown that poultry litter has significant nutritive value as a feedstuff for ruminants. Subsequently, concerns about the potential public health impacts of using poultry litter as well as other animal manures as feedstuffs emerged. The presence and impact of pathogens, such as species of Salmonella and Clostridium, in manures being used as feedstuffs was one of these concerns. There have been a number of reports from foreign countries of botulism in animals fed diets containing animal wastes (Fontenot et al., 1996).

For poultry litter, the response to this concern about potential pathogen transmission was the development of the practice known as deep or dry stacking (McCaskey, 1995). It consists simply of piling litter in a conical pile or stack after it is removed from a poultry house and raises in temperature to a maximum of 140 $^\circ$F (60 $^\circ$C) by microbes. Litter with a moisture content exceeding 25 percent may reach temperatures above 140 $^\circ$F if not covered to exclude air.

McCaskey et al. (1990) have shown that higher temperatures produce a material with a “charred” appearance and reduced nutritive value. They reported that excessively heated litter has about 50 percent of the dry matter digestibility of litter that has not been excessively heated. This estimate was based on the percentage of litter dry matter solubilized in rumen fluid after 48 hours. Also, it was observed that the amount of N bound to acid detergent fiber and considered not available approximately tripled in overheated litter.

The practice of deep stacking of poultry litter enhances its value as a feedstuff for ruminants by reducing concern about possible pathogen transmission. However, deep stacked poultry litter cannot be considered pathogen-free because the stacked litter is not mixed out of concern that reaeration will create the potential for excessive heating. Thus, outer regions of the deep stacked litter might not reach the temperatures necessary for pathogen destruction. In reality, deep stacking is composting in which oxygen availability limits the temperature and the degree to which dry matter (volatile solids) are destroyed.

When deep stacking is done in a roofed structure such as a litter storage shed or in covered piles, the potential water quality impacts are essentially nil; however, deep stacking in uncovered piles creates the potential for leaching and runoff losses of nutrients, oxygen-demanding organics, and pathogens, as well as producing a feedstuff with reduced nutritive value. Because of the heat generated, some ammonia volatilization is unavoidable, but is probably no greater than the losses associated with land application. With proper management, odor is not a significant problem.

The impact of deep stacking on land application for litter disposal is a direct function of the ability to market poultry litter as a feedstuff. If such a market exists, on-site land application requirements are reduced or become unnecessary; however, the impact on a larger scale is less clear. Although the utilization of litter N by ruminants can be relatively high, much of the litter P consumed will probably be excreted. Thus, typical values for the P content of beef cattle manure might not be appropriate for developing nutrient management plans for beef operations that feed significant quantities of broiler litter. Also, total manure production by the beef cattle fed poultry litter-amended rations may increase, depending on the dry matter digestibility and the ash content of the litter fed (Martin et al., 1983).

As with the temporary storage of solid poultry manure in a dedicated structure, fire due to spontaneous combustion is a risk associated with deep stacking of poultry litter. Thus, structure design to exclude precipitation and routine monitoring of litter temperature are important operational factors.

Although reliable data regarding the extent of the use of deep stacking are unavailable, anecdotal evidence indicates that the use of poultry litter as a feedstuff for beef cattle is fairly extensive in regions with significant broiler or turkey and beef cattle production. Thus, it appears reasonable to assume that the use of deep stacking is also fairly extensive.

Practice: The Thermo Master™ process

Thermo Tech™ Technologies, Inc., is a Canadian corporation in the business of converting food wastes into a high-energy and high-protein animal feed supplement, and converting municipal wastewater treatment sludges into a fertilizer material. The company has constructed several organic waste conversion facilities, known as "Thermo Master™ Plants," that employ the company's proprietary microbial organic waste digestion technology. The technology is protected by U.S. and Canadian patents with patent applications pending in several other countries.

The Thermo Master™ process was originally developed to create an animal feed supplement from relatively high solids content food wastes such as fruit and vegetable processing wastes and wastes of animal origin including meat, dairy, and fish processing wastes. Animal manures and wastewater treatment sludges also were considered for conversion into a fertilizer material. The process has been modified to enable processing of materials with a lower solids content.

In the Thermo Master™ process, autoheated aerobic digestion is operated at the relatively short residence time of 30 hours to maximize single-cell protein production using the influent waste material as substrate. The effluent from the digestion process is then dried and pelletized.

The Thermo Master™ process could, in theory, be a viable method for poultry and swine carcass disposal. In addition to recovering nutrients for use as an animal feed supplement, the absence of any pollutant discharges is an attractive characteristic of this process. Given that the process operates at thermophilic temperatures, at least a two- to three-log $_{10}$ reduction in pathogen densities should be realized (Martin, 1999). The process, however, has never been used for animal carcass disposal.

As with rendering, the problems of preserving, collecting, and transporting carcasses could limit use of this disposal alternative. A more significant limitation is the lack of any operating Thermo Master™ plants in the United States. Only two plants are in operation as of April, 2000, and they are both located in Canada near Toronto, Ontario. A third, located near Vancouver, British Columbia, is being rebuilt following a fire. Even if new plants were to be constructed in the United States, it is likely that they would be located in or near major metropolitan areas given the nature of the primary sources of process feedstocks. This would exacerbate the problem of carcass transportation.

8.2.3.2 Mortality Management

Improper disposal of dead animals at AFOs can result in ground water contamination and health risks. Most mortality management is accomplished through rendering of the dead animals. Rendering involves heating carcass material to extract proteins, fats, and other animal components to be used for meat, bone, and meal. Beef and dairy operations handle mortality management almost exclusively through rendering operations. In most instances the rendering operation will pick up the dead animals, resulting in no environmental impact on the operation. For this reason, the remainder of this section focuses on swine and poultry mortality management, and it will cover rendering, composting, and incineration.

Mortality Management: Swine

Large swine operations must dispose of significant numbers of dead pigs on a daily basis. For example, a 1,000 sow farrow-to-wean operation with an average of 22 piglets per litter and a pre-wean mortality rate of 12 percent will generate almost 16 tons of piglet carcasses per year, assuming an average weight of 6 pounds per carcass. Assuming an average sow weight of 425 pounds and a sow mortality rate of 7 percent per year, the total carcass disposal requirement increases to over 30 tons per year.

Improper disposal of swine carcasses can lead to surface or ground water contamination, or both, as well as noxious odors and the potential for disease transmission by scavengers and vermin. Historically, burial was the most common method of carcass disposal. Burial has been prohibited in many states, largely because of concerns regarding ground water contamination. The following subsections briefly describe and discuss the principal alternatives to burial for swine carcass disposal: composting, incineration, and rendering.

Practice: Composting

Description: Composting is the controlled decomposition or stabilization of organic matter (Gotaas, 1956). The process may be aerobic or anaerobic. If the composting mass is aerobic and suitably insulated, the energy released in the oxidation of organic carbon to carbon dioxide and water will produce a fairly rapid increase in the temperature of the composting mass. With suitable insulation, thermophilic temperature levels will be reached. The higher temperature increases the rate of microbial activity and results in quicker stabilization. Under anaerobic conditions, the rate of biological heat production is lower because fermentation generates less heat than oxidation, so the temperature increase in the composting mass is less rapid. Thermophilic temperature levels can still be attained with suitable insulation; however, the rate will be slower.

Application and Performance: Composting is a suitable method of carcass disposal for all swine operations. The compost produced can be spread on site if adequate land is available. Another recently cited disposal option for the compost is distribution or marketing as an organic fertilizer material or soil amendment. Thorough curing to preclude development of odor or vermin problems and screening to remove bones are necessary to make marketing a viable option. Another requirement for composting as a method of swine carcass disposal is the availability of a readily biodegradable source of organic carbon, such as sawdust, wood shavings, or straw.

When carcass composting is managed correctly, potential negative impacts on water and air quality are essentially nonexistent, assuming proper disposal of the finished compost. Mismanagement, however, can lead to seepage from the composting mass. This seepage has high concentrations of oxygen-demanding organics, N, and P; is a source of noxious odors; and attracts vermin.

Advantages and Limitations: One of the advantages of swine carcass composting is the relatively low capital cost of the necessary infrastructure. Depending on the volume of carcasses generated daily, one or more of a series of two composting bins are required. These bins should be located on a concrete pad in an open or partially enclosed shed-like structure. Critical to this capital cost advantage is the availability of a skid-steer or tractor-mounted front-end loader for handling materials. Federal and, in some instances, state cost sharing has been used to encourage the construction and use of swine mortality composting facilities.

A recent comparison of carcass composting and incineration for disposal of poultry mortalities suggests that the lower capital cost of carcass composting is offset by higher labor costs (Wineland et al., 1998). The development of more fuel-efficient incinerators has made incineration more cost competitive in recent years.

While the temperatures that can be attained in a mass of composting carcasses (130 to 150 °F) will result in significant reductions in pathogen densities, finished swine mortality compost cannot be considered pathogen-free. Therefore, appropriate biosecurity measures are necessary in the handling and ultimate disposal of the finished compost. Collection of carcasses by renderers presents a higher biosecurity risk, especially the risk of introducing disease from other operations. In contrast, the ash from carcass incineration is sterile.

Carcass composting in the swine industry appears to be best suited for the disposal of pre-wean and nursery mortalities because of the relatively small size of these carcasses. For larger animals (sows, gilts, boars, and feeder pigs), at least partial carcass dismemberment, an unpleasant task, is necessary.

Operational Factors: In the composting of swine mortalities, a single layer of carcasses or carcass parts is placed on a layer of the carbon source and finished compost or manure, followed by another layer of the carbon source and finished compost, and then carcasses. The pattern is repeated until a height of about 5 feet is reached. The pile is capped with a carbon source. Inadequate moisture will retard decomposition, whereas too much moisture will result in anaerobic conditions and process failure.

A proper facility is critical to the success of composting swine carcasses. As noted above, one or more of a series of two composting bins are required depending on the daily volume of carcasses generated. To maximize the rate of carcass decomposition and also to ensure complete decomposition of soft tissue, the composting mass should be transferred to a second bin after about 2 weeks of decomposition. This transfer process results in both mixing and aeration of the composting mass. Following an additional 2 weeks, the compost should be ready for storage and curing or ultimate disposal. While satisfactory decomposition can be realized without transfer and mixing, the time required is significantly longer.

Also critical to the success of composting swine carcasses is the initial combination of carcasses, a source of biodegradable carbon such as sawdust or chopped straw, a source of adapted microorganisms, and moisture. Although some cooperative extension publications recommend using manure as the source of an adapted microbial population, finished compost is equally suitable (Martin and Barczewski, 1996). The ratio, on a volume basis, of these ingredients should be 1 part carcasses, 1.5 parts of the carbon source, 0.5 to 0.75 part finished compost, and 0 to 0.5 part water. The objective is to create an initial C to N ratio of 20:1 to 30:1.

Demonstration Status: The first use of composting for animal carcass disposal occurred in the poultry industry during the 1980s (Murphy, 1988; Murphy and Handwerker, 1988). Since that time, this method of carcass disposal has also been adopted by the swine industry. It was estimated that 10.5 percent of swine operations use composting for mortality disposal (USDA APHIS, 1995).

Practice: Incineration

Description: Incineration or cremation is the reduction of swine carcasses to ash by burning at a high temperature under controlled conditions using specially designed equipment. Incineration temperatures can be as high as 3,500 °F, depending on equipment design. Incinerators using natural gas, propane, or No. 2 distillate fuel oil as a fuel are available.

Application and Performance: Incineration of swine carcasses is applicable to all operations where the cost of the equipment required can be justified by the volume of carcasses generated.

The potential for surface or ground water contamination associated with incineration is minimal, provided that liquid fuel tanks are contained properly and residual ash is disposed of properly. The P, K, and other elements contained in the carcasses are concentrated in the ash. Because of the high temperature of incineration, this ash is pathogen-free if cross-contamination with carcasses is avoided.

Odors and other air quality concerns led to a significant decline in carcass incineration in the past. Newly designed equipment, however, incorporates secondary combustion of stack gases, essentially eliminating these problems. Yet the emission of low levels of some air pollutants is unavoidable, as with any combustion process. Improper operation of the incinerator (e.g., reducing process temperature by overloading) can result in unacceptably high air pollutant emissions.

Advantages and Limitations: One of the more attractive aspects of incineration relative to other swine carcass disposal options, such as composting and rendering, is the complete destruction of pathogens. Another advantage is the relatively small mass of residual material (ash) requiring some form of ultimate disposal, especially in comparison with composting. Moreover, incineration has a relatively low labor requirement.

The principal perceived limitation of incineration is cost. The initial investment required is relatively high. A recent comparison of incineration and composting costs for poultry carcass disposal, however, suggests that the former has become cost competitive with the latter because of lower labor costs and improvements in incinerator fuel efficiency (Wineland et al., 1998).

Another limitation of incineration for swine carcass disposal is fixed capacity. This can be problematic when disease or other factors such as heat stresses cause a sizable increase in the rate of mortality.

Operational Factors: Because of the fixed capacity of incineration equipment, incineration of swine carcasses must occur on a regular basis. Ideally, carcass incineration should occur at least on a daily basis to minimize the potential for disease transmission. Routine maintenance of incineration equipment is also important to ensure reliability and minimize emission of air pollutants. An air pollutant emissions permit, a siting permit, or both, may be required for an incinerator.

Demonstration Status: Incineration has been used in the swine industry as a method of carcass disposal for many years. With recent technological advances in incinerator fuel efficiency and odor control, a reversal in the shift away from incineration and to other carcass disposal options, such as composting, may occur. It was estimated that 12.5 percent of swine operations use incineration, described as burning, for mortality disposal (USDA APHIS, 1995).

Practice: Rendering

Description: Rendering is the process of separating animal fats and proteins, usually by cooking. The recovered proteins are used almost exclusively as animal feedstuffs, while the recovered fats are used both industrially and in animal feeds.

There are two principal methods of rendering (Ensminger and Olentine, 1978). The first and older method uses steam under pressure in large closed tanks. A newer and more efficient method is dry rendering, in which all of the material is cooked in its own fat by dry heat in open steam-jacketed drums until the moisture has been evaporated. One advantage of dry rendering is the elimination of a separate step to evaporate the moisture in the material being rendered. Cooking temperatures range from 240 to 290 °F. Rendering can be a batch or a continuous flow process.

The two basic protein feedstuffs derived from rendering are meat meal and meat and bone meal. The basis for this differentiation is P content (National Academy of Sciences, 1971). Meat meal contains a maximum of 4.4 percent P on an as-fed basis. Meat and bone meal contains a minimum of 4.4 percent P.

Application and Performance: Most of the animal fat and protein recovered by rendering is derived from meat and poultry processing, but rendering can also be used to recover these products from swine carcasses. The ability to use rendering as a method of swine carcass disposal depends on the presence of a rendering facility servicing the area. Rendering plants are not widely distributed and are generally located near meatpacking and poultry processing plants. As the meatpacking and poultry processing industries have consolidated into fewer but larger operations, a similar pattern of consolidation in the rendering industry has also occurred. Because swine carcasses have minimal monetary value as a raw material for rendering, transportation only over limited distances can be justified economically.

Rendering is a capital-intensive process and requires careful process control to generate acceptable products. In addition, product volume has to be substantial to facilitate marketing. Because on-farm rendering is unlikely to be a viable option for swine carcasses, performance measures are not included.

Advantages and Limitations: For swine producers, disposal of mortalities by rendering has several advantages. One is that capital, managerial, and labor requirements are minimal in comparison with other carcass disposal options. A second advantage is the absence of any residual material requiring disposal, as is the case with both composting and incineration, albeit to a lesser degree. If carcass volume is adequate to justify daily pickup by the renderer, capital investment for storage is also minimal.

As discussed above, rendering is a feasible option for swine carcass disposal only if the swine production operation is located in an area serviced by a rendering plant. Also, not all rendering operations will accept mortalities, largely because of concerns about pathogens in the finished products.

Well-managed rendering operations will not accept mortalities more than 24 hours after death because of the onset of decomposition of fats and proteins, adversely affecting the quality of the final products. For swine operations that do not generate an adequate volume of carcasses to justify daily pickup by the renderer, carcass preservation by freezing, for example, is a necessity. While preservation of piglet carcasses by freezing may be justifiable economically, the cost of preserving larger animals is probably not justifiable because payment by renderers for carcasses is usually nominal at best. Typically, payment is no more than one to two cents per pound. Payment can be less, or there may even be a charge for removal, depending on transport distance.

Operational Factors: Since renderers usually pick up carcasses, stringent biosecurity precautions are essential to prevent disease transmission by vehicles and personnel serving several swine operations. Ideally, trucks should be disinfected before entering individual farms, and collection personnel should use disposable shoe coverings. Also, necessary carcass preservation measures should be employed to ensure that the renderer will continue to accept carcasses.

Demonstration Status: It was estimated that 32 percent of swine operations use rendering for mortality disposal, with 25.1 percent allowing the renderer to enter the operation and 6.9 percent placing carcasses at the perimeter of the operation for pickup (USDA APHIS, 1995).

Mortality Management: Poultry

Large poultry operations generate significant numbers of dead birds on a daily basis. For example, a flock of 50,000 broilers with an average daily mortality of 0.1 percent (4.9 percent total mortality) will result in approximately 2.4 tons of carcasses over a 49-day grow-out cycle (Blake et al., 1990). A flock of 100,000 laying hens averaging a 0.5 percent monthly mortality (6 percent annual mortality) will generate 11.25 tons of carcasses per year (Wineland et al., 1998). For a flock of 30,000 turkeys averaging 0.5 percent weekly mortality (9 percent total mortality), approximately 13.9 tons of carcasses will require disposal (Blake et al., 1990).

Improper disposal of poultry mortalities can lead to surface or ground water contamination, or both, as well as noxious odors and the potential for disease transmission by scavengers and vermin. The following subsections briefly describe and discuss the principal alternatives to burial used for dead bird disposal: composting, incineration, and rendering. Burial of dead birds has been prohibited in many states, principally because of concerns regarding ground water contamination. These alternatives for carcass disposal are also used in the swine industry and have been described in the previous section. Differences between the two sectors, however, are briefly noted.

Practice: Composting

Description: The general description of composting presented in the preceding section on swine mortality management also applies to poultry.

Application and Performance: As with swine, composting as a method of carcass disposal is suitable for all poultry operations. The compost produced can be spread on site if adequate land is available. Another disposal option for the compost is distribution or marketing as an organic fertilizer material or soil amendment. Thorough curing to preclude development of any odor or vermin problems and screening to remove bones are necessary to make marketing of carcass compost disposal a viable option. Another requirement for composting as a method of poultry carcass disposal is the availability of a readily biodegradable source of organic carbon such as sawdust, wood shavings, or straw.

When poultry carcass composting is managed correctly, potentially negative impacts on water and air quality are essentially nonexistent, assuming proper disposal of the finished compost. Mismanagement, however, can lead to seepage from the composting mass. This seepage has high concentrations of oxygen-demanding organics, N, and P; is a source of noxious odors; and attracts vermin.

Advantages and Limitations: As with swine carcass disposal, one of the advantages of poultry carcass composting is the relatively low capital cost of the necessary infrastructure, especially when compared with incineration. Depending on the volume of carcasses generated daily, one or more of a series of two composting bins are required. These bins should be located on a concrete pad in an open or partially enclosed shed-like structure. Critical to this capital cost advantage is the availability of a skid-steer or tractor-mounted front-end loader for handling materials. Federal and, in some instances, state and integrator cost sharing has been used to encourage the construction and use of poultry mortality composting facilities.

A recent comparison of carcass composting and incineration for disposal of poultry mortalities suggests, however, that the lower capital cost of carcass composting is offset by higher labor costs (Wineland et al., 1998). The development of more fuel-efficient incinerators has made incineration more cost competitive in recent years.

While the temperatures that can be attained in a mass of composting carcasses (130 to 150 °F) will result in significant reductions in pathogen densities, finished poultry mortality compost cannot be considered pathogen-free. Therefore, appropriate biosecurity measures are necessary in the handling and ultimate disposal of the finished compost. Collection of carcasses by renderers presents a higher biosecurity risk, especially the risk of introducing disease from other operations. In contrast, the ash from carcass incineration is sterile.

Operational Factors: In the composting of poultry mortalities, a single layer of carcasses is placed on a layer of the carbon source and finished compost or litter, followed by another layer of the carbon source and finished compost, and then carcasses. The pattern is repeated until a height of about 5 feet is reached. The pile is capped with a carbon source. Inadequate moisture will retard decomposition, while too much moisture will result in anaerobic conditions and process failure.

A proper facility is critical to the success of composting poultry carcasses. As noted above, one or more of a series of two composting bins are required depending on the daily volume of carcasses generated. To maximize the rate of carcass decomposition and also to ensure complete decomposition of soft tissue, the composting mass should be transferred to a second bin after about 2 weeks of decomposition. This transfer process results in both mixing and aeration of the composting mass. Following an additional 2 weeks, the compost should be ready for storage and curing or ultimate disposal. While satisfactory decomposition can be realized without transfer and mixing, the time required increases significantly.

Also critical to the success of composting poultry carcasses is the initial combination of carcasses, a source of biodegradable carbon such as sawdust, wood shaving, or chopped straw, a source of adapted microorganisms, and moisture. Although some cooperative extension publications recommend using litter or cake as the source of an adapted microbial population, finished compost is equally suitable (Martin and Barczewski, 1996). Martin et al. (1996) have suggested that use of cake be avoided. One recommendation, on a volume basis, is 1 part dead birds, 1.5 parts straw, 0.5 to 0.75 part litter, and 0 to 0.5 part water (Poultry Water Quality Handbook, 1998). Sawdust or shavings have been used successfully in place of straw. Basically, this same combination of materials is used for swine carcass composting. Again, the objective is to create an initial C to N ratio of 20:1 to 30:1.

Demonstration Status: The first use of composting for animal carcass disposal occurred in the poultry industry during the 1980s (Murphy, 1988; Murphy and Handwerker, 1988). Currently, composting for disposal of poultry mortalities is readily accepted by producers and used extensively. In a recent survey of broiler producers on the Delmarva Peninsula, 52.7 percent of 562 respondents reported using composting for dead bird disposal (Michel et al., 1996).

Practice: Incineration

Description: The general description of incineration presented in the precedingsection on swine mortality management also applies to poultry.

Application and Performance: As with swine, the use of incineration for poultry carcass disposal is applicable to all operations where the cost of the equipment required can be justified by the volume of carcasses generated.

As with swine carcass incineration, the potential for surface or ground water contamination associated with incineration is minimal, provided that liquid fuel tanks are properly contained and residual ash is disposed of properly. The P, potassium, and other elements contained in the carcasses are concentrated in the ash. Because of the high temperature of incineration, this ash is pathogen-free if cross-contamination with carcasses is avoided.

Odors and other air quality concerns led to a significant decline in carcass incineration in the past. Newly designed equipment, however, incorporates secondary combustion of stack gases, essentially eliminating these problems. Yet the emission of low levels of some air pollutants is unavoidable, as with any combustion process. Improper operation of the incinerator (e.g., reducing process temperature by overloading) can result in unacceptably high air pollutant emissions.

Advantages and Limitations: One of the more attractive aspects of incineration relative to other poultry carcass disposal options, such as composting and rendering, is the complete destruction of pathogens. Another advantage is the relatively small mass of residual material (ash) requiring some form of ultimate disposal, especially in comparison with composting. Moreover, incineration has a relatively low labor requirement.

The principal perceived limitation of incineration is cost. The initial investment required is relatively high. A recent comparison of incineration and composting costs for poultry carcass disposal, however, suggests that the former has become cost competitive with the latter because of lower labor costs and improvements in incinerator fuel efficiency (Wineland, et al., 1998).

Another limitation of incineration for poultry carcass disposal is fixed capacity. This can be problematic when disease or other factors such as heat stresses cause a sizable increase in the rate of mortality.

Operational Factors: Because of the fixed capacity of incineration equipment, incineration of poultry carcasses must occur on a regular basis. Ideally, carcass incineration should occur at least on a daily basis to minimize the potential for disease transmission. Routine maintenance of incineration equipment is also important to ensure reliability and minimize emissions of air pollutants. An air pollutant emissions permit, a siting permit, or both, may be required for an incinerator.

Demonstration Status: Incineration has been used to a limited degree in the poultry industry for carcass disposal for many years. In recent years, cost and odor problems resulted in a shift away from incineration to more seemingly attractive options such as composting. In a recent survey of broiler producers on the Delmarva Peninsula, only 3.3 percent of 562 respondents reported using incineration for dead bird disposal (Michel et al., 1996). Improvements in fuel efficiency and odor control, however, have renewed interest in this option for carcass disposal.

Practice: Rendering

Description: The general description of rendering presented in the previous section on swine mortality management also applies to poultry.

Application and Performance: As with swine, the ability to use rendering as a method of poultry carcass disposal depends on the presence of a rendering facility servicing the area. Because on-farm rendering is unlikely to be a viable option, performance measures are not included.

Advantages and Limitations: Rendering has the same advantages for poultry producers that it has for swine producers: (1) minimal managerial and labor requirements; and (2) the absence of any residual material requiring disposal.

Limitations include the need to preserve carcasses, because many operations will not generate a sufficient volume of carcasses to justify daily collection by a renderer. Several options have been demonstrated to be technically feasible for poultry carcass preservation. They include freezing, preservation using organic or mineral acids (Malone et al., 1998; Middleton and Ferket, 1998), preservation using sodium hydroxide (Carey et al., 1997), and lactic acid fermentation (Dobbins, 1988; Murphy and Silbert, 1990). All of these preservation strategies increase the cost of carcass disposal, and all but freezing increase labor requirements.

Another factor limiting the use of rendering for poultry carcass disposal is the problems that feathers create in the rendering process. Feathers absorb the fat separated by rendering and make the product difficult to handle and market. Feathers also dilute the nutritional and resulting market value of poultry by-products meal, especially when used as a feedstuff for nonruminant animals which cannot digest feathers.

Although feathers can be removed by hydrolysis, cooking at high temperature under pressure, protein quality is degraded. It has been shown, however, that feathers can be removed successfully up to 24 hours postmortem, using a batch scalding and picking system (Webster and Fletcher, 1998). Thus, renderers with feather picking equipment can accept significant quantities of poultry mortalities without compromising product quality.

Operational Factors: As with swine, stringent biosecurity precautions are essential to prevent disease transmission by vehicles and personnel serving several poultry operations. Moreover, carcass preservation measures are generally necessary.

Demonstration Status: Overall, the use of rendering for disposal of poultry mortalities is minimal because of the necessity of carcass preservation and the problem of feathers described above. In a recent survey of broiler producers on the Delmarva Peninsula, none of the 562 respondents reported using rendering for dead bird disposal (Michel et al., 1996). One of the major broiler integrators, however, is currently evaluating the use of rendering after the grower preserves the carcasses by freezing. The integrator supplies the freezer and the grower pays for the electricity. Preliminary indications are that the growers are pleased with this approach.

8.3 Nutrient Management Planning

Nutrient management is a planning tool farmers use to control the amount, source, placement, form, and timing of the application of nutrients and soil amendments (USDA NRCS, 1999). Planning is conducted at the farm level because nutrient requirements vary with such factors as the type of crop being planted, soil type, climate, and planting season. The primary objective of a nutrient management plan is to balance crop nutrient requirements with nutrient availability over the course of the growing season. By accurately determining crop nutrient requirements, farmers are able to increase crop growth rates and yields while reducing nutrient losses to the environment.

Proper land application of manure is dependent on soil chemistry, timing of application, and recommended guidelines for applying at agronomic rates (the amount of manure or commercial fertilizers needed to provide only the amount of a particular nutrient that will be used by a specific crop or crop rotation). Manure is an excellent organic fertilizer source and is a soil amendment that benefits a soil's chemical, physical, and biological properties. The predominant chemical benefit of manure to the soil is the supply of the major plant nutrients—N, P, and K. In addition, livestock manure supplies micronutrients and non-nutrient benefits such as organic matter, which are advantageous to plant growth. The organic matter increases the nutrient- and water-holding capacity of the soil and improves the physical structure. Finally, manure is a source of food and energy for soil microorganisms, which can directly and indirectly benefit the physical, chemical, and biological properties of the soil. The combination of these non-nutrient benefits to soil health has been found to boost corn yields by 7 percent, soybean yields by 8 percent, and alfalfa yields by 9 percent (Vetsch, 1999).

In spite of the benefits listed above, repeated applications of manure can cause high levels of N, P, K, and other micronutrients, as well as acidify soils and increase salinity. Excessive application of these nutrients can lead to surface runoff or leaching. Therefore, land application of manure, if improperly managed, can contribute to the degradation of surface water and ground water (Liskey et al., 1992). Excessive amounts of some nutrients in soils can also reduce crop yields (Brown, 1995).

More efficient use of fertilizer, animal manure, and process wastewater can result in higher yields, reduced input requirements, greater profits, and improved environmental protection. It is possible to further reduce fertilizer expenses and diminish water pollution by employing specific farming practices that help to reduce nutrient losses from manured fields. The best ways to conserve manure P and K are to apply only the amount of manure needed to meet the crop's nutrient needs and use conservation practices that reduce erosion and runoff from fields. This approach also aids in preventing N losses, but N management must also include proper handling, storage, treatment, and timing of manure application and incorporation into the soil.

CNMPs and PNPs:

When the sources of nutrients used on a farm include animal manure and process wastewater, manure management planning is incorporated within what is referred to by USDA (and described in Section 8.3.1) as a comprehensive nutrient management plan or CNMP (USEPA, 1999b). EPA is proposing to require all CAFO operators to develop and implement a Permit Nutrient Plan, or PNP. A PNP is a site-specific plan that describes how the operator intends to meet the effluent discharge limitations and other requirements of the NPDES permit. EPA's PNP and USDA's voluntary CNMP are very similar, and EPA used USDA's *Technical Guidance for Developing Comprehensive Nutrient Management Plans* as the template for developing the PNP. The PNP, however, establishes specific regulatory requirements that must be followed by CAFO operators to ensure adequate protection of surface water. The PNP is also narrower in scope than a CNMP since the CNMP guidance addresses certain aspects of CAFO operations that are not included as part of EPA's effluent guidelines and standards. For example, the CNMP guidance indicates that a CNMP should include insect control activities, disposal of animal medical wastes, and visual improvement considerations, but EPA's proposed regulations and PNP do not include such requirements.

The proposed PNPs are intended to be living documents that must be updated as circumstances change. As the primary planning document for determining appropriate practices at the CAFO, the PNP must be developed and modified by a certified nutrient management specialist. The PNP is intended to establish the allowable manure application rate for land applying manure and wastewater and to document how the rate was derived. The PNP would also describe other site-specific conditions that could affect manure and wastewater application, sampling techniques to be used in sampling manure and soils, the calibration of manure application equipment, and operational procedures for equipment used in the animal production areas.

8.3.1 Comprehensive Nutrient Management Plans (CNMPs)

As discussed in the USDA-EPA Unified National Strategy for Animal Feeding Operations (USEPA, 1999b), site-specific CNMPs may include some or all of the six components described below, based on the operational needs of the facility. Many of the CNMP components described in the strategy have been addressed in other parts of this document and are cross-referenced below. This section focuses on parts of component 2 (Land Application of Manure and Wastewater) and component 4 (Record Keeping), however, all six of the CNMP components, as described in the strategy, are presented here to illustrate what a CNMP may contain.

Component 1: Manure and Wastewater Handling and Storage: This portion of a CNMP, addressed more fully in Section 8.2, identifies practices for handling and storing manure to prevent water pollution. Manure and wastewater handling and storage practices should also consider odor and other environmental and public health concerns. Handling and storage considerations include the following:

- Clean water diversion. Siting and management practices should divert clean water from contact with feedlots and holding pens, animal manure, or manure storage systems. Clean water can include rain falling on the roofs of facilities, runoff from adjacent land, and other sources.

- Leakage prevention. Construction and maintenance of buildings, collection systems, conveyance systems, and permanent and temporary storage facilities should prevent leakage of organic matter, nutrients, and pathogens to ground or surface water.

- Adequate storage. Liquid manure storage systems should safely store the quantity and contents of animal manure and wastewater produced, contaminated runoff from the facility, and rainfall. Dry manure, such as that produced in broiler and turkey operations, should be stored in production buildings or storage facilities or otherwise stored in such a way as to prevent polluted runoff. The location of manure storage systems should consider proximity to water bodies, floodplains, and other environmentally sensitive areas.

- Manure treatments. Manure should be handled and treated to reduce the loss of nutrients to the atmosphere during storage; make the material a more stable fertilizer when applied to the land; or reduce pathogens, vector attraction, and odors, as appropriate.

- Management of dead animals. Dead animals should be disposed of in a way that does not adversely affect ground or surface water or create public health concerns. Composting and rendering are common methods used to dispose of dead animals.

Component 2: Land Application of Manure and Wastewater: Land application is the most common, and usually the most desirable, method of using manure and wastewater because of the value of the nutrients and organic matter they contain. Land application should be planned to ensure that the proper amount of nutrients are applied in a manner that does not adversely affect the environment or endanger public health. Land application in accordance with the CNMP should minimize the risk of adverse impacts on water quality and public health. Considerations for appropriate land application should include the following:

- Nutrient balance. The primary purpose of nutrient management is to achieve the level of nutrients (e.g., N and P) required to grow the planned crop by balancing the nutrients already in the soil and provided by other sources with those which will be applied in manure, biosolids, and commercial fertilizer. At a minimum, nutrient management should prevent the application of nutrients at rates that will exceed the capacity of the soil and the planned crops to assimilate nutrients and prevent pollution. Soils, manure, and wastewater should be tested to determine nutrient content.

- Timing and methods of application. Care must be taken when applying manure and wastewater to the land to prevent them from entering streams, other water bodies, or environmentally sensitive areas. The timing and methods of application should minimize the loss of nutrients to ground or surface water and the loss of N to the atmosphere. Manure and wastewater application equipment should be calibrated to ensure that the quantity of material being applied is what was planned. These topics are discussed in Section 8.4.

Component 3: Site Management: Tillage, crop residue management, grazing management, and other conservation practices should be used to minimize movement to ground and surface water of soil, organic material, nutrients, and pathogens from lands to which manure and wastewater are applied. Forest riparian buffers, filter strips, field borders, contour buffer strips, and other conservation practices should be installed to intercept, store, and use nutrients or other pollutants that might migrate from fields to which manure and wastewater are applied. Site management is addressed in Section 8.4.

Component 4: Record Keeping: CAFO operators should keep records that indicate the quantity of manure produced and how the manure was used, including where, when, and the amount of nutrients applied. Soil and manure testing should be incorporated into the record keeping system. The records should be kept after manure leaves the operation.

Component 5: Other Utilization Options: Where the potential for environmentally sound land application is limited, alternative uses of manure, such as sale of manure to other farmers, centralized treatment, composting, sale of compost to other users, and using manure for power generation may also be appropriate. Several of these options are described in Section 8.2. All manure use options should be designed and implemented in such a way as to reduce risks to human health and the environment, and they must comply with all relevant regulations.

Component 6: Feed Management: Animal diets and feed may be modified to reduce the amounts of nutrients in manure. Use of feed management activities, such as phase feeding, amino acid-supplemented low-protein diets, use of low-phytate-phosphorus grain, and enzymes such as phytase or other additives, can reduce the nutrient content of manure, as described in Section 8.1. Reduced inputs and greater assimilation of P by the animal reduce the amount of P excreted and produce a manure that has a nitrogen-phosphorus ratio closer to that required by crop and forage plants.

Other information that should be part of a nutrient management plan is provided in the USDA-NRCS Nutrient Management Conservation Practice Standard Code 590 (USDA NRCS, 1999); it includes aerial photographs or site maps; crop rotation information; realistic crop yield goals; sampling results for soil, manure, and so forth; quantification of all nutrient sources; and the complete nutrient budget for the crop rotation.

Practice: Developing a Comprehensive Nutrient Management Plan

Description: Effective nutrient management requires a thorough analysis of all the major factors affecting field nutrient levels. In general, a CNMP addresses, as necessary and appropriate, manure and wastewater handling and storage, land application of manure and other nutrient sources, site management, record keeping, and feed management. CNMPs also address other options for manure use when the potential for environmentally sound land application of manure is limited at the point where the manure is generated.

Nutrient management planning typically involves the use of farm and field maps showing acreage, crops and crop rotations, soils, water bodies, and other field limitations (e.g., sinkholes, shallow soils over fractured bedrock, shallow aquifers). Realistic yield expectations for the crops to be grown, soil and manure testing results, nutrient analysis of irrigation water and atmospheric deposition, crop nutrient requirements, timing and application methods for nutrients, and provisions for the proper calibration and operation of nutrient application equipment are all key elements of a nutrient management plan.

Application and Performance: CNMPs apply to all farms and all land to which nutrients are applied. Plans are developed by the grower with assistance, as needed, from qualified company staff, government agency specialists, and private consultants. To be effective, nutrient management plans must be site-specific and tailored to the soils, landscapes, and management of the particular farm (Oldham, 1999).

A wide range of studies has found that implementation of nutrient management plans result in improved nutrient use efficiency. In some cases, producers increased nutrient applications based on nutrient budget analyses, but reduced applications of N and P are more common. For example, average annual nutrient application rates were reduced by 14 to 129 pounds per acre for N and 0 to 106 pounds per acre for P in 19 USDA projects from 1991 to 1995 (Meals et al., 1996). The introduction of improved fertilizer recommendations in Pennsylvania resulted in a 40 percent reduction in N use statewide (Berry and Hargett, 1984). A pilot program on 48 farms in Iowa resulted in an average reduction of 9.6 pounds per acre N because of improved nutrient management (Hallberg et al., 1991).

Reductions in field losses of N and P due to implementation of nutrient management plans vary considerably, but a comprehensive review of field and modeling studies concluded that load reductions averaged 15 percent for N and 35 percent for P (Pennsylvania State University, 1992).

In a 6-year study of nutrient management in Pennsylvania, baseflow loads of N and P forms decreased, but stormflow discharges of total N and total P increased by 14 and 44 percent, respectively (Langland and Fishel, 1996).

Advantages and Limitations: A good nutrient management plan should help growers minimize adverse environmental impacts and maximize the benefits of using litter and manure. In a national survey of growers of corn, soybeans, wheat, and cotton, more than 80 percent of those who had used manure in the Northeast, southern plains, Southeast, and Corn Belt reported that they had reduced the amount of fertilizer applied to land receiving manure (Marketing Directions, 1998). Approximately 30 percent of the respondents reported that they had saved money through crop nutrient management, while more than 20 percent reported increased yields, about 18 percent claimed reduced fertilizer costs, and approximately 10 percent reported that profits had increased and the soil quality had improved. Despite the potential savings, some farmers are reluctant to develop nutrient management plans because of the cost. Only 4 to 22 percent of respondents indicated that they have a nutrient management plan.

Proper crediting and application of hog manure has been reported to save $40 to $50 per acre in fertilizer expenses in Iowa (CTIC, 1998a). Similarly, injecting hog manure has resulted in savings of $60 to $80 per acre in Minnesota. Although savings vary from farm to farm, proper crediting and application of manure under a good nutrient management plan can result in considerable cost savings for producers.

When animal manure and litter are used as nutrient sources, those activities which affect the availability and characteristics of such sources need to be factored into the nutrient management plan. For example, a nutrient management plan in which poultry litter is used as a nutrient source should take into account the amount of litter to be removed and the time of removal so that sufficient land is available for proper land application shortly after removal. Alternatively, the plan would need to consider whether storage facilities are available for the quantity of material that must be handled prior to land application. Whenever possible, litter removal should be planned so that fresh litter, containing the maximum amount of nutrients, can be applied immediately to meet crop or forage plant needs.

The CNMP will need to be revisited and possibly revised if the livestock facility increases in size, or if there are changes in animal types, animal waste management, processes, crops, or other significant areas.

Nutrient management services are available in the major farming regions, and both low-tech and high-tech options, such as precision agriculture, are available to producers. A CNMP is only as good as the information provided; the extent to which assumptions regarding yield, weather, and similar factors prove true; and the extent to which the plan is followed precisely.

Operational Factors: Climate, temperature, and rainfall are all critical factors to be considered in the development of a nutrient management plan. Since CNMPs are site-specific, the requirements of each CNMP will vary depending on the conditions at each facility.

Demonstration Status: A report on state programs related to AFOs indicates that 27 states already require the development and use of waste management plans (USEPA, 1999a). The complexity and details of these plans vary among states, but the plans typically address waste generated, application rate, timing, location, nutrient testing, and reporting provisions. Further, industry data and site visits conducted by EPA indicate that practically all CAFOs have some form of management plan in place.

8.3.2 Nutrient Budget Analysis

For animal operations at which land application is the primary method of final disposal, a well-designed nutrient management plan determines the land area required to accept manure at a set rate that provides adequate nutrients for plants and avoids overloading soils and endangering the environment. The four major steps of this process are as follows:

1. Determine crop yield goals based on site-specific conditions (e.g., soil characteristics).

2. Determine crop nutrient needs based on individual yield goals.

3. Determine nutrients available in manure and from other potential sources (e.g., irrigation water).

4. Determine nutrients already available in the soil.

These four steps constitute a nutrient budget analysis, which provides the operator with an estimate of how much animal waste can be efficiently applied to agricultural crops so that nutrient losses are minimized. Various organizations, including Iowa State University (ISU, 1995), USDA NRCS (1998b), and USEPA (1999b), have developed guidance on performing nutrient budget analysis. The Iowa State University guidance includes detailed worksheets for estimating nutrient needs versus supply from animal manure and other sources.

8.3.2.1 Crop Yield Goals

Practice: Establishing Crop Yield Goals

Description: Establishing realistic yield goals should be the first step of a nutrient management plan. The yield goal is the realistic estimate of crop that will be harvested based on the soil and climate in the area (USDA NRCS, 1995). Realistic yield goals can be determined through the following:

- Historical yield information (Consolidated Farm Service Agency-USDA)

- Soil-based estimates of yield potential (county soil survey books and current soil nutrient content reports)

- Farmer’s or owner’s records of past yields

- Yield records from a previous owner

Yield potential is based on soil characteristics and productivity. The soil’s yield potential can be obtained from Soil Survey Reports, county extension agencies, or Natural Resources Conservation Service (NRCS) offices. As the equation below shows, individual yield goals are calculated by multiplying the total acreage of a certain soil type by the yield potential of that soil, then dividing that sum by the total acres in the field:

$$\frac{\text{Total Acreage} \times \text{Yield Potential}}{\text{Total Acres in the Field}} = \frac{(\quad)}{(\quad)} = \_\_\_\_\_\_ \text{ bu / acre (Individual Yield Goal)}$$

Application and Performance: Realistic yield goals apply to all farms and all land to which nutrients are applied. Yield goals can be developed by the grower with assistance, as needed, from qualified company staff, government agency specialists, and private consultants. To be effective, yield goals must be site-specific, tailored to the soils on each field.

How well this practice performs depends on both good science and good fortune. Farmers are typically encouraged to set yield goals 5 to 10 percent above the average yield for the past 5 years or so (Hirschi et al., 1997). The intent is allow the farmer to benefit from a good year, while still reducing waste in the event that an off year occurs. Hirschi reports, however, that a survey of farmers in Nebraska showed that only one in ten reached their yield goals, with a full 40 percent of the farmers falling more than 20 percent below their yield goals.

Estimation of realistic yield goals does not address direct treatment or reduction of any pollutants, but is essential to determining the proper manure and commercial fertilizer application rates.

Advantages and Limitations: Reliance on a realistic yield goal is, by its very nature, an advantage for farmers. The challenge is to establish a yield goal that is truly realistic. Farmers who rely on their own yield records should use an average from the past 5 to 7 years, recognizing that it is impossible to foretell growing seasons accurately (Oldham, 1999).

If yield goals are set too high, there is the risk that nutrients will be applied in excess of crop needs. This translates into increased expense, increased levels of nutrients in the soil, and increased risk to surface water and ground water (Hirschi et al., 1997). If yield goals are set too low, the crop yield may be diminished because of a lack of nutrients. Further, if the crop yield is low during a bumper crop year, the producer risks a substantial loss of profits.

Universities publish yield goal information for use by farmers in all states, providing a ready source of information in the absence of better, site-specific records. In addition, seed suppliers have yield information that can be shared with farmers, including the results from local field trials.

Operational Factors: A key challenge in estimating crop yield is determining which historic yield data, industry data, and university recommendations are most appropriate for a given farm. Farmers need to recognize that exceptionally good years are rare (Hirschi et al, 1997). Assumptions regarding the year’s weather are also key, and, because farming is a business, crop prices affect farmers’ estimates of realistic yield as well.

If planting dates are affected by spring weather, yields may suffer, creating the potential for overapplication of nutrients. Similarly, extended droughts or wet periods may affect yields. Hail and other similar weather events can also harm crops, resulting in actual yields that fall short of even reasonable yield goals.

Demonstration Status: Estimation of crop yield is a basic feature of farming, although the methods used and accuracy of the estimates vary.

8.3.2.2 Crop Nutrient Needs

Practice: Estimating Crop Nutrient Needs

Description: Crop nutrient needs are the nutrients required by the crop and soil to produce the yield goal. Crop nutrient needs can be calculated for detailed manure nutrient planning. For animal feeding operations, N and P are the primary nutrients of concern, and significant research has been conducted on specific crop requirements for these nutrients. In some cases, nutrient planning analyses also evaluate K requirements.

Crop nutrient needs can be estimated by multiplying the realistic yield goal by a local factor for each nutrient-crop combination. For example, N factors for corn are provided for three regions in Iowa (USDA NRCS, 1995). If the yield goal is 125 bushels per acre and the N factor is 0.90, the N need for corn is 112.5 pounds per acre (125 x 0.90).

Application and Performance: Estimation of crop nutrient needs is a practice that applies to all farms and all land to which nutrients are applied. These estimates can be developed by the grower with assistance, as needed, from qualified company staff, government agency specialists, and private consultants. Nutrient uptake and removal data for common crops are available from the NRCS, the local extension office, and other sources (Oldham, 1999).

The accuracy of this calculation depends on the accuracy of the yield goal and nutrient factors for the crop. In the case of Iowa corn, for example, N factors vary from 0.90 to 1.22. A farmer preparing for a good year might add a 10 percent cushion to the yield goal of 125 bushels per acre used above, resulting in a revised yield goal of 137.5 bushels per acre. The N need increases to 123.75 pounds per acre, an increase of 10 percent as well. If the year turns sour and the yield is 112.5 bushels per acre (10 percent less), the excess N applied becomes 22.5 pounds per acre (123.75-101.25) instead of 11.25 pounds per acre (112.5-101.25), or 100 percent greater.

Estimation of crop nutrient needs does not address direct treatment or reduction of any pollutants, but is essential to determining the proper manure and commercial fertilizer application rates.

Advantages and Limitations: The determination of N needs should account for any N in the organic fraction of manure that is not available the first year, any N carryover from previous legume crops, N carryover from previous manure applications, and any commercial N that will be applied. The major factors determining the amount and availability of carryover N are the total amount of N applied, N uptake in the initial crop, losses to air and water, N concentration, carbon-to-nitrogen ratio, soil temperature, and soil moisture (Wilkinson, 1992).

In their analysis of nutrient availability from livestock, Lander et al. (USDA NRCS, 1998a) assumed that 70 percent of N applied in manure would be available to the crop. Ammonia volatilization, nitrate leaching, and runoff losses reduce the amount of available nutrient, and the percentage available also varies depending on soil temperature, soil moisture, organism availability, and the presence of other nutrients and essentials. When dry or liquid manure is incorporated immediately following application in the north-central region of the United States, about 50 percent of the N is available to the crop (Hirschi et al., 1997).

In North Carolina, it is estimated that half of the total N in irrigated lagoon liquid and 70 percent of the total N in manure slurries that are incorporated into the soil is available to plants (Barker and Zublena, 1996). Plant availability coefficients for N range from 25 percent (dry litter or semisolid manure broadcast without cultivation, and liquid manure slurry irrigated without cultivation) to 95 percent (injected liquid manure slurry and lagoon liquid), depending on form of the manure and method of application (Barker, 1996). For both P and K, the range is 60 to 80 percent, with the higher values for injection of liquid manure slurries and lagoon liquids, and application of lagoon liquids through broadcasting or irrigation with cultivation. The lower values in the range apply to broadcasting dry litter and semisolid manure with no cultivation. The results from plot studies conducted on Cecil sandy loam in Georgia indicate that carryover N from broiler litter should be factored into nutrient management planning for periods longer than 3 years (Wilkinson, 1992).

In Ohio, only about one-third of the organic N in animal manure is available to crops during the year it is applied (Veenhuizen et al., 1999). The P and K in the manure are available during the year they are applied, as are the equivalent amounts of fertilizer-grade P and K. Ohio State University Extension has published tables that show the estimated percentage of residual organic N that will be available in the 10 years after initial application.

In addition to organic N in manure, other sources of N can be significant and are included in the calculation of N needs:

- Mineralization of soil organic matter
- Atmospheric deposition
- Residue mineralization
- Irrigation water

If appropriate, contributions from these sources should be subtracted from the total amount of N needed. A general value for calculating the N mineralized per acre from soil organic matter (SOM) is 40 pounds per year for each 1 percent of SOM. The amount of N from atmospheric deposition can be as much as 26 pounds per acre per year, but local data should be used for this estimate. Irrigation additions can be estimated by multiplying the N concentration (in parts per million) by the quantity of water applied (in acre-inches) by 0.227 (USDA NRCS, 1996a).

As discussed earlier, nutrient planning based on N levels alone could lead to excessive soil P levels, thereby increasing the potential for P to be transported in runoff and erosion. Soil P levels should be determined and compared with crop needs before manure or fertilizer containing P is applied. This can be accomplished by comparing annual P removal rates based on the type of crop planted with the amount of P applied the previous year. As with N, data are available for plant removal rates by specific crop.

Operational Factors: As noted above, the major factors determining the amount and availability of carryover N include losses to air and water, soil temperature, and soil moisture (Wilkinson, 1992). In addition, mineralization of soil organic matter, atmospheric deposition, residue mineralization, and irrigation water applications are all related to climate, temperature, and rainfall.

Demonstration Status: Estimation of crop nutrient needs is a basic feature of farming. The methods used vary, however, as does the accuracy of the estimates.

8.3.2.3 Nutrients Available in Manure

Manure is an excellent fertilizer because it contains at least low concentrations of every element necessary for plant growth. The most important macronutrients in manure are N, P, and K, all of which come from urine and feces. The chemical composition of manure when it is excreted from the animal is determined largely by the following variables:

- Species of animal
- Breed
- Age
- Gender
- Genetics
- Feed ration composition

The composition of manure at the time it is applied usually varies greatly from that at the time it was excreted from the animal. The nutrients in manure undergo decomposition at varying rates influenced by the following factors:

- Climate (heat, humidity, wind, and other factors)

- Length of time the manure is stored

- Amount of feed, bedding, and water added to manure before removal from the animal housing facility

- Type of production facility

- Method of manure handling and storage

- Method and timing of land application

- Use of manure/pit additives
- Soil characteristics at time of application
- Type of crop to which manure is applied
- Net precipitation/evaporation in storage structure
- Uncontrollable anomalies (e.g., broken water line)
- Ratio of nutrients that have been transformed and/or lost to the atmosphere or soil profile

Given these many factors, it is nearly impossible to predict the nutrient content of manure in every animal production setting. Several state extension and university publications have attempted to predict nutrient contents for different species of animals at specific production phases. These book values are an educated guess at best and vary widely from state to state. It is imperative that livestock producers monitor the nutrient content of their manure on a consistent basis. Knowing the content of macronutrients in manure is an important step to proper land application.

Nitrogen

The total amount of N in manure is excreted in two forms. Urea, which rapidly hydrolyzes to ammonia, is the major N component of urine. Organic N, excreted in the feces, is a result of unutilized feed, microbial growth, and metabolism in the animal.

$$\text{Total N} = NH_3 \text{ (ammonia)} + \text{organic N}$$

The ratio of ammonia to organic N in the manure at the time of excretion is largely dependent on species, feed intake, and the other factors discussed above.

Before land application, inorganic N forms can be lost either to the atmosphere or into the soil profile, decreasing the nutrient value of the manure. Depending on the type of manure- handling and storage system and other factors described above, variable amounts of organic N can be mineralized to inorganic forms, which then can be lost to the atmosphere or into the soil profile. Nitrogen can be lost from manure in the following three ways:

1. NH_3 (ammonia) is volatilized into the atmosphere.

2. NO_3 (nitrate, a product of mineralization and nitrification) undergoes denitrification and is released into the atmosphere as N_2 (inert N gas).

3. NO_3 (nitrate, a water soluble form of N) is leached and carried down through the soil profile, where it is unavailable to plants.

Agitation of liquid manure prior to land application is extremely important. Solids will separate from still manure. The liquid will largely consist of the mineralized, inorganic forms of N, whereas the solid portions will contain the organic forms of N that are unavailable to plants. Proper agitation suspends the solids and helps ensure that the manure will be a more uniform and predictable fertilizer.

When manure is applied to land, the N content exists in two major forms, the ratio of which can be determined only by manure analysis. The amount of N that will be available to fertilize the plant will depend on the method and timing of application. The balance of the N available to the plant will be lost in one of the three ways described above or will remain immobilized in the organic form. It is generally agreed that 25 to 50 percent of N applied in the organic form will undergo mineralization and become available to plants in the first year. The remaining organic N will mineralize and become available in subsequent years.

When manure is applied to the surface of land without incorporation into the soil, much of the inorganic N remains on the surface, is lost, and will never be available to the plant. Volatilization of ammonia is the most significant loss factor and is greatest when drying conditions (dry, warm, sunny days) dominate. Field estimates of volatilization loss from surface-applied manure range from about 10 to 70 percent of ammonia N applied (CAST, 1996).

When manure is incorporated into the soil, inorganic forms of N available to the plant are placed directly into the root zone and volatilization is minimized. The inorganic ammonia/ammonium is either taken up by the plant or converted to nitrate. The nitrate can then be taken up by the plant, denitrified, and released into the atmosphere as N gas, or carried by water through the root zone. In addition, the organic N fraction has more contact with soil microbes when incorporated, resulting in a greater rate of mineralization.

Phosphorus

The vast majority of P contained in manure is derived from the feces. Only small amounts of P are present in livestock urine. As with N, the amount of P excreted by an animal depends on several factors already discussed.

The introduction of water, bedding, and feed into the manure can affect both the nutrient concentration and the content of the manure product. Manure handling and storage have little influence on the P concentration. Any loss of P is a result of runoff from feedlots or solids settling in holding basins, storage tanks, or lagoons. This will not be a loss if it is collected and used later.

Most of the P is present in solid manure. As stated for N, proper agitation resuspends the solids and makes the manure a more uniform and predictable fertilizer.

Although method and timing of land application have little direct effect on the transformation of P to plant-available forms, they greatly influence the potential loss of P through runoff. Estimates of P vary widely (CAST, 1996); however, by current estimates, somewhere near 70 percent is available for plant uptake in the first year following manure application (Koelsch, 1997).

Potassium

In most species, K is equally present in both urine and feces. Similarly, the amount of K in manure is fairly constant between liquids and solids and is not influenced by agitation. As with the other macronutrients, the amount of K excreted by an animal depends on a multitude of factors already discussed.

As with P, the introduction of water, bedding, and feed to the manure can affect both the K concentration and the content of the manure product. Manure handling and storage have little influence on the K concentration. Any loss of K is a result of runoff from feedlots or solids settling in holding basins, storage tanks, or lagoons. This will not be a loss if it is collected and used later.

As for P, the method and timing of land application have little direct effect on the transformation of K to plant-available forms, but they greatly influence the potential loss of K through runoff. Most of the K in manure is in the soluble form and is therefore readily available for plant uptake. Availability is estimated to be about 90 percent (Koelsch, 1997).

Swine Specific Information

Swine excrete approximately 80 percent of the N and P and approximately 90 percent of the K in the feed ration (Sutton et al., 1996). Swine manure can be handled as a slurry, liquid (with the addition of wastewater), or solid (with the addition of large amounts of bedding).

Estimates of the nutrient content of swine manure classified by manure handling type and production phase are given in Table 8-19. The values were compiled from university, extension service, and government agency publications from around the United States. The wide range of values is due to the many factors discussed earlier in this section.

Poultry Specific Information

Excreted poultry manure has a moisture content of around 80 percent. It can be handled as a slurry or liquid, or in a dry form with added bedding (referred to as litter). Estimates of the nutrient content of chicken and turkey manure are given in Table 8-20. The values were compiled from university, extension service, and government agency publications from around the United States. The wide range of values is due to the many factors discussed earlier in this section.

Dairy Specific Information

Because of the variety of housing and production options associated with dairies, many dairies have a combination of solid-, liquid-, and/or semisolid-based handling systems. Milking parlors commonly generate a large amount of wastewater from frequent flushing and cleaning of facilities and cows. Dry cows are often housed outdoors in open lots, while cows being milked may be kept in covered or completely enclosed freestall barns or holding pens.

Estimates of the nutrient content of dairy manure classified by manure handling type are given in Table 8-21. The values were compiled from university, extension service, and government agency publications from around the United States. The wide range of values is due to the many factors discussed earlier in this section.

Table 8-19. Swine Manure Nutrient Content Ranges

Source	Units	Total N	NH_4	P	K
ASAE, 1998	pounds/ton	12.4	6.9	4.3	4.4
USDA NRCS, 1996a (farrow, storage tank under slats)	pounds/1,000 gal	29.2	23.3	15.0	23.3
USDA NRCS, 1996a (nursery, storage tank under slats)	pounds/1,000 gal	40.0	33.3	13.3	13.3
USDA NRCS, 1996a (grow/finish, storage tank under slats)	pounds/1,000 gal	52.5	—	22.5	18.3
USDA NRCS, 199a6 (breeding/gestation, storage tank under slats)	pounds/1,000 gal	25.0	—	10.0	17.5
USDA NRCS, 1996a (anaerobic lagoon liquid)	pounds/1,000 gal	2.9	1.8	0.6	3.2
USDA NRCS, 1996a (anaerobic lagoon sludge)	pounds/1,000 gal	25.0	6.3	22.5	63.3
USDA NRCS, 1998a (Breeding hogs, after losses)	pounds/ton	3.3	—	3.6	7.0
USDA NRCS, 1998a (Other types of hogs, after losses) [a]	pounds/ton	2.8	—	2.8	7.2
Jones and Sutton, 1994 (farrow, pit storage)	pounds/1,000 gal	15.0	7.5	5.2	9.1
Jones and Sutton, 1994 (nursery, pit storage)	pounds/1,000 gal	24.0	14.0	8.7	18.3
Jones and Sutton, 1994 (grow/finish, pit storage)	pounds/1,000 gal	32.8	19.0	11.5	22.4
Jones and Sutton, 1994 (breeding/gestation, pit storage)	pounds/1,000 gal	25.0	12.0	13.5	22.4
Jones and Sutton, 1994 (farrow, anaerobic lagoon)	pounds/1,000 gal	4.1	3.0	0.9	1.7
Jones and Sutton, 1994 (nursery, anaerobic lagoon)	pounds/1,000 gal	5.0	3.8	1.4	2.7
Jones and Sutton, 1994 (grow/finish, anaerobic lagoon)	pounds/1,000 gal	5.6	4.5	1.7	3.5
Jones and Sutton, 1994 (breeding/gestation, anaerobic lagoon)	pounds/1,000 gal	4.4	3.3	1.9	3.3
Reichow, 1995 (no bedding)	pounds/ton	10.0	6.0	3.9	6.6
Reichow, 1995 (bedding)	pounds/ton	8.0	5.0	3.1	5.8
NCSU, 1994 (paved surface scraped)	pounds/ton	13.0	5.6	5.8	7.6
NCSU, 1994 (liquid manure slurry)	pounds/1,000 gal	26.5	16.8	8.3	12.6
NCSU, 1994 (anaerobic lagoon liquid)	pounds/1,000 gal	4.7	3.8	0.8	4.0
NCSU, 1994 (anaerobic lagoon sludge)	pounds/1,000 gal	24.4	5.9	23.0	5.4

—, data not available.
[a] selected for nutrient production calculations throughout this document

Table 8-20. Poultry Manure Nutrient Content Ranges

Source	**Units**	**Total N**	**NH_4**	**P**	**K**
ASAE, 1998 (layer)	pounds/ton	26.3	6.6	9.4	9.4
USDA NRCS, 1996a (layer, anaerobic lagoon supernatant)	pounds/1,000 gal	6.3	4.6	0.8	8.3
USDA NRCS, 1996a (layer, anaerobic lagoon sludge)	pounds/1,000 gal	32.5	7.7	45.8	6.0
USDA NRCS, 1996a (layer with no bedding or litter)	pounds/ton	35.4		22.9	25.0
Jones and Sutton, 1994 (layer, pit storage)	pounds/1,000 gal	60.0	13.0	19.7	23.2
Jones and Sutton, 1994 (layer, anaerobic lagoon)	pounds/1,000 gal	7.0	5.5	1.7	2.9
NCSU, 1994 (layer paved surface scraped)	pounds/ton	28.2	14.0	13.8	16.2
NCSU, 1994 (layer unpaved deep pit storage)	pounds/ton	33.6	11.8	22.3	21.9
NCSU, 1994 (layer liquid manure slurry)	pounds/1,000 gal	57.3	36.8	22.7	27.5
NCSU, 1994 (layer anaerobic lagoon liquid)	pounds/1,000 gal	6.6	5.6	0.7	8.5
NCSU, 1994 (layer anaerobic lagoon sludge)	pounds/1,000 gal	20.8	6.5	33.7	8.1
ASAE, 1998 (broiler)	pounds/ton	25.9	—	7.1	9.4
USDA NRCS, 1996a (broiler litter)	pounds/1,000 gal	38.9	—	19.4	22.9
USDA NRCS, 1998a (broiler, as excreted)	pounds/ton	26.8	—	7.8	10.5
USDA NRCS, 1998a (broiler, after losses) [a]	pounds/ton	16.1	—	6.6	9.5
Jones and Sutton, 1994 (broiler, pit storage)	pounds/1,000 gal	63.0	13.0	17.5	24.1
Jones and Sutton, 1994 (broiler, anaerobic lagoon)	pounds/1,000 gal	8.5	5.0	1.9	2.9
NCSU, 1994 (broiler litter)	pounds/ton	71.4	12.0	30.3	38.7
NCSU, 1994 (stockpiled broiler litter)	pounds/ton	32.6	6.9	33.5	26.6
NCSU, 1994 (broiler house manure cake)	pounds/ton	45.5	11.8	23.0	29.9
ASAE, 1998 (turkey)	pounds/ton	26.4	3.4	9.8	10.2
USDA NRCS, 1996a (turkey litter)	pounds/1,000 gal	72.4	0.8	32.9	37.0
USDA NRCS, 1998a (turkeys for slaughter, as excreted)	pounds/ton	30.4	—	11.8	11.6
USDA NRCS, 1998a (turkeys for slaughter, after losses) [a]	pounds/ton	16.2	—	10.1	10.4
USDA NRCS, 1998a (turkey hens, as excreted)	pounds/ton	22.4	—	13.2	7.6
USDA NRCS, 1998a (turkey hens, after losses) [a]	pounds/ton	11.2	—	11.2	6.8
Jones and Sutton, 1994 (turkey tom, pit storage)	pounds/1,000 gal	53.0	16.0	17.5	24.4
Jones and Sutton, 1994 (turkey hen, pit storage)	pounds/1,000 gal	60.0	20.0	16.6	26.6
Jones and Sutton, 1994 (turkey tom, anaerobic lagoon)	pounds/1,000 gal	8.0	6.0	1.7	3.7
Jones and Sutton, 1994 (turkey hen, anaerobic lagoon)	pounds/1,000 gal	8.0	6.0	1.7	3.3
NCSU, 1994 (turkey house manure cake)	pounds/ton	44.8	20.1	20.3	24.8
NCSU, 1994 (stockpiled turkey litter)	pounds/ton	31.6	5.5	30.4	25.0

—, data not available.
[a] selected for nutrient production calculations throughout this document

Table 8-21. Dairy Manure Nutrient Content Ranges

Source	Units	Total N	NH_4	P	K
ASAE, 1998	pounds/ton	10.5	1.8	2.2	6.7
USDA NRCS, 1996a (as excreted, lactating cow)	pounds/ton	11.3	—	1.8	6.5
USDA NRCS, 1996a (as excreted, dry cow)	pounds/ton	8.8	—	1.2	5.6
USDA NRCS, 1996a (heifer)	pounds/ton	7.3	—	0.9	5.6
USDA NRCS, 1996a (anaerobic lagoon supernatant)	pounds/1,000 gal	1.7	1.0	0.5	4.2
USDA NRCS, 1996a (anaerobic lagoon sludge)	pounds/1,000 gal	20.8	4.2	9.2	12.5
USDA NRCS, 1996a (aerobic lagoon supernatant)	pounds/1,000 gal	0.2	0.1	0.1	—
USDA NRCS, 1998a (milk cows, as excreted)	pounds/ton	10.7	—	1.9	6.7
USDA NRCS, 1998a (milk cows, after losses) [a]	pounds/ton	4.3	—	1.7	6.0
USDA NRCS, 1998a (heifer & heifer calves, as excreted)	pounds/ton	6.1	—	1.3	5.0
USDA NRCS, 1998a (heifer & heifer calves, after losses) [a]	pounds/ton	1.8	—	1.1	4.5
Reichow, 1995 (dry without bedding)	pounds/ton	9.0	4.0	1.7	8.3
Reichow, 1995 (dry with bedding)	pounds/ton	9.0	5.0	—	—
Jones and Sutton, 1994 (mature cow, pit storage)	pounds/1,000 gal	31.0	6.5	6.6	15.8
Jones and Sutton, 1994 (heifer, pit storage)	pounds/1,000 gal	32.0	6.0	6.1	23.2
Jones and Sutton, 1994 (dairy calf, pit storage)	pounds/1,000 gal	27.0	5.0	6.1	19.9
Jones and Sutton, 1994 (mature cow, anaerobic lagoon)	pounds/1,000 gal	4.2	2.3	0.8	2.5
Jones and Sutton, 1994 (heifer, anaerobic lagoon)	pounds/1,000 gal	4.3	2.1	0.9	2.5
Jones and Sutton, 1994 (dairy calf, anaerobic lagoon)	pounds/1,000 gal	3.0	2.0	0.4	2.1
NCSU, 1994 (paved surface scraped)	pounds/ton	10.3	2.5	3.1	7.1
NCSU, 1994 (liquid manure slurry)	pounds/1,000 gal	22.0	9.2	6.0	16.6
NCSU, 1994 (anaerobic lagoon liquid)	pounds/1,000 gal	4.9	3.2	1.2	5.4
NCSU, 1994 (anaerobic lagoon sludge)	pounds/1,000 gal	19.2	6.2	18.3	7.7

—, data not available.
[a] selected for nutrient production calculations throughout this document

Beef Cattle Specific Information

Most beef cattle are produced in an open-lot setting, but some moderate-sized operations produce beef in confinement. The nutrient content of feedlot manure is extremely difficult to quantify because of inconsistency in collection methods and content. Varying amounts of dirt, bedding, and precipitation are mixed with the bedding at different times of the year.

Estimates of the nutrient content of beef manure are given in Table 8-22. The ranges were compiled from university, extension service, and government agency publications from around the United States. The wide range of values is due to the many factors discussed earlier in this section.

Practice: Manure Testing

Description: The nutrient composition of manure varies widely among farms because of differences in animal species and management, and manure storage and handling (Busch et al., 2000). The only method available for determining the actual nutrient content of manure for a particular operation is laboratory analysis. Typical laboratory reports show the moisture content and percentage of N, P, K, Ca, Mg, and Na, as well as the concentration (parts per million) of Zn, Fe, Cu, Mn (McFarland et al., 1998; USDA NRCS, 1996a). Other information, such as the pH and conductivity for liquid samples, is also provided.

Sampling should be performed as close as possible to the time of land application to limit error resulting from losses occurring during handling, storage, and application (Schmitt, 1999; Busch et al., 2000; Bonner et al., 1998; Sharpley et al., 1994). The best time to collect a representative manure sample is during the loading or application process (Schmitt, 1999), but the test results from such sampling cannot be used to plan the current manure applications. Sampling during hauling is considered more accurate and safer than sampling at storage structures (Busch et al., 2000). Subsamples should be collected from several loads and then composited into a single sample. This applies to liquid, solid, or semisolid systems. Because the nutrients in manure are not distributed evenly between the urine and feces portions, mixing is critical to obtaining a representative sample.

Barker and Zublena (1996) recommend that land-applied manure be sampled and analyzed twice annually for nutrient and mineral content. New sampling should be conducted whenever animal management practices change. For example, if there is a significant change in animal rations or operation management (e.g., a change in the size or type of animals raised), new sampling should be conducted. If manure is applied several times a year, samples should be taken during the period of maximum manure application. For example, if the manure that has accumulated all winter will be used as a nutrient source, sampling should be done before application in the spring.

Table 8-22. Beef Manure Nutrient Content Ranges

Source	Units	Total N	NH_4	P	K
ASAE, 1998	pounds/ton	11.7	3.0	3.2	7.2
USDA NRCS, 1996a (as excreted, high forage diet)	pounds/ton	10.5	—	3.7	8.1
USDA NRCS, 1996a (as excreted, high energy diet)	pounds/ton	10.2	—	3.2	7.1
USDA NRCS, 1996a (feedlot manure)	pounds/ton	24.0	—	16.0	3.4
USDA NRCS, 1998a (beef cows, as excreted)	pounds/ton	11.0	—	3.8	8.3
USDA NRCS, 1998a (beef cows, after losses) [a]	pounds/ton	3.3	—	3.2	7.4
USDA NRCS, 1998a (steers, calves, bulls, & bull calves, as excreted)	pounds/ton	11.0	—	3.4	7.9
USDA NRCS, 1998a (steers, calves, bulls, & bull calves, after losses) [a]	pounds/ton	3.3	—	2.9	7.1
USDA NRCS, 1998a (fattened cattle, as excreted)	pounds/ton	11.0	—	3.4	7.9
USDA NRCS, 1998a (fattened cattle, after losses) [a]	pounds/ton	4.4		2.9	7.1
Reichow, 1995 (dry without bedding)	pounds/ton	21.0	7.0	6.1	19.1
Reichow, 1995 (dry with bedding)	pounds/ton	21.0	8.0	7.9	21.6
Jones and Sutton, 1994 (pit storage)	pounds/1,000 gal	20.0	—	3.1	16.5
Jones and Sutton, 1994 (anaerobic lagoon)	pounds/1,000 gal	4.0	—	0.6	2.7
NCSU, 1994 (paved surface scraped)	pounds/ton	13.8	1.9	4.2	10.7
NCSU, 1994 (unpaved surface scraped)	pounds/ton	25.0	4.7	7.8	17.9
NCSU, 1994 (liquid manure slurry)	pounds/1,000 gal	35.0	14.6	9.9	61.6
NCSU, 1994 (anaerobic lagoon, liquid)	pounds/1,000 gal	3.4	2.3	0.8	4.1
NCSU, 1994 (anaerobic lagoon, sludge)	pounds/1,000 gal	38.2		25.7	12.1

—, data not available.
[a] selected for nutrient production calculations throughout this document

For systems that are emptied or cleaned out once a year, it is recommended that sampling be conducted each time the manure is applied (Busch et al., 2000). This applies to uncovered lagoons, pits, basins, and stacking slabs. Manure from under-barn concrete pits or covered aboveground tanks will not vary as much between applications, unless the type of animal or another significant factor changes. Systems emptied twice a year or more might differ between application times, so a fall analysis might not be accurate for planning spring applications.

Application and Performance: Manure sampling is a practice that applies to all farms and all land on which manure is applied. The farmer or trained consultants can conduct the sampling.

Manure sampling does not address direct treatment or reduction of any pollutants, but is essential to determining the proper manure and commercial fertilizer application rates.

Advantages and Limitations: Manure analysis is the only way in which the actual nutrient content can be determined. Standardized tables of manure nutrient content do not reflect how variable the true nutrient content can be, but they can be useful in planning facilities and land application areas (Hirschi et al., 1997).

Convenient laboratory reports allow farmers to easily determine the pounds per ton of nutrients in solid manure or pounds per acre-inch in liquid manure (McFarland et al., 1998). Laboratories are available at universities in most states, and lists of service providers can be obtained from county offices and the Internet.

Without manure analysis, farmers might buy more commercial fertilizer than is needed or spread too much manure on their fields (USDA NRCS, 1996a). Either practice can result in overfertilization, which, in turn, can depress crop yields and cut profits. Improper spreading of manure also can pollute surface and ground water.

Sampling from manure application equipment is quick, but the test results cannot be used to plan the current year's manure applications. Sampling before hauling allows use of the test results for the current year, but retrieving an accurate sample is difficult because the manure is not mixed. Further, there is the danger of falling into manure storage structures.

Operational Factors: Sample collection procedures vary considerably depending on manure form and storage, but all are intended to provide representative samples in a safe and convenient manner. Homogeneity is the key to simple sampling procedures, but the nutrient content of manure usually varies considerably within storage structures and stockpiles. For this reason, agitation of liquid manure and mixing of solid manure are generally recommended prior to sampling. Alternatively, several samples can be taken from different locations and depths within a lagoon, pit, or manure stack. Sampling each of several loads of hauled manure is another option to address spatial variability of manure nutrient content. The process of agitating and loading manure is believed to provide mixing that ensures representative sampling (Busch et al., 2000).

The number of samples to be taken for suitable results depends on the variability of the manure sampled (Busch et al., 2000). One sample may be adequate for agitated liquid slurries and lagoon liquids, whereas three or more samples may be needed for stacked solids. It is recommended that one sample be taken per poultry house.

Hirschi et al. (1997) recommend taking solid manure samples from several locations in a manure stack or on a feedlot, mixing them together in a tied, 1-gallon plastic bag, placing that bag inside another bag, and then freezing the sample before shipping to a laboratory for analysis. Busch et al. (2000) say that 10 to 20 subsamples should be taken from different depths and locations using a pitchfork or shovel. In Texas, five to seven random subsamples are recommended (McFarland et al., 1998). The subsamples are placed in a pile and mixed before a composite sample is taken.

Busch et al. (2000) recommend that samples be taken from the manure in the tank or spreader box on its way to the field for application. For solid manure, samples should be collected from application equipment using a pitchfork, shovel, or plastic glove, avoiding large pieces or chunks of bedding. The sample taken to the lab should be a mixture of manure taken from several (5 to 10) loads representing the beginning, middle, and end of the application process. Subsamples should be mixed thoroughly, prior to filling a sample jar three-fourths full, allowing room for gas expansion. Jars should be cleaned and sealed in a plastic bag, and samples should be frozen before being mailed.

Bonner et al. (1998) suggest that samples can be collected by using catch pans in the field as the material is applied to the land. Samples from multiple pans are mixed to form the overall sample, and a 1-liter plastic bottle is filled halfway to allow for gas expansion. Samples should be frozen or kept cold until delivered to a laboratory.

Rather than sampling from the lagoon or pit, samples can be retrieved with a plastic pail or a coffee can on a pole from the top of the spreader or from the bottom unloading port (Busch et al., 2000). Sampling should be done immediately after filling.

Hirschi et al. (1997) recommend agitating or mixing liquid manures prior to sampling unless it is more practical to take samples from several areas within a lagoon or pit and then mix them. To sample from lagoons and storage facilities, a plastic container attached to a pole or rod is recommended (Bonner et al., 1998; McFarland et al., 1998; Busch et al., 2000). Alternatively, a ½- or ¾- inch PVC pipe can be pushed into the manure to a depth no closer than 1 foot from the bottom (Busch et al., 2000). The sample can be secured by placing a hand over the top of the pipe and pulling the pipe up. Samples should be taken from 5 to 10 locations around the lagoon, covering several depths to include solids. After mixing the samples in a bucket, a representative sample is then taken to a laboratory for analysis.

Demonstration Status: Manure sampling is practiced widely across the United States, but many farmers still do not test manure or employ a N credit from manure when determining commercial fertilizer needs (Stevenson, 1995). A 1995 survey of 1,477 swine producers showed that 92 percent of operations had not had their manure tested for nutrients within the past 12 months (USDA APHIS, 1995). Approximately 6 percent had tested their manure for nutrients once during the past 12 months, while another 1.5 percent had tested it twice. These findings are supported by a crop nutrient management survey in which only 2 to 17 percent of respondents in various regions stated that they factored manure nutrient values into their nutrient management plans (Marketing Directions, 1998).

8.3.2.4 Nutrients Available in Soil

A major problem in using organic nutrient sources such as animal waste is that their nutrient content is rarely balanced with the specific soil and crop needs. For example, the N: P ratio in applied manure is usually around 3 or less, whereas the ratio at which crops use nutrients typically ranges from 5 to 7. Therefore, when manure is applied at rates based solely on N analysis and crop need for N, P is applied in excess of crop needs. Because the amounts of P added in manure exceed the amounts removed by crops, continuous use of manure can result in accumulations of excess P in the soil, increasing the potential for P to be transported in runoff and erosion (Sharpley et al., 1999).

A recent change of emphasis in nutrient management programs has been to base manure application rates on both P and N needs. Different soil types can accommodate different P concentrations before experiencing significant P export in runoff. The amount of P that a soil can hold depends on the availability of binding sites. For example, a clayey soil will tend to be able to retain more P than a sandy soil because clays have a greater surface area and typically contain a greater proportion of iron, which has a strong affinity for P. Table 8-23 demonstrates the variability of the P binding capacity of several soils. Phosphorus bound to soils is primarily in a particulate form; however, as a soil becomes saturated with P, the finite number of binding sites will be overwhelmed and P can be released into runoff in a soluble form.

Table 8-23. Maximum P-Fixation Capacity of Several Soils of Varied Clay Contents

Soil Great Group (and series)	Location	Percent clay	Maximum P fixation (mg P/ kg soil)
Evesboro (Quartzipsamment)	Maryland	6	125
Kitsap (Xerochrept)	Washington	12	453
Matapeake (Hapludult)	Maryland	15	465
Newberg (Haploxeroll)	Washington	38	905

Source: Brady and Weil, 1996.

The concept of a P threshold (TH) has been developed to identify soil P levels at which soluble losses of P in runoff become significant. The recently revised USDA NRCS nutrient management policy (Part 402) addressing organic soil amendments, such as manures, proposes that for soils with a known P TH the following P manure application rates apply:

- If soil P levels are below 75 percent of the P TH, N-based manure application is allowed.

- If soil P levels are between 75 percent and 150 percent of the P TH, manure application rates should be based on the amount of P estimated to be removed by the crop.

- If soil P levels are between 150 percent and 200 percent of the P TH, manure application rates should be based on one-half the amount of the P estimated to be removed by the crop.

- If soil P levels are greater than twice (200 percent) the P TH, no manure should be added to the soil.

- When no soil-specific TH data are available, P application should be based on soil P test levels.

- If the soil P test level is low or medium, the application rate of organic soil amendments (e.g., manure) can be based on the soil's N content.

- If the soil P level is high, the manure application rate should be based on 1.5 times the P estimated to be removed by the crop.

- If the soil P level is very high, the manure application rate should be based on the P estimated to be removed by the crop.

- If the soil P level is excessive, no manure should be applied.

Using this threshold concept, several states are developing P indexes to account for site-specific conditions that influence both soluble P losses and particulate P losses resulting from erosion (Lemunyon and Gilbert, 1993; Sharpley, 1995). This approach would categorize agricultural fields using a quantitative index that can be helpful in assessing the potential risk of P contamination of local water bodies. Manure and fertilizer application programs can then be developed accordingly. For instance, an area prone to P transport, such as a field rich in P located on erodible soils adjacent to a reservoir, would receive a high score identifying the importance of a strict nutrient management program. The economic concerns raised by a P-based plan may be significant because a larger land area may be required in order to dispose of manure from livestock operations.

Practice: Soil Testing

Description: Soil testing, an important tool for determining crop nutrient needs, evaluates the fertility of the soil to determine the basic amounts of fertilizer and lime to apply (USDA NRCS, 1996a). Soil tests should be conducted to determine the optimum nutrient application of N and P, pH, and organic matter. Typical laboratory reports show soil pH, P, K, Ca, Mg, Zn, and Mn levels, plus fertilizer and lime recommendations (USDA NRCS, 1996a). Special analyses for organic matter, nitrate-N, and soluble salts can be requested.

The best time to sample soil is after harvest or before fall or spring fertilization. Late summer and fall are best because K test results are most reliable at these times (Hirschi et al., 1997). The worst time to sample is shortly after the application of lime, commercial fertilizer, or manure, or when the soil is extremely wet. Samples are usually composited to determine a general application rate for a specific field or field section. The goal is to obtain a representative view of the field conditions. This can be achieved by sampling in areas that have similar soil types, crop rotation, tillage type, and past fertility programs. In addition, soil samples should be taken at random in a zigzag pattern, making sure to avoid irregularities in the land (e.g., fence lines, very wet areas) to get samples that accurately portray the landscape. Two weaknesses of random sampling in a zigzag pattern are the assumptions that the composite sample is representative of the entire field and that the result of the sampling produces an average value for the field (Pocknee and Boydell, 1995). Samples can be gathered and composited over smaller areas to determine distinct treatment options. To evaluate the variability of the land, the grid method of dividing the field into 5-acre plots can also be used. Treatment decisions can be made by balancing labor requirements, environmental concerns, and economics.

Grid-cell sampling and grid-point sampling are two sampling methods used on farms where precision farming is practiced. In grid-cell sampling, an imaginary grid is laid over the sampling area and soil cores are taken randomly within each cell, bulked, and mixed. A subsample is then taken from the composite sample for analysis. This approach is considered similar to the random sampling method, with the exception that the sampled area is divided up into many smaller "fields." In grid-point sampling, a similar imaginary grid is used, but the soil cores are taken from within a small radius of each grid intersection, bulked, mixed, and subsampled for analysis. Each of these methods has its limitations. Grid-cell sampling is very time-intensive because most of the field needs to be covered in the sampling process, whereas grid-point sampling will not work well unless grid sizes are very small. Thus, both methods tend to be expensive because of the labor involved. A newer method, directed sampling, is based on spatial patterns defined by some prior knowledge about a field. Sampled areas are divided into homogeneous soil units of varying size. Factors such as field management history, soil maps, soil color, yield maps, topography, and past soil tests are combined and analyzed using a geographic information system (GIS) to determine optimal sampling patterns.

Sampling equipment for grid sampling includes four-wheelers and trucks equipped with global positioning system (GPS) capabilities and mechanized sampling arms (Pocknee and Boydell, 1995). Costs for custom service range from $7 to $15 per acre, including soil sampling, analysis of standard elements, and mapping.

Recommendations regarding sampling frequency range from once a year to once every 4 years. In Arizona, soil sampling for residual nitrate content analysis is recommended prior to planting annual crops (Doerge et al., 1991). For sandy soils in North Carolina, sampling is recommended once every 2 to 3 years; testing once every 4 years is suitable for silt and clay loam soils (Baird et al., 1997). A minimum frequency of once every 4 years is generally recommended in the central United States (Hirschi et al., 1997). In Mississippi, soil samples should be taken once every 3 years or once per crop rotation (Crouse and McCarty, 1998).

Application and Performance: Soil sampling is a practice that applies to all farms and all land to which nutrients are applied. The farmer or trained consultants can conduct the sampling.

Soil sampling does not address direct treatment or reduction of any pollutants, but is essential to determining the proper manure and commercial fertilizer application rates.

Advantages and Limitations: Soil analysis is the only way in which the actual nutrient content can be determined. Nitrogen testing has not been consistently reliable because N is highly mobile in soil, but drier parts of the Corn Belt have had some success with both the early spring nitrate-N test and the pre-sidedress N test (Hirschi et al., 1997). There is also some evidence that the pre-sidedress test is most helpful on soils to which manure has been applied.

A late spring N test ensures that the proper amount of N was applied to the crops. Because this test is used to make site-specific adjustments of application rates, following the recommendations provided by this test can help achieve expected crop yields. For example, where N is too high, the late spring N test will indicate that additional N application is not needed by the crop and may contaminate water supplies. Records should be kept and adjustments made to N applications on future crops.

Without soil analysis, farmers might buy more commercial fertilizer than is needed or spread too much manure on their fields (USDA NRCS, 1996a). Either practice can result in overfertilization, which, in turn, can depress crop yields and cut profits. Improper spreading of manure also can pollute surface and ground water.

Convenient laboratory reports allow farmers to easily determine the pounds of nutrients per acre of soil (McFarland et al., 1998). Recommendations based on soil testing results are developed using crop response data from within a state or region with similar soils, cropping systems, and climate (Sims et al., 1998). For this reason, it is important to send samples to a laboratory that is familiar with the crops, soils, and management practices that will be used on the particular farm. The better the information provided to laboratories for each soil sample—such as previous fertilizer use, management plans, and soil series—the greater the potential for receiving a better recommendation. Laboratories are available at universities in most states, and lists of service providers can be obtained from county offices and the Internet.

Operational Factors: Soil samples can be taken with a probe, auger, or spade and collected in a clean bucket. Probes and augers are preferred because they provide an equal amount of soil from each depth (Crouse and McCarty, 1998). For uniform fields, one sample is satisfactory, but most fields are not uniform in treatment, slope, soil type, or drainage, and so should be divided into small areas of 5 to 10 acres each for sampling (USDA NRCS, 1996a). It is recommended that a soil map be used to guide sampling, and a separate, composite soil sample should be taken for each distinct kind of land, soil texture, soil organic matter, fertility level, and management unit (Crouse and McCarty, 1998). The samples should be taken from 20 or more places in the field, using a zig-zag pattern (USDA NRCS, 1996a). Samples should not be taken from unusual areas such as turn rows, old fence rows, old roadbeds, eroded spots, areas where lime or manure have been piled, or in the fertilizer band of row crops. A soil auger, soil tube, or spade can be used for sampling at the plow depth for cropland (6 to 8 inches or more) and at 2 to 4 inches for pasture. Samples should be placed in a clean plastic pail, mixed thoroughly with all clods broken up, and then sent to a laboratory in a 1/2-pint box for analysis.

Recommendations regarding the appropriate field size to be sampled vary somewhat, as shown in Table 8-24.

Table 8-24. Recommended Field Size for Soil Sampling

Location	Field Size	Comments	Source
Arizona	40 acres or less	15-20 subsamples	Doerge et al., 1991
Hawaii	2-5 acres	5-10 subsamples	Hue et al., 1997
Minnesota	5-20 acres	15-20 subsamples	Rosen 1994
North Carolina	20 acres or less	15-20 subsamples	Baird et al., 1997
Texas	10-40 acres	10-15 subsamples	McFarland et al., 1998
U.S.	20-30 acres	20-25 subsamples	Sims et al., 1998
U.S.	5-10 acres	20 or more subsamples	USDA NRCS, 1996a

Sampling for the early spring nitrate-N test involves taking soil samples in 1-foot increments down to a depth of 2 to 3 feet in early spring, while the pre-sidedress N test calls for sampling from the top 1 foot of soil when corn is 6 to 12 inches tall (Hirschi et al., 1997). Guidelines on interpretation of early spring nitrate tests vary across states.

Phosphorus soil tests are based on the chemical reactions that control P availability in soils (Sims et al., 1998). These reactions vary among soils, so a range of soil tests is available in the United States, including the Bray P1 (used in the North Central and Midwest Regions), Mehlich 3 (in widespread use in the United States), Mehlich 1 (Southeast and Mid-Atlantic), Morgan and Modified Morgan (Northeast), and Olsen and AB-DTPA (West and Northwest).

Demonstration Status: Soil testing is widely practiced in the United States. In a national survey of corn, soybeans, wheat, and cotton growers, 32 to 60 percent of respondents said that they perform soil testing (Marketing Directions, 1998).

8.3.2.5 Manure Application Rates and Land Requirements

Practice: Determining Manure Application Rates and Land Requirements

Description: The final step of a nutrient management analysis is to determine the amount of manure that can be applied to field crops to meet crop needs while simultaneously preventing excessive nutrient losses. This step involves using the information developed in the nutrient budget analysis to compare crop nutrient requirements with the supply of nutrients provided per unit volume of animal waste. Soil testing helps in determining the rates at which manure should be applied by establishing which nutrients are already present in the soil and available to the crop. Testing manure identifies the amount and types of nutrients it contains and helps to ensure that nutrients are not overapplied to the land. Depending on the cropping system, different amounts of nutrients will be required for optimum production. This final analysis allows the operator to determine how much land acreage is required to apply the animal manure generated or, conversely, how much manure can be applied to the available acreage. These final calculations are illustrated in Figures 8-13 and 8-14.

Figure 8-13 illustrates that two possible strategies for determining the correct agronomic application rate of manure are (1) applying enough manure to ensure the proper amount of N is available to the crop and (2) applying manure based on desired amounts of P, then adding commercial N and K to make up the differences in crop needs. Depending on the frequency of application, the first method might increase the risk of oversupplying P and K, thereby potentially adversely affecting soil and water quality (Dick et al., 1999). For this reason, the strategy requiring the greater land area for spreading is selected in the analysis illustrated by Figure 8-13.

Application and Performance: Determining manure application rates and land requirements applies to all farms and all land to which manure is applied. This analysis does not address direct treatment or reduction of any pollutants, but is essential to determining the proper manure and commercial fertilizer application rates.

Determine land area needed for manure application.

Total pounds of usable nutrients available and pounds of nutrients available to plants in each gallon have been calculated. This information should be used to calculate the number of acres you need for manure application.

From nitrogen planning:
Net usable nitrogen available ____________ lb
Net nitrogen amount ÷ ____________ lb N/acre
Land area needed for spreading nitrogen: = ____________ acres

From phosphorus planning:
Net usable P_2O_5 available: ____________ lb
Total P_2O_5 needs: ÷ ____________ lb P_2O_5/acre
Land area needed for spreading P_2O_5: = ____________ acres

Acres required:
Greater of the two above values (a or b): ____________

Adapted from Iowa State University, 1995.

Figure 8-13. Example Procedure for Determining Land Needed for Manure Application

Determine manure volume to apply.

Total annual volume of manure:		____________	gal or T
Land area required for spreading:	÷	____________	acres
Manure volume used on field:	=	____________	gal or T/acre

If the field is smaller than the acres calculated above, calculate the manure to apply to this field:

Land area in field:		____________	acres
Manure volume to apply :	x	____________	gal or T/acre
Manure volume used on field:	=	____________	gal or T

Determine the number of gallons or tons of manure remaining to be spread:

Total annual volume of manure:		____________	gal or T
Manure volume used on field:	–	____________	gal or T
Manure volume remaining:	=	____________	gal or T

Manure volume remaining:		____________	gal or T
Manure volume to apply :	÷	____________	gal or T/acre
Additional land area for spreading:	=	____________	acres

Adapted from Iowa State University, 1995.

Figure 8-14. Example Calculations for Determining Manure Application Rate

Advantages and Limitations: Without this analysis, farmers may buy more commercial fertilizer than is needed or spread too much manure on their fields (USDA NRCS, 1996a). Either practice can result in overfertilization, which, in turn, can depress crop yields and cut profits. Improper spreading of manure also can pollute surface and ground water.

In cases where there is inadequate land to receive manure generated on the farm, alternative approaches to handling the manure, described elsewhere in this document, need to be considered.

Operational Factors: Although the correct manure application rate is determined by soil and manure nutrient composition, as well as the nutrient requirements for the crop system, further consideration should be given to soil type and timing of application. Attention to these factors aids in determining which fields are most appropriate for manure application. Before applying manure, operators should consider the soil properties for each field. Coarse-textured soils (high sand content) accept higher liquid application rates without runoff because of their increased permeability; however, manure should be applied frequently and at low rates throughout the growing season because such soils have a low ability to hold nutrients, which creates a potential for nitrate leaching (NCSU, 1998). Fall applications of animal manure on coarse-textured soils are generally not recommended. Fine-textured soils (high clay content) have slow water infiltration rates, and therefore application rates of manure should be limited to avoid runoff. Application on soils with high water tables should be limited to avoid nitrate leaching into ground water (Purdue University, 1994).

Demonstration Status: A 1995 survey of 1,477 swine producers showed that 92 percent of operations had not had their manure tested for nutrients within the past 12 months (USDA APHIS, 1995). Approximately 6 percent had tested their manure for nutrients once during the past 12 months, while another 1.5 percent had tested it twice. These findings are supported by a crop nutrient management survey in which only 2 to 17 percent of respondents in various regions stated that they factored manure nutrient value into their nutrient management plans (Marketing Directions, 1998). Like manure testing, analysis of land requirements and application rates is practiced widely across the United States, but many farmers still do not test manure or employ a N credit from manure when determining commercial fertilizer needs (Stevenson, 1995).

8.3.3 Record Keeping

The key to a successful nutrient management system is sound record keeping. Such a record-keeping regime should include the following:

Practice: Record Keeping

Description: Record keeping for a CNMP includes recording manure generation; field application (amount, rate, method, incorporation); the results and interpretation of manure, soil, and litter analysis; visual inspections of equipment and fields; manure spreader calibration worksheets; manure application worksheets (nutrient budget analyses); and related information on a monthly or more frequent basis.

Application and Performance: Record keeping applies to all farms and all land to which nutrients are applied. Record keeping does not address direct treatment or reduction of any pollutants, but is essential to tracking the results of activities associated with nutrient management.

Advantages and Limitations: Without record keeping, farmers will have little ability to determine what works and does not work with regard to on-farm nutrient management. Failure to learn from past successes and mistakes may cause farmers to continue in an endless loop of buying more commercial fertilizer than is needed, spreading too much manure on their fields, and realizing smaller profits than would otherwise be obtainable. For example, tracking manure sampling locations, dates, and methods will help establish a firm basis for adjusting sampling frequencies to provide an accurate assessment of manure nutrient content (Busch et al., 2000).

Record keeping can seem to be nothing but a burden unless tools are provided with which farmers can analyze the information for their own benefit. Fortunately, a great number of tools are currently available from universities and industry to help farmers use their records to make better business decisions. For example, MAX (Farming for Maximum Efficiency Program) is a program designed to help farmers look at their profit margins, rather than just their yields (CTIC, 1998b). MAX software is provided to cooperators to help them document their savings.

Operational Factors: Record keeping can be performed using pencil and paper, personal computers, portable computers, or GIS-based systems.

Demonstration Status: Record keeping of some form is conducted on all farms as a matter of business.

8.3.4 Certification of Nutrient Management Planners

Practice: Training and Certification for Nutrient Management Planners

Description: CNMPs should be developed or modified by a certified specialist. Certified specialists are persons who have a demonstrated ability to develop CNMPs in accordance with applicable USDA and state standards and are certified by USDA or a USDA-sanctioned organization. Certified specialists would include individuals who have received certifications through a state or local agency, third-party organization approved by NRCS, or NRCS personnel. In addition, USDA develops agreements with third-party vendors similar to the 1998 agreement with the Certified Crop Advisors (CCAs) and consistent with NRCS standards and specifications (or state standards if more restrictive).[1] CCAs provide technical assistance to producers in nutrient management, pest management, and residue management. The purpose of using a certified specialist is to ensure that CNMPs are developed, reviewed, and approved by persons who have the appropriate knowledge and expertise to ensure that plans fully and effectively address the core components of CNMPs, as appropriate and necessary, and that plans are appropriately tailored to the site-specific needs and conditions of the farm. Because of the multidisciplinary nature of CNMPs, it is likely that a range of expertise will be needed to develop an effective CNMP (e.g., professional engineer, crop specialist, soil specialist).

Application and Performance: Certification of nutrient management planners applies to all farms and all land to which nutrients are applied. Farmers may seek certification themselves or choose to seek assistance from certified professionals when developing their nutrient management plans.

Certification provides no direct treatment or reduction of any pollutants, but is essential to ensuring that CNMPs developed and implemented are effective in preventing pollution.

Advantages and Limitations: Without certification, those who develop CNMPs might not have the skills or knowledge necessary to develop cost-effective plans. This could result in both water pollution and less-than-optimal farm profits.

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[1] Third-party vendor certification programs may include, but are not limited to, (1) the American Society of Agronomy's certification programs, including Certified Crop Advisors (CCA) and Certified Professional Agronomists (CPAg), Crop Scientists (CPCSc), and Soil Scientists (CPSSc) (2) land grant university certification programs (3) National Alliance of Independent Crop Consultants (NAICC); and (4) state certification programs.

If a producer chooses to attain certification, a time commitment is required, and training and travel expenses may be incurred. Course fees of $25 and 1 day of time lost are considered reasonable estimates of costs based on a review of both state training programs for nutrient management and pesticide certification costs provided by various state extension services. The major advantage of becoming certified is that the farmer will be able to develop his or her own CNMPs without the need for outside technical assistance. Certification would ultimately provide benefits with regard to time commitments, convenience, and expense.

Farmers who choose not to obtain certification will need to purchase services from those who are certified.

Operational Factors: Producers might need to travel within their state to attain certification.

Demonstration Status: Some states already have certification programs in place for nutrient management planning, which can provide an excellent foundation for CNMP certification programs. In addition, USDA develops agreements with third-party vendors similar to the 1998 agreement with the Certified Crop Advisors (CCAs).

8.4 Land Application and Field Management

Two important factors that affect nutrient loss are field application timing and application method.

8.4.1 Application Timing

The longer manure remains in the soil before crops take up its nutrients, the more likely those nutrients will be lost through volatilization, denitrification, leaching, erosion and surface runoff. Timing of application is extremely important. To minimize nitrogen losses, a good BMP is to apply manure as near as possible to planting time or to the crop growth stage during which nitrogen is most needed. Because of regional variations in climate, crops grown, soils, and other factors, timing considerations vary across regions.

Spring is the best time for land application to conserve the greatest amount of nutrients. Available nutrients are used during the cropping season. Nutrient losses are still possible, however, because the likelihood of wet field conditions may result in export by surface runoff or leaching. Spring applications result in less time for organic decomposition of manure (an issue for manure with a low percentage of moisture) and the release of some nutrients. Four main considerations often prevent manure application in the spring. First, a livestock producer might not have sufficient storage capacity for an entire year of manure and might be forced to apply at multiple times during the year. Second, time constraints and labor availability for farmers and applicators during the spring season make it difficult to complete manure application. Third, time constraints are complicated further if there are wet field conditions. Finally, applying manure in the spring creates a potential for greater soil compaction which can cause yield loss. Field equipment, such as heavy manure tanks, compacts the soil and can alter soil structure and reduce water movement. Tillage to break up this compaction is not a viable option in reduced-till cropping systems. Freezing and thawing cycles in winter months lessen the effect of compaction caused during fall application.

Conversely, fall application usually results in greater nutrient losses (25 to 50 percent total nitrogen loss) than spring application, especially when the manure is not incorporated into the soil (MWPS, 1993). These nitrogen losses are a result of ammonia volatilization and conversion to nitrate, which may be lost by denitrification and leaching. Fall applications allow soil microorganisms time to more fully decompose manure and release previously unavailable nutrients for the following cropping season. This is especially advantageous for solid manure, which contains high levels of organic matter. When temperatures are below 50 °F, microbial action of the soil slows and prevents nitrification, thereby immobilizing some of the nutrients. In the fall, manure is best applied to fields to be planted in winter grains or cover crops. If winter crops are not scheduled to be planted, manure should be applied to fields that require nutrients in the subsequent crop year or have the most existing vegetation or crop residues, or to sod fields to be plowed the next spring.

Summer application is suitable for small-grain stubble, noncrop fields, or little-used pastures. Manure can also be applied effectively to pure grass stands or to old legume-grass mixtures, but not on young stands of legume forage. Summer application allows a farmer or applicator to spread out the workload of a busy spring and fall.

Winter is the least desirable application time, for both nutrient utilization and pollution prevention. Late fall or winter applications might be desirable because of greater labor availability and better soil trafficability. Although there may be significant losses of available nitrogen, the organic nitrogen fraction will still contribute to the plant-available nitrogen pool. The potential for nutrient runoff is an environmental concern for applications that cannot be incorporated, especially during winter. Winter applications of manure should include working the manure into the soil either by tillage or by subsurface injection, thereby reducing runoff. In northern areas, frozen soil surfaces prevent rain and melting snow from carrying nutrients into the soil and make incorporation and injection impossible. Where daily winter spreading is necessary, manure should be applied first to fields that have the least runoff potential. Application on frozen or snow-covered ground should be avoided because of the possibility of runoff.

8.4.2 Application Methods

Manure can be handled as a liquid (less than 4 percent solids), semisolid or slurry (4 to 20 percent solids), or solid (greater than 20 percent solids). The amount of bedding and water dilution influence the form, as do the species and production phase of the animals. Consequently, the manure form dictates the way manure will be collected, stored, and finally applied to land (MWPS, 1993).

Liquid manure and slurry manure are applied using similar methods, but equipment needs for the two manure forms may vary depending on percentage of solids content. Chopper pumps may be necessary to reduce the particle size of bedding or feed. Agitation of liquid manure is extremely important prior to land application. Inadequate agitation results in inconsistent nutrient content and makes the manure difficult to credit as a valuable fertilizer source. A lack of uniform application can also lead to nutrient excesses and deficiencies, yield loss, and increased incidence of ground and surface water contamination. Furthermore, insufficient agitation can cause a buildup of solids in the storage tank and lead to decreased capacity. A disadvantage to liquid manure handling systems is that they may require the addition of water for collection of the manure, increasing the amount of material that must be handled and applied.

The liquid-based manure is applied to fields by means of tank wagons, drag-hose systems, or irrigation systems. Tank wagons can either broadcast manure (surface apply) or inject it into the soil. The method of injection, and the corresponding level of disturbance to the soil surface, is extremely variable. With the proper implement type, disruption to the soil surface and residue cover can be minimal and appropriate for reduced-tillage operations. Depending on the specific implement chosen, injection is the preferred method in reduced-till or no-till cropping systems.

Soil incorporation occurs immediately and crop residues are left on the surface to act as a mulch. The amount of exposed soil surface is minimized, resulting in reduced erosion. Injection systems can reduce odor by 20 to 90 percent (Hanna, 1998). There is less nutrient loss to air and diminished runoff as well. For injection, a liquid manure spreader or "umbilical" system and equipment to deposit manure below the soil surface are necessary. Injection requires more horsepower, fuel, and time than broadcasting. Liquid-based manure can also be pumped from a tanker or storage facility located adjacent to the field through a long flexible hose. This umbilical or drag-hose system is feasible for both broadcasting and injecting manure. Irrigation equipment applies liquid manure pumped directly from storage (usually lagoons). Wastewater and manure can be applied by means of sprinkler or surface (flood) irrigation.

Solid manure is broadcast using box-type or open-tank spreaders. Spreader mechanisms include paddles, flails, and augers. Rate calibration of box spreaders is often difficult, resulting in less uniform application, difficulty crediting fertilizer values, nutrient excesses and deficiencies resulting in yield loss, and increased potential for ground and surface water contamination.

Surface application, or broadcasting, is defined as the application of manure to land without incorporation. Simply applying manure to the soil surface can lead to losses of most of the available nitrogen, depending on soil temperature and moisture. Nitrogen is lost through volatilization of ammonia gas, denitrification of nitrates, and leaching. Volatilization losses are greatest with lower humidity and with increases in time, temperature, and wind speed. High-moisture conditions can carry water-soluble nitrates through the soil profile and out of the plant root zone, potentially causing ground water contamination. University extension services generally recommend a certain correction factor (Table 8-25). Environmental conditions such as temperature, wind, and humidity influence this factor. Generally, phosphorus and potassium losses are negligible, regardless of application method. However, some phosphorus and potassium is lost through soil erosion and runoff.

Table 8-25. Correction Factors to Account for Nitrogen Volatilization Losses During Land Application of Animal Manure

Application Method	Correction Factor
Direct injection	0.98
Broadcast and incorporation within 24 hours	0.95
Broadcast and incorporation after 24 hours	0.80
Broadcast liquid, no incorporation	0.75
Broadcast dry, no incorporation	0.70
Irrigation, no incorporation	0.60

Source: Adapted from Iowa State University Extension PM-1811, November 1999.

Solid and liquid manures can be incorporated into the soil by tillage in a row-crop system. Incorporation increases the amount of nitrogen available for crops by limiting volatilization, denitrification, and surface runoff. Incorporation also reduces odor and encourages mineralization of organic nitrogen by microbial action in the soil, thereby increasing the amount of nitrogen readily available to the plants. Although incorporation by tillage makes the nutrients less susceptible to runoff, the resulting reduction in crop residue can increase sediment runoff. If manure nutrients are to be fully used, incorporation should be performed within 12 to 24 hours of land application.

8.4.3 Manure Application Equipment

Livestock producers and custom manure applicators consider six predominant criteria when choosing an application system: (1) the amount of land to be covered/fertilized; (2) the amount of manure to be spread; (3) water content and consistency of the manure; (4) the frequency of application and importance of timeliness; (5) soil trafficability; and (6) distance between storage and the field to be treated. The fundamental classes of application equipment are solid waste spreaders, liquid waste tankers, umbilical systems, and liquid waste irrigation systems. Table 8-26 presents the advantages and disadvantages of the different application systems.

Table 8-26. Advantages and Disadvantages of Manure Application Equipment

Application Method	Description	Advantages	Disadvantages
Solid			
Box spreader	Common box spreader with aprons, paddles, or hydraulic push system. Depending on size, can be pulled by as small as a 15-hp tractor.	Equipment readily available. Mobile. Equipment relatively inexpensive. High solids content allows less total volume to be handled.	Limited capacity. High labor and time requirement. Fairly difficult to achieve uniform application. Significant nutrient loss and odor if not incorporated immediately. Moderate risk of soil compaction. Uneven applications when conditions are windy.
Flail spreader	V-bottom spreader with chains attached to a rotating shaft to sling the manure out of the top or side of the tank. Can be pulled by 30- to 90-hp tractor.	Wide, even application. Spreads solid, frozen, chunky, slurry, semisolid, or bedded manure. Low maintenance because of few moving parts.	Moderate risk of soil compaction. Higher cost and power requirements than box spreader. Significant nutrient loss and odor if not incorporated immediately. Uneven applications when conditions are windy.

Application Method	Description	Advantages	Disadvantages
Hopper spreader	V-bottom spreader with large auger across bottom of spreader. Manure spread by impeller on side.	Wide, even application.	Moderate risk of soil compaction. Higher cost and power requirements than box spreader. Significant nutrient loss and odor if not incorporated immediately. Uneven applications when conditions are windy.
Liquid (Broadcast)			
Tank spreader	Mounted tank shoots manure in widespread pattern. Can be on one side, both sides, or directly behind spreader. Also can have drop hoses. Spreading width of 15 to 25 feet. Capacity of 1,000 to 5,000 gallons.	Simple to manage. Less costly than injectors. Requires less horsepower than injectors.	Great nutrient loss and odor possibilities. Uneven applications when conditions are windy. Air contact results in some nutrient loss. High risk of soil compaction.
Tractor-pulled flexible hose (drag-hose)	Manure is pumped from the storage facility or tanker at the edge of the field through hose pulled by tractor. Tractor-mounted unit consists of pipe, nozzle, and deflector plate. Spread pattern similar to that of broadcast tank spreader.	Simple design. Relatively inexpensive. Low power required to pull hose. Low risk of soil compaction.	Great nutrient loss and odor possibilities. Uneven applications when conditions are windy. Air contact results in some nutrient loss. May be limited by distance from storage to fields and by terrain.
Liquid (Injection)			
Tank spreader	Front- or rear-mounted tank. Soil is opened and manure deposited below surface by variable methods. Capacity of 1,000 to 5,000 gallons.	Odor is minimized. Nutrients not lost to atmosphere. Nutrients can be placed near plant's root zone in a standing crop. Depending on implement type, soil surface and residue disturbed minimally.	Pulling injectors requires more horsepower. Operation difficult in stony soil. More expensive than broadcasting. High risk of soil compaction. Increased application time as compared with broadcasting.
Tractor-pulled flexible hose (drag-hose)	Manure is pumped from storage facility or tanker at the edge of the field through hose pulled by tractor and fed into injectors. Injectors must be lifted from ground to turn. Rigid, swinging pipe on equipment prevents hose damage by tractor. 150- to 200-hp tractor needed.	Odor controlled during spreading. Nitrogen retained. Requires less power than tanker injection systems. Low soil compaction risk.	Some manure may be spilled at end of runs. May be limited by distance from the storage to fields and by terrain. Increased application time as compared with broadcasting by drag-hose.
Irrigation			

Application Method	Description	Advantages	Disadvantages
Surface irrigation	Manure transported to application site through rigid irrigation pipes. Manure spread on field via gated pipes or open ditches.	Low initial investment. Low energy requirements. Little equipment needed. Little soil compaction. Few mechanical parts. Timely manure application.	Moderate labor requirement. High degree of management skill needed. Limited to slopes of less than 2%. May be limited by distance to field. High odor levels possible. Difficult to control runoff and achieve uniform application. Significant nutrient loss if not incorporated immediately.
Hand-moved sprinklers	Manure transported through rigid irrigation pipes, including a mainline and one or more aluminum pipe laterals. One parcel irrigated at a time. Pipe is disassembled and moved by hand to next parcel.	Low initial investment. Few mechanical parts. Low power requirement. Adapts to field shape. Little soil compaction. Timely manure application.	High labor requirement. Sprinklers can clog. Significant nutrient loss if not incorporated immediately. High odor levels possible. Uneven distribution in windy conditions.
Towline sprinklers	Manure transported through rigid irrigation pipes, including a mainline and one or more al uminum pipe laterals. One parcel irrigated at a time. Laterals are stronger and are moved using a tractor.	Low initial investment. Requires less labor than hand-move sprinklers. Few mechanical parts. Low power requirement. Little soil compaction. Timely manure application.	Not adaptable to irregular field shapes because of fixed laterals. Sprinklers can clog. Require tractor lanes for towing in tall crops. Significant nutrient loss if not incorporated immediately. High odor possible. Uneven distribution in windy conditions.
Stationary big gun	Manure transported through rigid irrigation pipes. Single large gun sprays manure in a circle. Must be moved by hand.	Moderate labor requirement. Few mechanical parts. Adaptable to irregular land area. Requires less pipe than small sprinklers. Big nozzle allows spreading of manures with more solids. Little soil compaction. Timely manure application.	Moderate to high initial investment. High power requirement. Uneven distribution in windy conditions. Significant nutrient loss if not incorporated immediately. High odor possible.
Towed big gun	Manure transported through rigid irrigation pipes. Functions like a towline system with the laterals replaced by a big gun.	Few mechanical parts. Requires less labor than hand-move or stationary gun systems. Requires less pipe than small sprinklers. Big nozzle allows spreading of manures with more solids. Little soil compaction. Timely manure application.	Moderate to high initial investment. High power requirement. Uneven distribution in windy conditions. Less adaptable to land area. Requires tractor driving lanes. Significant nutrient loss if not incorporated immediately. High odor possible.

Application Method	Description	Advantages	Disadvantages
Traveling gun	Manure transported through rigid irrigation pipes. Irrigation gun travels across field, spreading manure in semicircular pattern. Hard or soft hose types available. Soft hose system is less expensive.	Lowest labor requirement of all sprinkler systems. Big nozzle allows spreading of manures with more solids. Little soil compaction. Less energy required than tank spreader. Timely manure application.	High initial costs. May be limited by distance to field. Uniform application difficult in very windy conditions. Possibility of high odor levels. Significant nutrient loss if not incorporated immediately. Environmental damage likely if not supervised. High odor possible.

Sources: Adapted from MWPS, 1993, and Bartok, 1994.

Practice: Solid Manure Application with Spreaders

Description: Solid and semisolid manure can be applied to land using box, V-bottom, or flail spreaders. Spreaders are either tractor-pulled or mounted on trucks, depending on the load capacity. The manure is discharged from the rear, side, or bottom of the spreader with the aid of paddles, flails, chains, or augers (MWPS, 1993).

Application and Performance: Solid waste application methods are appropriate for manure containing 20 percent or more solids (MWPS, 1993). Spreaders are most appropriate for smaller operations with frequent manure removal from small areas (USDA NRCS, 1996a).

Advantages and Limitations: Spreaders are relatively inexpensive but have a limited load capacity. They require power to operate and, because of the open-air application method, often present odor problems during and after application. In addition, calibration can be difficult and create a problem with uniform application and nutrient crediting. Most spreaders must be filled using a tractor front-end loader. Smaller spreaders require a greater time investment because of the number of return trips to the manure source for refilling. Increasing spreader capacity reduces the time investment but increases the risk of soil compaction. V-box bottom spreaders can achieve a more uniform application than box spreaders but require more power and investment.

Operational Factors: Spreaders are constructed of treated wood or steel and include a plastic or fiberglass interior lining to assist with loading and unloading. The spreaders can rot or rust, depending on the construction material, and tractor front-end loaders can damage the spreader and lining during loading. To prevent deterioration and damage, operators should load the spreader carefully, clean and lubricate it regularly, and protect it from the weather.

Demonstration Status: Of grower-finisher swine operations that dispose of waste on owned or rented land, 57.8 percent use broadcast/solid spreader methods. Only 13.7 percent of large grower-finisher operations (marketing more than 10,000 head) use broadcast/solid spreader methods (USDA APHIS, 1996a).

On dairy farms with fewer than 100 milk cows, 90.6 percent broadcast manure with a solid spreader. As herd size increases, solid handling is less common. Solid handling is most common in the northeastern and midwestern areas of the United States (USDA APHIS, 1997).

Fewer than 1 in 7 producers with fewer than 100 milk cows incorporates manure into soil within 24 hours of application. This ratio increases with herd size to more than one-third of producers with more than 500 cows incorporating manure into the soil in less than 24 hours (USDA APHIS, 1997).

Practice: Liquid Manure Application With Tankers

Description: Manure is applied to the soil surface or injected into the soil using spreader pump tankers or vacuum tankers. The spreader pump tanker is composed of a tank and pump mounted on a truck or wagon and requires a separate pump to load the manure. The vacuum tanker is mounted in a similar fashion but includes a pump that both loads and unloads the manure. Tankers usually include an agitating device (either auger or pump type) to keep solids suspended. Chopper pumps may be needed to prevent malfunctions caused by clogging with manure solids or fibrous material. A gated opening at the rear bottom of the tank either discharges the manure into a spinner for broadcasting or directs it through hoses to an injection device.

Application and Performance: Tankers are used for spreading slurry and liquid manure with less than 10 percent solids. Tankers are appropriate for moderate- to large-sized operations. Thorough agitation prior to and during tanker loading is necessary to limit inconsistency of manure.

Tankers using injection systems can decrease runoff by causing minimal soil surface disturbance and maintaining a residue cover.

Advantages and Limitations: Broadcast tankers use less power and are less expensive than injector tankers but result in greater nutrient loss and odor problems. Tankers with injector systems decrease the loss of nitrogen and odorous gases to the atmosphere and place nutrients near the plant's root zone where they are needed; furthermore, depending on the specific injector system, there is a significant decrease in disturbance to the soil surface and residue, limiting the potential for erosion. The weight of both types of tanker spreaders can cause soil compaction.

Operational Factors: Tankers must be cleaned and repaired regularly and should be protected from the weather. Vacuum pumps, moisture traps, pipe couplers, tires, and power shafts must be maintained regularly. Sand, often used in dairy freestall barns, can cause damage to the pumps. A vacuum tanker used for swine manure typically lasts 10 years (USDA NRCS, 1996a).

Demonstration Status: Slurry surface application is practiced at 46.0 percent of all grower-finisher operations that apply wastes to land, while subsurface injection of slurry is practiced at 21.9 percent of these operations (USDA APHIS, 1996a).

Slurry surface application is practiced at 44.6 percent of dairy farms having more than 200 milk cows. Subsurface slurry application is practiced at only 8.6 percent of dairy operations of the same size (USDA APHIS, 1997).

Practice: Liquid Manure Application With a Drag-Hose System

Description: The drag-hose system pumps manure from the manure storage tank, or from a portable tank adjacent to the field, through a supply line that can be up to 3 miles long. The supply line attaches to a flexible hose that is pulled across the field by a tractor. Manure is fed through the hose to applicator implements similar to the types found on tankers. The manure can be broadcast or injected.

Application and Performance: Drag-hose systems are used for spreading slurry and liquid manure with less than 10 percent solids. They are appropriate for moderate- to large-sized operations. Up to 40 acres of a field can be covered before the hoses must be repositioned. Thorough agitation prior to and during pumping is necessary to limit inconsistency of manure.

Use of certain injection systems can decrease runoff and erosion by causing minimal soil surface disturbance and maintaining residue cover.

Advantages and Limitations: The drag-hose system eliminates the need for repeated trips with a wagon or tanker to the manure storage site. It takes more initial setup time, but overall it has a smaller fuel and labor requirement than other spreader systems. Another benefit is decreased soil compaction and decreased road traffic. The weight of the liquid-based manure is dispersed over a much greater surface area and there is less equipment weight.

The person using a drag-hose system must be careful to not cut the line or break the umbilical cord during manure application.

For application rates under or around 2,000 gallons per acre, a drag-hose may not be practical because a certain amount of pressure is needed to keep the hose from collapsing.

Operational Factors: The application of drag-hose systems is limited by the distance the supply lines can travel, as well as by terrain.

Demonstration Status: Drag-hose systems are becoming increasingly popular as consolidation takes place in livestock production. It should be noted that the demonstration figures given in the tanker section also pertain to and include swine and dairy operations using the drag-hose system for slurry application.

Practice: Liquid Waste Application by Irrigation

Description: Irrigation systems use pipes to transfer liquid manure and wastewater from the containment facility (usually a lagoon) to the field. Wastewater can be transferred to the field through portable or stationary pipes or through an open ditch with siphon tubes or gated pipe. Manure is applied to the land using either a sprinkler or surface irrigation system.

Sprinkler systems most often used for manure disposal include handmove sprinklers, towlines, and big guns (MWPS, 1993). Surface irrigation systems include border, furrow, corrugation, flood, and gated pipe irrigation (MWPS, 1993). Descriptions of individual irrigation systems are included in Table 8-26.

Application and Performance: Irrigation systems are increasingly used by hog operations that spread over a million gallons of wastewater per year (USDA NRCS, 1996a). Most irrigation systems can handle manure that contains up to 4 percent solids (MWPS, 1993). Solid separation practices may be necessary to achieve this level.

Irrigation system selection varies according to the percentage of solids present in the manure, the size of the operation, the labor and initial investment available, field topography, and crop height.

Advantages and Limitations: Irrigation systems minimize soil compaction, labor costs, and equipment needed for large operations, and they spread the manure more quickly than tank spreaders. Also, irrigation makes it possible to move large quantities of manure in a short time period. Finally, irrigation systems can be used to transport water during dry periods, and they are especially effective if crop irrigation systems are already in place.

However, nitrogen is easily lost to volatilization and denitrification if not incorporated into the soil. Odor from the wastewater can create a nuisance. Other problems that might alter the viability of the irrigation system include windy conditions that reduce the uniformity of spreading and increase odor problems off-site, the fact that soils might not be permeable enough to absorb the rapidly applied liquid, and a crop height that prevents application (MWPS, 1993; USDA NRCS, 1996a).

Although irrigation systems can reduce the overall labor cost of large spreading operations, labor communication and coordination are needed for initiating, maintaining, and ceasing an irrigation cycle. System operators must agitate manure before and during pumping to keep solids in suspension. Surface irrigation application must be closely monitored to control runoff and application uniformity. Pipes must be flushed with clean water after manure is applied to prevent clogs. Irrigation pipes are susceptible to breakage and should be regularly inspected.

Operational Factors: Single-nozzle sprinklers perform better where wind is a problem. Also, one large nozzle is less likely to plug than two smaller nozzles with the same flow capacity.

Demonstration Status: Irrigation of swine wastewater is practiced at 12.8 percent of grower-finisher operations which dispose of their waste on owned or rented land. Nearly 80 percent of grower-finisher operations with more than 10,000 head use irrigation for land application of manure.

Land application of wastewater by irrigation is also common at large dairy operations; 40.5 percent of producers with more than 200 cows used irrigation for manure application.

Practice: Center Pivot Irrigation

Description: Center pivots are a method of precisely irrigating virtually any type of crop (with the exception of trees) over large areas of land. In a center pivot, an electrically driven lateral assembly extends from a center point where the water is delivered, and the lateral circles around this point, spraying water. A center pivot generally uses 100 to more than 150 pounds of pressure per square inch (psi) to operate and therefore requires a 30- to 75-horsepower motor.

The center pivot system is constructed mainly of aluminum or galvanized steel and consists of the following main components:

> Pivot: The central point of the system around which the lateral assembly rotates. The pivot is positioned on a concrete anchor and contains various controls for operating the system, including timing and flow rate. Wastewater from a lagoon, pond, or other storage structure is pumped to the pivot as the initial step in applying the waste to the land.
>
> Lateral: A pipe and sprinklers that distribute the wastewater across the site as it moves around the pivot, typically 6 to 10 feet above the ground surface. The lateral extends out from the pivot and may consist of one or more spans depending on the site characteristics. A typical span may be from 80 to 250 feet long, whereas the entire lateral may be as long as 2,600 feet.
>
> Tower: A structure located at the end point of each span that provides support for the pipe. Each tower is on wheels and is propelled by either an electrically driven motor, a hydraulic drive wheel, or liquid pressure, which makes it possible for the entire lateral to move slowly around the pivot.

The center pivot is designed specifically for each facility, based on wastewater volume and characteristics, as well as site characteristics such as soil type, parcel geometry, and slope. The soil type (i.e., its permeability and infiltration rate) affects the selection of the water spraying pattern. The soil composition (e.g., porous, tightly packed) affects tire size selection as to whether it allows good traction and flotation. Overall site geometry dictates the location and layout of the pivots, the length of the laterals, and the length and number of spans and towers. Center pivots can be designed for sites with slopes of up to approximately 15 percent, although this depends on the type of crop cover and methods used to alleviate runoff. Figure 8-15 presents a schematic of a central pivot irrigation system.

Application and Performance: Using a center pivot, nutrients in the wastewater, such as nitrogen and phosphorus, can be efficiently applied to the cropland to meet crop needs. With a known nutrient concentration in the wastewater, the animal waste can be agronomically applied to cropland very precisely by appropriately metering the flow based on crop uptake values. Agronomic application helps reduce runoff of pollutants from cropland and overapplication of nutrients to the soil.

Center pivot irrigation does not provide wastewater treatment. Nutrients, pathogens, and other pollutants simply pass through and are distributed by the center pivot.

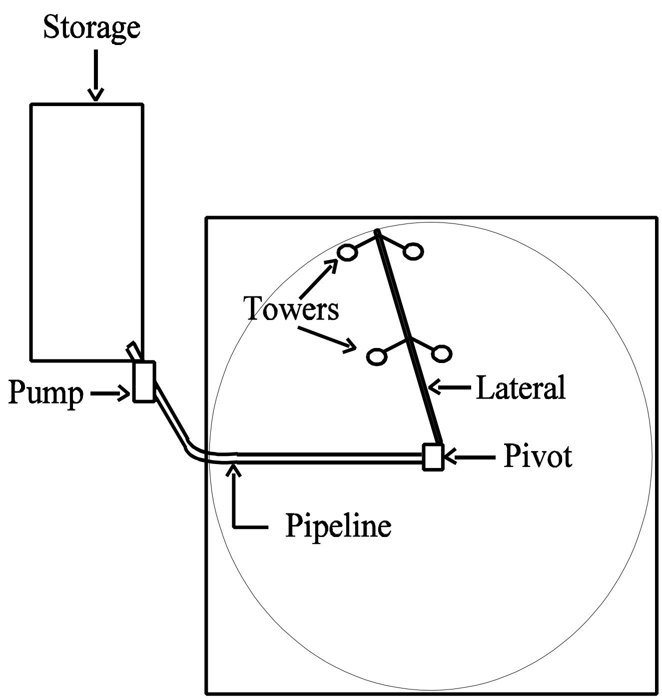

Figure 8-15. Schematic of a Center Pivot Irrigation System

Operational Factors: According to one manufacturer (Valley Industries), center pivot systems can be designed to handle wastes containing up to 5 percent solids. Thus, it may be necessary to have a solids removal step (e.g., settling basin or mechanical separator) prior to wastewater storage and subsequent land application. It is also a good practice to flush the pipes with clean water following waste application to prevent clogging of pipes and sprinkler nozzles.

Salt accumulation in the soil may be an issue, especially in drier climates. Salt concentrations in the wastewater and soil should be monitored to determine if salinity is a problem at a particular site.

Odor may also be a problem when using a center pivot to apply liquid animal wastewater to the land. However, techniques can be implemented to reduce the dispersion of the waste stream into the wind, such as positioning the sprinklers closer to the ground, using low trajectory sprinklers, and using low pressure sprinklers. Proper timing of application based on environmental conditions (i.e, monitoring wind velocity and direction) can also help reduce odor problems.

Application efficiency (i.e., the percentage of the total water pumped that reaches the ground or plant surface) depends primarily on climatic factors such as ambient temperature, relative humidity, and wind velocity and direction. A typical application efficiency is about 90 percent, provided that at least 1 inch of water is applied.

Advantages and Limitations: As noted above, a center pivot is an effective means of distributing liquid animal waste and supplying nutrients to cropland at agronomic rates. The center pivot design is fairly flexible and can be adapted to a wide range of site and wastewater characteristics. Center pivots are also advantageous because they can distribute the wastewater quickly, uniformly, and with minimal soil compaction. Center pivots have low operating labor costs compared with manual application methods.

One limitation of a center pivot system is the relatively high capital investment it entails. Other limitations may result from sloped lands, high solids content of waste, and potential odor problems. Center pivots are also vulnerable to high winds and lightning. Additionally, swine waste is fairly corrosive so the waste either needs to be treated to reduce its corrosivity or system components such as piping need to be corrosion-resistant (e.g., galvanized or lined pipe). Another concern with center pivot spraying is nitrogen loss through volatilization, which is estimated to be as high as 25 percent (USDA NRCS, 1996a).

Demonstration Status: Center pivots have been in operation in the United States since the 1950s. In the 1970s, center pivots started to become popular as a means of land-applying wastewater from municipal, industrial, and agricultural sources. Today, center pivots are widely used in agriculture, including land application of wastewater from swine, beef, and dairy facilities.

Practice: Calibration of Application Equipment

Description: Three conditions must be addressed to ensure that application rates are accurate (Schmitt and Rehm, 1998). First, analysis of a properly collected manure sample is needed to quantify nutrient content. Second, the rate of manure being applied to the field must be known and kept constant; calibration must be conducted for all manure applications. Third, the application or spread pattern of the manure must be uniform throughout the field.

Manure spreaders can discharge manure at varying rates, depending on forward travel speed, power take-off speed, gear box settings, discharge opening, width of spread, overlap patterns, and other parameters (USDA NRCS, 1996a). Calibration defines the combination of settings and travel speed needed to apply manure at a desired rate.

The actual rate at which a spreader applies manure will differ from the manufacturer's estimates, so calibration is necessary to ensure accurate manure application (Hirschi et al., 1997). Two basic methods, the load-area method and weight-area method, can be used for calibration (USDA NRCS, 1996a). In the load-area method, the amount of manure in a loaded spreader is measured and the rate is determined based on the number of loads needed to cover a known area of land. In the weight-area method, manure spread over a small surface is weighed, and the weight per unit area is calculated. Although there are only two basic calibration methods, a variety of specific calibration procedures are available, many of which require knowledge of the tank's or spreader's load size (Hirschi et al., 1997).

For solid systems, the spreader can be weighed before and after going to the field to determine the weight of manure spread (Schmitt and Rehm, 1998). Using the width of the spread manure and the distance traveled per load, the weight of manure applied per acre can be calculated. Alternatively, the rate per acre can be estimated using the weight of a full load as determined with a scale, the number of loads per field, and the field acreage. A third method is to lay a tarp or sheet of strong plastic in a field and make a pass over it with the spreader. The manure deposited on the tarp or sheet of plastic is then collected and weighed. Using the area of the tarp or plastic sheet, the weight of manure applied per unit area can be determined. Because of the small area involved in this method, there is high variability, so multiple samples should be collected. Knowledge of the variability in application rate, however, is useful information when one considers that uniform application is desired.

For liquid systems, calibration requires that the manure be measured in gallons per acre. The best way to determine the volume applied is to weigh the tank before and after spreading the manure and then to divide by the density of liquid manure (8.3 lb/gallon) (Schmitt and Rehm, 1998). Combining this information with the width of the spread pattern and the distance the tank travels before emptying the tank will provide the data necessary to determine the application rate. A second option for liquid systems that does not involve a scale is to fill the tank, count the number of loads applied uniformly per unit area of field, and then calculate the volume per acre using the known volume of a filled tank.

Manure application rates must often be adjusted to match the recommended rate (Schmitt and Rehm, 1998). The most common method of changing the application rate is to change the speed at which the spreader is driven across the field. Solid manure equipment may also have an adjustment that changes the chain speed in the box, thereby changing the application rate. Liquid manure application equipment may have valve opening adjustments to alter the rate. Because the flow rate may change from the beginning to the end of a tank of liquid manure, some equipment uses pressurized tanks, flow pumps, and newer distributor designs to address the problem of variable flow. Once equipment is adjusted or driving rates are changed to achieve new application rates, recalibration is necessary to maintain the accuracy in calculating application rates.

A wide range of water measurement devices is available, including some that primarily measure rate or volume of flow and some that primarily measure rate of flow (USDA NRCS, 1997). A suitable measuring device, calibrated in the laboratory or field, can be used to determine total application volume, which, combined with the measured nutrient concentration in the applied liquid, can be used to determine the quantity of nutrients applied to the receiving land. Dividing the quantity of nutrients by the land acreage provides the nutrient application rate. Rain gauges can be used in the field to check the uniformity of application of sprinkler systems.

Application and Performance: Calibration is a practice that applies to all farms and all land on which manure is applied, and it can be performed by the producer with little training.

Calibration of manure application equipment provides no direct treatment or reduction of any pollutants, but it is essential to accurate application of manure.

Advantages and Limitations: Calibrating manure applicators helps to ensure that applications are adequate for crop needs, but not excessive and a source of water quality problems (USDA NRCS, 1995).

Calibration of spreaders should take less than 1 hour (Hirschi et al., 1997).

Operational Factors: Agitation of liquid manure is extremely important prior to land application. Inadequate agitation results in inconsistent nutrient content and makes the manure difficult to credit accurately as a valuable fertilizer source. A lack of uniform application can also lead to nutrient excesses and deficiencies, yield loss, and increased incidence of ground and surface water contamination.

Solid manure is broadcast using box-type or open-tank spreaders. Spreader mechanisms include paddles, flails, and augers. Rate calibration of box spreaders is often difficult, resulting in less uniform application, difficulty crediting fertilizer values, nutrient excesses and deficiencies resulting in yield loss, and increased potential for ground and surface water contamination.

Windy conditions can affect the uniformity of applications with sprinklers. System operators must agitate manure before and during pumping to keep solids in suspension. Surface irrigation application must be closely monitored to control runoff and application uniformity.

Demonstration Status: Calibration of manure spreaders is a topic that has been addressed in technical guidance and extension service publications across the United States. Information regarding the extent to which farmers calibrate manure applicators was not found, but information regarding the extent to which manure is sampled is probably indicative of the maximum extent to which calibration is practiced.

Manure sampling is practiced widely across the United States, but many farmers still do not test manure or employ a nitrogen credit from manure when determining commercial fertilizer needs (Stevenson, 1995). A 1995 survey of 1,477 swine producers showed that 92 percent of operations had not had their manure tested for nutrients within the past 12 months (USDA NAHMS, 1999). Approximately 6 percent had tested their manure for nutrients once during the past 12 months, while another 1.5 percent had tested it twice. These findings are supported by a crop nutrient management survey in which only 2 to 17 percent of respondents in various regions stated that they factored manure nutrient value into their nutrient management plans (Marketing Directions, 1998).

Practice: Transportation of Waste Off Site

Description: Animals at an animal feeding operation generate a large amount of liquid and semi-solid waste every day. This waste is rich in nutrients and can be applied to cropland as fertilizer. Often, there are more nutrients present in the waste than can be used by the crops on site. In this case, or in the case where the operation has no cropland, the waste must be transported off site to a facility that can manage the waste properly.

Application and Performance: At an agronomic application rate, some facilities will be able to apply all produced animal waste to on-site cropland. However, some animal feeding operations do not have sufficient land to accommodate all of the waste on site. These facilities must transport the waste off site using farm equipment or by hiring a contractor to haul the waste away. Hiring a contractor is a viable option for operations that do not have the capital to purchase their own trucks to haul excess waste.

Transportation does not "treat" the waste; however, it does move the waste off the farm. By transporting the waste off site, the operation prevents potential pollution by limiting the time that waste remains on the feedlot, and thereby reduces the likelihood of nutrients, pathogens, and other pollutants being carried from the stockpile by rainfall, runoff, seepage, or volatilization.

The cost of transporting waste off site is determined by the quantity and consistency of the waste as well as the distance the waste must be transported to be managed properly. Semisolid or liquid manure can be more expensive to haul because it requires a tanker truck for transport and is heavier due to a higher moisture content. Solid waste is easier to handle and is therefore less expensive to transport. Because the amount of manure transported off site is dictated by the amount that is applied to on-site cropland, it is expected that facilities will apply semisolid waste to fields before they apply solid waste. The distance manure must be hauled to be properly managed depends on the proximity of crops that need additional nutrients.

Advantages and Limitations: One advantage of transportation as a waste management practice is not having to treat and dispose of the waste on site. Excess waste at one operation can be transported to and used as fertilizer at another operation, distributing the nutrient load among cropland at multiple facilities. In addition, in some cases the operation owner is able to sell the waste to a compost or fertilizer facility or another farm operation. This income can potentially offset the cost of the transportation.

It is important to consider the potential non-water-quality impacts that result from increased diesel truck traffic. EPA assumes that some facilities do not currently apply at agronomic rates, and therefore, there will be an increase in excess waste once operations begin applying agronomically. This increase in excess waste requires an increase in truck traffic, causing an increase in exhaust emissions from the trucks transporting the waste.

Operational Factors: There are three operational factors considered in determining transportation practices: the amount of waste to be transported, type of waste to be transported (semisolid or liquid), and the distance from the operation to the off-site destination. The amount of waste to be transported per year determines the size of the trucks that are required and the time that is spent hauling the waste. The consistency of the waste determines the type of truck that is used and the cost of handling that waste. The distance of the off-site facility from the operation determines how far the waste must be hauled and the cost of transporting the waste. The regional location of the operation also plays a role in determining how frequently the waste needs to be transported (e.g., if there are seasons in which the waste is not applied, due to climate or crop cycles).

Demonstration Status: It is not known what portion of animal feeding operations have their waste hauled by contractors and what portion opt to own and operate their own vehicles. It is assumed that each operation chooses the most economically beneficial option, which in most cases is to contract-haul the waste off site.

Beef: Eleven percent of beef feedlots across the country currently sell excess manure waste, and 27 percent give away their manure waste. Approximately 3 percent of beef operations currently pay to have manure waste hauled off site (USDA APHIS, 2000).

Dairy: In 1997, 23 percent of dairies with more than 200 head give away some portion of their manure waste, and 18 percent sold or received compensation for their manure waste (USDA APHIS, 1997).

Poultry: Most poultry operations are currently transporting their waste off site. Nationwide, broiler operations transport about 95 percent of their waste. The percentage of layer operations transporting waste varies by region: 40 percent in the Central region, 100 percent in the Midwest region, 75 percent in the Mid-Atlantic region, 95 percent in the Pacific region, and 50 percent in the South region (USDA NAHMS, 2000).

Swine: Four to six percent of swine operations currently transfer some manure off site (USDA APHIS 1995), while 23 percent of small swine operations and 54 percent of large swine operations do not have enough land to apply agronomically under an N-based application scenario (Kellogg et al., 2000).

8.4.4 Runoff Control

Fields to which manure is to be applied should have an appropriate conservation management system in place to prevent nutrients from leaving the landscape. In the event of mismanaged manure application, such as applying manure prior to an unexpected rainfall, conservation practices that reduce soil erosion and water runoff, including grassed waterways, sediment basins, and buffers, can help to minimize the transport of nutrients off-site.

Susceptibility to erosion and the rate at which it occurs depend on land use, geology, geomorphology, climate, soil texture, soil structure, and the nature and density of vegetation in the area. Soil erosion can be caused by wind or water and involves the detachment of soil particles, their transport, and their eventual deposition away from their original position. Movement of soil by water occurs in three stages: (1) soil particles, or aggregates, are detached from the soil surface when raindrops splash onto the soil surface or are broken loose by fast-moving water; (2) the detached particles are removed or transported by moving water; and (3) the soil particles fall out of suspension when the water velocity slows, and are deposited as sediment at a new site.

Soil erosion caused by water is generally recognized in four different forms: sheet erosion, rill erosion, ephemeral erosion, and gully erosion. Erosion occurs during or immediately after rainstorms or snowmelt. Sheet erosion is the loss of a uniform, thin layer of soil by raindrop splash or water runoff. The thin layer of topsoil, about the thickness of a dime, disappears gradually, making soil loss visibly imperceptible until numerous layers are lost.

Rill erosion often occurs in conjunction with sheet erosion and is a process in which numerous channels, a few inches deep, are formed by fast-flowing surface water. The detachment of soil particles results from the shear stress that water exerts on the soil. The shear stress is related to the velocity of water flow. Therefore, when water gains velocity on steeper and longer slopes, rill erosion increases. Sheet and rill erosion carry mostly fine-textured small particles and aggregates. Fine-textured particles contain the bulk of plant-available nutrients, pesticides, and other absorbed pollutants because there is more surface area per given volume of soil.

Ephemeral erosion occurs when concentrated water flows through depressions or drainage areas. The water forms shallow channels that can be erased by tillage practices. Ephemeral erosion is a precursor to gully erosion if left untreated.

Once rills become large enough to restrict vehicular access, they are referred to as gullies. Gully erosion results from the removal of vast amounts of topsoil and subsoil by fast-flowing surface water through depressions or drainage areas. Gully erosion detaches and transports soil particles that are the size of fine to medium sand. These larger soil particles often contain a much lower proportion of absorbed nutrients, organic material, and pollutants than the fine-textured soil particles from sheet and rill erosion.

It is not practical to prevent all erosion, but the preferred strategy is to reduce erosion losses to tolerable rates. In general terms, tolerable soil loss, sometimes referred to as T, is the maximum rate of soil erosion that can occur while still maintaining long-term soil productivity. These tolerable soil loss levels determined by USDA NRCS are based on soil depth and texture, parent material, productivity, and previous erosion rates. The levels range from 1 to 5 tons/acre/year (2 to 11 metric tons/hectare/year). The strategies for controlling erosion involve reducing soil detachment and reducing sediment transport.

Surface water runoff contains pollutants, including nutrients (e.g., nitrogen and phosphorous) and some pathogens. Excessive manure application can cause increased nitrate concentration in water. If the rate of manure application exceeds plant or crop nitrogen needs, nitrates may leach through the soil and into ground water. Nitrates in drinking water are the cause of methemoglobinemia ("blue baby syndrome").

Agricultural nonpoint source pollutants, such as those contained in manure, can migrate off the field and into surface water through soil erosion. Excessive nutrients attached to the sediment and carried into surface water bodies can cause algae blooms, fish kills, and odors. Combinations of BMPs can be used to protect surface water by reducing the amount of nutrient-rich sediment that is detached and transported away from a field.

A BMP is a practical, affordable strategy for conserving soil and water resources without sacrificing profitability. BMPs that reduce soil erosion are part of a broader integrated soil management system that improves overall soil health and water quality. In addition, BMPs benefit crop production in a variety of ways, such as improved drainage, improved moisture-holding capacity, pest management, and ultimately, long-term profitability.

Runoff Control Practices

Livestock manure can be a resource if managed correctly. A large proportion of livestock manure is returned to the land as organic fertilizer. Unfortunately, if manure is handled incorrectly, it can become a source of pollution that ends up in streams or lakes. The nutrients in animal manure, especially phosphorus and nitrogen, can cause eutrophication of water.

Eutrophication is a natural process that takes place in all surface water bodies. The natural process is accelerated by increased sediment and nutrient loading in the water. It is characterized by an aquatic environment rich in nutrients and prolific plant production (algae). As a result of nutrient enrichment, the biomass of the water body increases and eventually produces a noxious environment that accelerates algae growth, leading to a reduction in water quality.

The transport of manure nutrients to streams and lakes is very similar to the transport of nutrients from commercial fertilizers. Nitrogen is water-soluble and moves largely with the flow of water. Injecting or incorporating manure into the land however, significantly reduces the amount of nitrogen transported with runoff. Yet nitrogen can still move with ground water or subsurface water flow.

Reducing phosphorous levels in surface water is the best way to limit algae growth. Most of the phosphorous transported by surface water is attached to sediment particles. Therefore, reducing soil erosion is essential to protecting water quality.

Manure from properly managed grazing animals has little detrimental effect on water quality. In a grazing system, 100 percent of the manure generated by the grazing animal is applied to the land daily. In addition, the runoff from a well-managed grazing system carries very little sediment or nutrients; however, manure from feedlots or overgrazed pastures is more susceptible to runoff and sediment delivery (Hatfield, 1998).

Practices to Reduce Soil Detachment

The most effective strategy for keeping soil on the field is to reduce soil detachment. Crop canopy and crop residue on the soil surface protect against soil detachment by intercepting falling raindrops and dissipating their energy. In addition, a layer of plant material on the ground creates a thick layer of still air next to the soil to buffer against wind erosion. Keeping sufficient cover on the soil is therefore a key factor to controlling both wind and soil erosion.

Conservation practices, such as no-tillage, preserve or increase organic matter and soil structure. No-tillage reduces soil detachment and transport and results in improved water infiltration and surface stability. No-tillage also increases the size of soil aggregates, thereby reducing the potential of wind to detach soil particles.

Combinations of the following practices can be used to effectively reduce soil detachment by wind or water erosion:

- Conservation tillage (including mulch-tillage, no-tillage, strip-tillage, and ridge-tillage)
- Cover crops
- Contour stripcropping/contour buffer strips
- Crosswind trap strips
- Crosswind ridges
- Crosswind stripcropping
- Crop rotation, including small grains, grasses, and forage legumes
- Chemical fallow or no fallow
- Grassed waterways
- Pasture management
- Shelterbelts/field windbreaks

Practices to Reduce Transport Within the Field

Sediment transport can be reduced in several ways, including the use of vegetative cover, crop residue, and barriers. Vegetation slows runoff, increases infiltration, reduces wind velocity, and traps sediment. Strips of permanent vegetation (e.g., contour strip cropping and contour grass strips) slow runoff and trap sediment. Contour farming creates rough surfaces that slow surface water velocity and reduce transport of sediment.

Reductions in slope length and steepness reduce sediment-carrying capacity by slowing velocity. Terraces and diversions are common barrier techniques that reduce slope length and slow, or stop, surface runoff.

By decreasing the distance across a field that is unsheltered from wind, or by creating soil ridges and other barriers, sediment transport by wind can be reduced.

Combinations of the following practices can be used to effectively reduce soil transport by wind or water erosion:

- Buffers
  - Shelterbelts/field windbreaks
  - Contour strip cropping/contour buffer strips
  - Riparian buffers
  - Filter strips
  - Grassed waterways
  - Field borders
  - Crosswind trap strips
  - Contour or cross slope farming
- Conservation tillage, (including mulch-tillage, no-tillage, strip-tillage, and ridge-tillage)
- Crop rotation including grains, grasses and forage legumes
- Chemical fallow or no fallow
- Cover crops
- Crosswind ridges
- Crosswind stripcropping
- Diversions
- Ponds
- Sediment basins
- Terraces

Practices to Trap Sediment Below the Field or Critical Area

Practices are also typically needed to trap sediment leaving the field before it reaches a wetland or riparian area. Deposition of sediment is achieved by practices that slow water velocity and increase infiltration. Combinations of the following practices can be used to effectively trap sediment below the field or critical area:

- Contour strip cropping/contour buffer strips
- Crosswind traps strips
- Crosswind stripcropping
- Diversions
- Filter strips
- Grassed waterways
- Ponds
- Riparian buffers
- Sediment basins

- Shelterbelts/field windbreaks
- Terraces
- Wetlands

Practices That Have Multiple Functions to Reduce Detachment, Transport, and Sediment Delivery

Many conservation practices have multiple functions. Table 8-27 identifies the primary functions of each practice.

Considerations in BMP Selection

The selection of the most effective BMPs to protect water quality depends on the objectives of the farmer and the specific site conditions of individual fields. The best combination of BMPs for any specific field depends on factors such as the following:

- Rainfall—more rainfall means more erosion potential.
- Soil type—some soils erode more easily than others.
- Length of slope—a longer slope has increased potential for erosion due to increased runoff energy.
- Steepness of slope—steep slopes erode more easily than gradual slopes.
- Ground cover—the more the soil is covered with protective grasses, legumes, or crop residues, the better the erosion control.

Other factors to consider include:

- Type of farm operation
- Size of the field or farm
- Nutrient levels of manure
- Nutrient requirements of crops
- Proximity to a waterway (stream, lake), water source (drinking water well), or water of the state
- Relationship of one erosion control practice to other supporting conservation practices
- Conservation plan if required by USDA NRCS
- Economic feasibility

Table 8-27. Primary Functions of Soil Conservation Practices

Conservation Practice	Detachment	Transport	Sedimentation
Chemical fallow or no fallow	O	O	
Conservation Tillage (mulch-till, ridge-till, strip-till, and no-till)	X / O	X / O	
Contour or Cross Slope		X	
Contour Stripcropping/Contour Buffer Strips	X	X	X
Cover Crops	X	X	
Crop Rotation, including small grains, grasses, and forage legumes	X	X	
Crosswind Trap Strips	O	O	O
Crosswind Ridges	O	O	
Crosswind Stripcropping	O	O	O
Diversions		X	X
Field Borders		X	
Filter Strips		X	X
Grassed Waterways	X	X	X
Ponds		X	X
Riparian Buffers		X	X
Sediment Basins		X	X
Shelterbelts/Field Windbreaks	O	O	O
Terraces		X	X
Wetlands			X

Note: X = water erosion; O = wind erosion

Agricultural nonpoint source runoff management practices that protect natural resources generally have two principal goals: (1) to reduce runoff volume and (2) to contain and treat agricultural runoff. An effective runoff control system meets both of these goals by integrating several practices in a way that meets the needs of the particular management system. Strategies for controlling erosion involve reducing soil detachment, reducing sediment transport, and trapping sediment before it reaches a water body.

Soil erosion can be reduced by using a single conservation practice or a combination of practices. The following section explains conservation practices that can be used separately or in combination to reduce manure runoff and improve water quality.

Practice: Crop Residue Management

Description: Tillage operations influence the amount and distribution of plant residues on or near the soil surface. In the past, the preferred system, conventional tillage, was designed to bury as much residue and leave the soil surface as smooth as possible, which unfortunately led to significant soil erosion. In contrast, residue management systems are designed to leave residue on top of the soil surface to increase infiltration and reduce erosion. In general, the more residue left on the soil surface, the more protection from erosion the soil has. The amount of crop residue left after planting depends on the original amount of residue available, the tillage implements used, the number of tillage passes, and the depth and speed at which tillage was performed.

Crop residue management has been designated by many terms since its inception. The Natural Resources Conservation Service (NRCS) and the Conservation Technology Information Center (CTIC) have adopted the following terms and definitions.

- Conventional-till: Tillage types that leave less than 15 percent residue cover after planting. Generally this involves plowing or intensive (numerous) tillage trips.

- Reduced-till: Tillage types that leave 15 to 30 percent residue cover after planting.

- Conservation tillage: Any tillage and planting system that leaves 30 percent, or more, of the ground covered after planting with the previous year's crop residues. Conservation tillage systems include mulch-till, no-till, strip-till, and ridge-till.

    - Mulch-till: Full-width tillage that disturbs the entire soil surface is performed prior to and during planting. Tillage tools such as chisels, field cultivators, discs, sweeps, or bands are used. Weed control is accomplished with herbicides and/or cultivation.

    - No-till and strip-till: The soil is left undisturbed from harvest to planting except strips up to one-third of the row width (strips may involve only residue disturbance or may include soil disturbance). Planting or drilling is accomplished using disc openers, coulter(s), row cleaners, in-row chisels, or roto-tillers. Weeds are controlled primarily with herbicides. Cultivation may be used for emergency weed control. Other common terms used to describe no-till include direct seeding, slot planting, zero-till, row-till, and slot-till.

    - Ridge-till: The soil is left undisturbed from harvest to planting except for strips up to one-third of the row width. Planting is completed on the ridge and usually involves the removal of the top of the ridge. Planting is completed with sweeps, disc openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weeds are controlled with herbicides (frequently banded) and/or cultivation. Ridges are rebuilt during cultivation (CTIC, 1998a).

No-till, strip-till, and ridge-till provide the most soil conservation protection.

Application and Performance: Plant residues can aid in soil erosion control. Residues can protect the soil from the time of rowcrop harvest through the time the succeeding crop has developed sufficiently to provide adequate canopy protection. Conservation tillage reduces soil erosion by reducing detachment. It also reduces transport by minimizing soil crusting and increasing infiltration, which reduces runoff. The residue acts as small dams, slowing the movement of water across the field and reducing its ability to carry soil particles.

Conservation tillage increases the size of soil aggregates, which reduces the potential of wind to detach soil particles and thereby reduces wind erosion. The residue also slows the wind speed at ground level, reducing its ability to carry soil particles.

Advantages and Limitations: Benefits other than soil conservation that can be gained include the following:

- Reduced tillage costs
- Reduced labor
- Reduced runoff
- Reduced fuel use
- Reduced machinery wear
- Reduced particulate matter in air from wind erosion
- Increased soil moisture
- Improved surface water quality
- Increased water infiltration
- Decreased soil compaction
- Improved soil tilth
- Increased populations and diversity of wildlife
- Increased sequestration of greenhouse gases (carbon dioxide)

Normally, the cost of changing from a conventional tillage system to a conservation tillage system is minimal if current equipment can be adapted. The cost of changing is associated with the purchase of additional attachments for equipment and depends on the type of conservation tillage to be done (no-till, ridge-till, mulch-till, and so forth). The incremental cost of these attachments may range from $1.00 to $3.00/acre/year. However, if equipment is impossible to adapt or needs extreme adaptations, the investment in changing to a conservation tillage system can become significant.

Intensive overall management is critical to the success of a no-tillage or ridge-tillage system. Constraints and challenges within the system should be considered before choosing a no-tillage or ridge-tillage method. The most successful system needs a strong commitment from a knowledgeable manager. Management considerations and system constraints include the following:

- Manure application and the need to incorporate
- Alternative methods or equipment modifications for nutrient placement
- The need to apply and/or incorporate lime
- Planter and harvesting attachments need to be correctly installed and maintained
- Critical timing of field operations
- Greater reliance on herbicides for weed control
- Shifts in weed populations and weed varieties
- Increased nitrogen requirements due to an increase in residue that has a high carbon-to-nitrogen ratio
- Delays in spring field operations due to cold, wet soils
- Delayed seed germination due to cold, wet soils

Conservation tillage can be used on cropland fields where excess sheet and rill erosion and wind erosion are a concern. Conservation tillage is most effective when used with other supporting conservation practices such as grassed waterways, contouring, and field borders.

Operational Factors: In the northern areas of the United States where soil temperatures stay colder for longer periods of time, no-till may not be as well adapted as some of the other conservation tillage systems. In these areas strip-till or ridge-till may be better options.

Demonstration Status: Conservation tillage is used across the United States and in conjunction with all the major crops.

Practice: Crop Rotation

Description: Crop rotation is the practice of alternating high-residue crops with low-residue crops on the same piece of land, from year to year. Although crop rotations can vary significantly, a typical rotation giving significant erosion protection could include high-residue-producing crops like small grains and hay, and low-residue-producing row crops like corn and soybeans. A typical rotation using these crops would be corn-soybeans-corn-small grain-hay-hay.

Application and Performance: The soil conservation purpose of a crop rotation is to alternate crops that have high erosion potential with crops that have low erosion potential because it is the average soil loss over time that is critical. It is expected that in those years when low-residue crops are planted, significant erosion may occur. However, in years when high-residue crops are planted, very little erosion will occur. Therefore, the average rate of soil erosion throughout the rotation sequence will be significantly lower than it would be if only low-residue crops had been planted. A rotation of corn-soybeans-corn-small grain-hay-hay could be expected to reduce soil erosion by 50 percent as compared with just corn and soybeans, depending on the tillage system (Renard et al, 1997).

Advantages and Limitations: Weather conditions, unexpected herbicide carryover, and marketing considerations may result in a desire to change a scheduled crop rotation. Since most farmers want to balance production acres of different crops, they need to have the flexibility of changing the rotations in one field because of an unexpected condition in another field.

Operational Factors: Crop rotation can be used where sheet and rill erosion is a problem on cropland. Crop rotation works best with other supporting conservation practices such as conservation tillage, contouring, and grassed waterways. A market or use for the small grains or hay is needed before farmers will adopt the use of crop rotation.

Demonstration Status: The use of crop rotations is generally adopted in those regions that have dairy herds because of the need for hay.

Practice: Contouring and Cross-Slope Farming

Description: Contour farming is the practice of tilling, planting, and cultivating crops around a slope on a nearly level line that slowly grades water to a nonerosive area that can handle concentrated flow. In gentle rains, the contoured rows are able to slowly grade the water to a nonerosive area such as a grassed waterway or field border. In heavier rains, when the water runs over the tops of the rows, the rows serve as mini-dams to slow the water. Slowing the water allows for more infiltration of water into the soil profile and reduces sediment transport in the field.

On some slopes, strict contour farming that results in sharp turns and endless point rows is impractical. Farm machinery may be too large to accommodate the tight turns and numerous point rows and increases the amount of time required to complete field operations. In this case, an alternative to contouring is cross-slope farming, which allows greater deviation from the contour line. Although cross-slope makes farming easier, it is generally only half as effective as contouring in reducing soil erosion.

In some areas of the country, using a rollover plow on the contour is beneficial to turn the soil uphill while performing conventional tillage. By using a rollover plow on the contour, soil is mechanically moved up-slope.

To allow for the removal of water in a concentrated flow, waterways need to be seeded, or shaped and seeded.

Application and Performance: Contouring can reduce soil erosion by 25 to 50 percent and cross-slope farming can reduce soil erosion by 10 to 25 percent depending on slope length, slope steepness, field roughness, and row grade (Renard et al, 1997).

Advantages and Limitations: Because contouring and cross-slope farming slow the runoff of water, water infiltration is increased and soil erosion is reduced. The increased water infiltration may also mean more available subsoil moisture during the growing season. Horsepower requirements may also be lower when farming on the contour or cross-slope.

On longer slopes, both contouring and cross-slope farming become less effective and should then be used in combination with a supporting conservation practice such as terraces or contour strip cropping.

The major disadvantage of contouring, and to a lesser extent cross-slope farming, is the increased time needed to perform the tilling, planting, spraying, cultivating, and harvesting operations. Contouring may require 25 to 50 percent more time as compared with farming straight rows. Cross-slope farming may require 10 to 25 percent more time as compared to farming straight rows. This increased time leads to higher labor, fuel, and equipment costs on a per acre basis.

Operational Factors: Contouring or cross-slope farming can be used on most slopes on which row crops are planted.

Demonstration Status: Contouring or cross-slope farming is widely adopted across the United States.

Practice: Contour Stripcropping/Contour Buffer Strips

Description: Contour stripcropping is a system of growing crops in approximately even-width strips or bands on the contour. The crops are arranged so that a strip of meadow or close-growing crop is alternated with a strip of row crop. Contour stripcropping combines the soil protection of both contouring and crop rotation. The widths of rowcrop strips should equal the widths of the hay or small grain strips. The strips of hay or small grain slow water flow and trap sediment from the row crop strips above them.

Contour buffer strips can be used when a higher percentage of row crop acres are needed. A contour buffer strip system allows for the hay or small grain strips to be narrower than the strips of row crop. Because a contour buffer strip system results in more row crop acres, it is less effective than contour strip cropping in reducing soil erosion.

The strip width depends on the steepness of the slope and the management practices being used. It is also designed to accommodate the width of equipment (planters, sprayers, and harvesters). An even number of equipment passes along each strip improves field operation efficiency by starting and finishing a pass at the same end of the field. Grassed field borders and grassed waterways are an integral part of any stripcropping system. They provide access lanes and safe areas for concentrated water runoff.

Application and Performance: Contour stripcropping is very effective in reducing sheet and rill erosion. It can reduce soil loss by as much as 75 percent, depending on the type of crop rotation and the steepness of the slope. Depending on the width of the grass strip and the row crop strip and the steepness of the slope, contour buffer strips can reduce sheet and rill erosion by as much as 75 percent or as little as 20 percent (Renard et al., 1997).

Advantages and Limitations: Choosing to use contour stripcropping or contour buffer strips is an excellent conservation practice for a farmer who can use small grains or hay. Instead of planting one entire field to small grains or hay and another entire field to row crops, strips of hay or grain can be alternated, thereby reducing soil erosion.

Effective stripcropping systems require strips that are wide enough to be farmed efficiently. If possible, consolidation of fields may be necessary. The major disadvantage of using contour stripcropping or contour buffer strips as an erosion control practice is the same as that of contouring: increased time to perform the field operations (e.g., tillage, planting, spraying, and harvesting). These practices may require 25 to 50 percent more time than farming straight rows. Increased time used in field operations leads to higher labor, fuel, and equipment costs on a per acre basis.

Operational Factors: Contour stripcropping and contour buffer strips can be used where sheet and rill erosion are a problem in cropland, and they work best with other supporting conservation practices such as conservation tillage and grassed waterways. The use of contour stripcropping and contour buffer strips is practical only if there is a market or use for the small grains or hay.

Demonstration Status: The use of crop rotations is generally adopted in those regions that have dairy herds, beef cattle, or sheep because of the need for hay.

Practice: Grassed Waterways

Description: Grassed waterways are areas planted to grass or other permanent vegetative cover where water usually concentrates as it runs off a field. They can be either natural or man-made channels. Grass in the waterway slows the water as it leaves the field. Grassed waterways can serve as safe outlets for graded terraces, diversions, and contour rows. They can also serve as passageways for water that enters a farm from other land located higher in the drainage basin. Grassed waterways significantly reduce gully erosion and aid in trapping sediment.

Application and Performance: Grassed waterways protect the soil from erosion at points of concentrated water flow. They are designed to safely carry runoff water from the area that drains into them to a stable outlet. Small waterways are designed in a parabolic shape and are built wide enough and deep enough to carry the peak runoff from a 24-hour storm that would be expected to occur once every 10 years.

The decision to mow or not to mow grassed waterways depends on supporting conservation practices and other management concerns. To increase the lifespan of the waterway, it is best to mow or clip the grass in the waterway. If grasses are allowed to grow, the flow rate of the waterway is slowed, increasing the rate of sedimentation in the waterway, which in turn increases the cost of maintaining the waterway. If waterways are clipped, however, water flows faster and the sediment is carried farther down slope before being dropped out. If manure is applied in the waterway drainage area, grassed waterways should not be mowed. To prevent excessive sedimentation in the unmowed waterways, other supporting conservation practices, such as contouring, conservation tillage, or barrier systems, should be in place.

Advantages and Limitations: The goal of a waterway design is to protect against soil loss while minimizing siltation and gullying in the waterway. Gullies can form along the side of a waterway if the water does not enter the waterway or if the runoff spills out of the waterway and runs parallel to it. This can be caused by inadequate design (too shallow or too narrow) or inadequate maintenance, and in some cases by flooding. Even under the best conditions, grassed waterways tend to either silt in or develop channels or gullies. Timely maintenance and repairs can prevent major reconstruction. Silt can be cleaned out and small gullies can be filled in. However, if the waterway is damaged too badly, it will need to be completely reshaped and reseeded. Often heavy equipment such as a bulldozer or a scraper is required.

Grassed waterways permanently take land out of cereal and row crop production, but they can be harvested for forage production if the farmer has a use and/or market for the forage and the equipment to harvest the forage.

The cost of waterway construction depends on the depth and width of the waterway. It ranges from $1.50 to $3.50 per linear foot, with mulch and seed. In addition to the construction cost, there is a maintenance cost. The cost to maintain a waterway is highly variable depending on drainage area size, soil type, grade of the waterway, and level of control of soil erosion above the waterway. Some waterways can function for 10 years without maintenance, whereas others need maintenance on a yearly basis.

Operational Factors: Grassed waterways can be used where ephemeral erosion and gully erosion are a problem.

Demonstration Status: Grassed waterways are used across the United States and in conjunction with all the major crops.

Practice: Terraces

Description: Terraces are earthen structures that run perpendicular to the slope and intercept runoff on moderate to steep slopes. They transform long slopes into a series of shorter slopes. On shorter slopes, water velocity is slower and therefore has less power to detach soil particles. Terraces slow water, catch water at intervals down slope, and temporarily store it in the terrace channel.

Depending on the soil type, the water can either infiltrate into the ground or be delivered into a grassed waterway or an underground tile. Terraces are spaced to control rill erosion and to stop ephemeral gullying. Terrace spacing is determined by several factors, including soil type, slope, and the use of other supporting conservation practices such as conservation tillage and crop rotation. When more than one terrace is placed on a hillside, it is best to construct the terraces parallel to each other and at spacings that are multiple widths of field equipment. This approach helps eliminate short rows and improves the efficiency of field operations.

Application and Performance: Terraces reduce the rate of runoff and allow soil particles to settle out.

Advantages and Limitations: One of the biggest advantages of terraces is that they are permanent conservation practices. A farmer usually does not adopt terracing one year and decide the next year not to use it, unlike such management practices as conservation tillage or contouring. In almost all cases, terraces will not be removed until they have exceeded their life expectancy of 20 years.

A disadvantage of terraces is that they are built with heavy construction equipment and the soil structure around the terrace can be permanently altered. Terraces are built by pushing soil up, and they usually require a bulldozer. Compaction on the lower side of the terrace is always a concern and can last for years after the terrace is constructed.

Terraces can permanently remove land from production. The amount of land removed from production depends on the terrace system installed, but it normally ranges from 0 to 5 percent of the overall land base. The cost to install terraces ranges between $0.75 and $3.00 per linear foot, including seeding. In many cases terraces also require either a tile line or a waterway as an outlet for the water. The cost of installing tile can range from $.75 to $1.50 per linear foot. Waterway costs are covered in the section on grassed waterways. It can cost in the range of $100 to $165 to protect 1 acre of land with terraces and suitable outlets. In addition to construction costs, there are always maintenance costs. If excessive rains occur, terraces will overtop and require maintenance. The sediment collected in terrace channels should be cleaned out periodically, at least every 10 years, or sooner, depending on the sedimentation rate. Maintenance also includes removing trees and shrubs from the terrace and repairing rodent damage.

In addition to the loss of cropland and cost of construction and maintenance, terraces are laid out on the contour, which can increase the time, fuel, and equipment costs associated with field operations. See the section on contouring and cross-slope farming for costs associated with contouring.

Operational Factors: Terraces can be used when sheet, rill, or ephemeral erosion are a concern.

Demonstration Status: Terraces are widely adopted across the United States.

Practice: Field Borders

Description: A field border is a band or strip of perennial vegetation, usually grass and/or legume, established at the edge of a field. From a soil conservation standpoint, field borders are used to replace end rows that run up and down a hill. Sometimes field borders replace end rows all the way around the field, and other times they are used where slope length and steepness present a concern for soil erosion. Field borders can be used in fields that are contoured, cross-sloped, contour stripcropped, contour buffer stripped, or terraced.

Application and Performance: Field borders reduce detachment, slow transport, and help reduce sediment load in water.

Advantages and Limitations: Field borders reduce acres of cereal crops or row crops in production. However, if the field border is planted to forage, it can be harvested, as long as the farmer has the proper equipment and a use or market for the crop. The cost of seeding an acre of field borders is approximately $50 to $70 per acre.

Operational Factors: Field borders can be used with all crops and in all regions of the United States.

Demonstration Status: Field borders are commonly used as a conservation practices in combination with other practices.

Practice: Sediment Basin

Description: A sediment basin is a barrier structure constructed to collect and store manure, sediment, or other debris.

Application and Performance: Sediment basins are constructed to accumulate and temporarily store water runoff. For controlling manure runoff, sediment basins may be used in two types of settings: to capture feedlot runoff or to capture field runoff. As runoff accumulates and water is slowly discharged through an outlet, soil particles settle out and are trapped in the basin. Frequently, a filter strip is positioned as a secondary treatment practice below the sediment basin to catch the additional sediment flowing through the outlet. Sediment basins reduce the transport of soil and manure by flowing water.

Advantages and Limitations: The construction cost of sediment basins is quite variable, depending on the steepness of the land and the size of the drainage area flowing into the basin. However, basins are normally a cost-effective practice to capture sediment.

On-site erosion control cannot be achieved with sediment basins, because they do little to stop detachment and transport of soil.

Operational Factors: Sediment basins can be used with all crops and in all regions of the United States.

Demonstration Status: Sediment basins are commonly used as a conservation practices in all cropland systems.

Practice: Cover Crops

Description: A cover crop is a crop of close-growing grass, legumes, or small grain grown primarily for seasonal protection and soil improvement. These crops are also known as green manure crops. Cover crops are usually grown for 1 year or less, except where there is permanent cover (e.g., orchards). They increase vegetative and residue cover during periods when erosion energy is high, and especially when primary crops do not furnish adequate cover. Cover crops may be established by conventional or conservation tillage (no-till or mulch-till) methods or by aerial seeding.

Cover crops should be planted immediately after harvest of a primary crop to maximize the erosion control benefits. Recommended seeding dates vary from year to year and depend on soil type, local climatic conditions, field exposure, and the species of cover crop being grown.

Application and Performance: Cover crops control erosion during periods when the major crops do not furnish adequate cover. Since cover crops provide a quick canopy, they reduce the impact of raindrops on the soil surface, thereby reducing soil particle detachment. Cover crops also slow the surface flow of water, reducing transport of sediment and increasing water infiltration. Cover crops can add organic material to the soil; they improve water infiltration, soil aeration, and soil quality. In addition, cover crops can control plant nutrients and soil moisture in the root zone. If a legume crop is used as a cover crop, it will provide nitrogen for the next year's crop.

Actively growing cover crops use available nutrients in the soil, especially nitrogen, thus preventing or decreasing leaching or other loss. These nutrients may then become available to the following crop during the decaying process of the green manure.

Advantages and Limitations: Cover crops increase transpiration. In areas of the United States where moisture is limited, cover crops may use up too much of the available soil moisture. Loss of available soil moisture may reduce the yield of the primary crop planted after the cover crop, reducing profits.

Preparing a seedbed and drilling in a winter cereal crop costs $40 to $45 per acre. Broadcast seeding after harvest, followed by a tillage pass that levels the soil surface, costs $35 per acre. Broadcast seeding prior to harvest costs $15 per acre.

Operational Factors: Cover crops can be used when major crops do not furnish adequate cover and sheet and rill erosion is a problem.

Demonstration Status: Cover crops are used throughout the United States.

Practice: Filter Strip/Riparian Buffer

Description: Filter strips are strips of grass used to intercept or trap field sediment, organics, pesticides, and other potential pollutants before they reach a body of water.

Riparian buffers are streamside plantings of trees, shrubs, and grasses that can intercept contaminants from both surface water and ground water before they reach a stream.

Application and Performance: Filter strips and riparian buffers are designed to intercept undesirable contaminants such as sediment, manure, fertilizers, pesticides, bacteria, pathogens, and heavy metals from surface and subsurface flows of water to a waterbody. They provide a buffer between a contaminant source and waterbodies. Buffers and filter strips slow the velocity of water, allowing soil particles to settle out.

Advantages and Limitations: Buffer strips and riparian buffers reduce the acreage in cereal crops or row crops, but they can be harvested for forage production if the farmer has a use or market for the forage and the equipment to harvest the forage. Depending on whether the filter strip or riparian buffer strip is seeded to grass or planted to trees, the cost of seeding can range from $50 to $500 per acre.

Operational Factors: Buffer strips and riparian buffers can be used with all crops and in all regions of the United States.

Demonstration Status: Filter strips and riparian buffers have been widely promoted and adopted throughout the United States with programs like the Conservation Reserve Program (CRP).

Practice: Crosswind Trap Strips, Crosswind Ridges, Crosswind Stripcropping, and Shelterbelts/Field Windbreaks

Description: Crosswind trap strips are rows of perennial vegetation planted in varying widths and situated perpendicular to the prevailing wind direction. They can effectively prevent wind erosion in cropping areas with high, average annual wind speeds.

Crosswind ridges are formed by tillage or planting and are aligned across the prevailing wind erosion direction. The ridges reduce wind velocity near the ground, and the soil particles that do start to move are trapped in the furrows between the ridge crests.

Crosswind stripcropping is growing crops in strips established across the prevailing wind direction and arranged so that the strips susceptible to wind erosion are alternated with strips having a protective cover that is resistant to wind erosion.

A shelterbelt or field windbreak is a row (or rows) of trees, shrubs, or other plants used to reduce wind erosion, protect young crops, and control blowing snow. Shelterbelts also provide excellent protection from the elements for wildlife, livestock, houses, and farm buildings. Field windbreaks are similar to shelterbelts but are located along crop field borders or within the field itself. In some areas of the country, they may also be called hedgerow plantings.

Application and Performance: These practices are designed to reduce soil erosion by increasing the soil roughness and reducing the wind speed at the soil surface.

Advantages and Limitations: The same practices that reduce wind erosion also reduce moisture loss. Snow is more likely to stay on the field than to blow off, thereby increasing soil moisture. A drawback to crosswind trap strips, shelterbelts, and field windbreaks is that they take cropland out of production. Also, they are a physical barrier to operations such as manure application with an umbilical cord system.

Operational Factors: These practices can be used anywhere that wind erosion is a concern in row crops.

Demonstration Status: These practices are used where row crops are planted in the Plains states.

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